DEVELOPMENT OF AN INFORMATIONAL RESOURCE TO INFORM GLOBAL PRIORITIZATION OF EFFORTS TO CONSERVE THREATENED, EXCEPTIONAL PLANT TAXA

by

Sara Helm Wallace

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Sara Helm Wallace

Approved: ____
D. Janine Sherrier, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ____
D. Janine Sherrier, Ph.D.
Interim Chair of the Department of Plant and Soil Sciences

Approved: ____
Mark Rieger, Ph.D.
Dean of the College of Agriculture and Natural Resources

Approved: ____
Ann Ardis, Ph.D.
Interim Vice Provost for Graduate and Professional Education

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ABSTRACT

Plant taxa that are threatened toward extinction are often a priority for conservation research. While many threatened, vascular, seed-bearing taxa can be conserved *ex situ* in seed banks, others cannot be seed-banked. These non seed-bankable taxa are known as "exceptional." There is currently no comprehensive resource available to plant conservation researchers that identifies threatened, exceptional plant taxa and their storage needs.

This research refined the definition of "exceptional," and then compiled and analyzed data about the seed storage behavior of threatened, vascular plant taxa in the U.S. and Canada. Researchers in the field of plant conservation were surveyed to obtain their opinion of the best parameters for the definition of "exceptional" as it pertains to threatened, vascular, seed-bearing plant taxa. A list of 5,923 threatened plant taxa of the U.S. and Canada was then sent to many of the survey's respondents requesting information regarding the seed storage behavior of the taxa. The information contributed by the researchers was compiled and standardized for analysis.

Based on the responses from researchers representing 147 institutions, the definition of exceptional is: An exceptional plant taxon is a species, subspecies, or variety of vascular, seed-bearing plant which cannot be seed-banked because the seed

biology or availability satisfies one or more of the following conditions: produces recalcitrant seeds, produces few or no seeds, cannot be easily propagated by seed, produces poor-quality or non-viable seeds, seeds are not easily accessible for collection when mature (or at all), or produces seeds infrequently.

Information provided by 22 researchers resulted in further knowledge of the seed storage behavior of 2,090 threatened, vascular seed-bearing plant taxa of the U.S. and Canada. Of the 156 exceptional taxa, 53% are trees and 27% are shrubs. Hawaii and Florida account for 90% of the exceptional taxa. In addition, those with seed storage behaviors of exceptional tend to be from the more evolutionarily advanced orders.

The list and corresponding seed storage behavior information generated from this study will help researchers identify priorities for effective and efficient conservation of threatened, exceptional plants and their ecosystems. Furthermore, the list will facilitate communication, target conservation efforts, and support funding for the research of these taxa. Lastly, this list can serve as a model for the generation of a global list.

Six Supplemental Spreadsheet Files Included in Electronic Version: Appendix G Known Status, Appendix H Unknown Status, Appendix J Suggested Additions, Appendix K Pteridophytes, Appendix M Seed Storage Behavior List, Appendix N Threatened List

Chapter 1

INTRODUCTION

Conservation of Threatened Taxa

All plants should be conserved if it is within our grasp to do so (Ehrlich and Ehrlich 1981). Although known agricultural, economic, cultural, scientific, and popular significance may provide the most obvious reasons for conservation, the rest of the plants on the planet deserve preservation because we do not know what their uses could be (Frankel, Brown and Burdon 1995).

The Convention on Biological Diversity (CBD) is a United Nations effort to manage and sustain biological diversity on Earth. The Convention was signed by 168 leaders of countries in 1992 and 1993, and includes not only the conservation of individual species, but also their ecosystems and their abilities to interact (United Nations 1993). A group of botanists later devised the Global Strategy for Plant Conservation (GSPC), which was accepted by the Convention on Biological Diversity in 2002 and updated in 2010. The GSPC consists of five general objectives under which fall 16 specific targets with the end goal of improving global plant conservation by 2020 (CBD 2010a). Also in 2010, the Conference of the Parties, the supreme decision-making body of the CBD, adopted a new Strategic Plan for Biodiversity 2011-2020, which "provides an overarching framework on biodiversity, not only for the biodiversity-related conventions, but for the entire United Nations system and all other partners engaged in biodiversity management and policy development" (CBD 2010b). The Strategic Plan for Biodiversity 2011-2020 includes the Aichi Biodiversity Targets, which are not limited to plants but include conservation of all species and their ecosystems (CBD 2010c).

To maintain biodiversity, threatened taxa should be given priority for conservation (BGCI 2012). Target 8 of the GSPC requires that "at least 75% of threatened plant species be stored in *ex situ* collections, preferably in the country of origin, and at least 20% be made available for recovery and restoration programs" (CBD 2010d). Target 12 of the Aichi Biodiversity Targets requires that, "by 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained" (CBD 2010c). The CBD estimates that, as of 2014, 29% of threatened species have been conserved *ex situ* worldwide (Sharrock et. al 2014). The consequence of not meeting the GSPC and Aichi targets and others is a continuing loss of biodiversity.

Scientists have assigned threatened conservation statuses to species based on many factors, such as species abundance, distribution, population trends, and threats (NatureServe 2015a). The major factors contributing to the threats include: habitat change due to climate change, pollution, invasion of non-native species, or changing landscapes from human involvement (MEA 2005).

Globally, there are over 12,500 *known* threatened vascular plant species (IUCN 2015). However, it has been estimated that 22% to 47% of the world’s approximately

310,000 to 422,000 plant species may currently be threatened with extinction (Pitman and Jorgensen 2002). In the U.S. and Canada, nearly 8,600 of the over 25,000 total native plant taxa are known to be threatened (NatureServe 2015b).

Definition of Exceptional

Many of the Earth's plant taxa, regardless of their current level of conservation need, are being actively preserved in two main ways. The first, *in situ* conservation, is the practice of preserving plants within their natural habitats. With *in situ* conservation comes the necessity of restoring the plants' habitats in order to encourage continued growth and reproduction of wild populations, allowing for natural evolution of genetic diversity. (BGCI 2012). It has been shown that in plants and animals, threatened taxa have reduced genetic diversity, which increases their risk for extinction (Spielman, Brook and Frankham 2004). Although *in situ* conservation ideally maintains balance by allowing for evolution within the ecosystem, thereby optimizing genetic diversity, it also requires a great deal of time and resources (Li and Pritchard 2009).

Ex situ conservation can be complementary to *in situ* conservation (Smith et al. 2011), and is becoming an increasingly important method of conservation as natural ecosystems are supplanted by "human-dominated ecosystems" (Li and Pritchard 2009). *Ex situ* conservation removes propagules from their natural environments and stores them long-term, often with the goal of eventual reintroduction *in situ* (Linington and Pritchard 2001). Entire living plants or plant parts are placed within the collections of botanical gardens, arboreta, private collectors, and gene banks, and are conserved *via* living plant collections, seed banks, cryopreservation units, and tissue culture storage. *Ex situ* conservation can preserve genetic diversity of plant taxa but excludes them from natural conditions and evolutionary processes. When natural conditions are declining or lost, however, ex situ conservation is critical and often the only method of conservation.

Ex situ conservation of plants or plant material likely costs less than 1% of the cost of their *in situ* conservation (Li and Pritchard 2009). Dr. Valerie Pence (2011) compared different methods of *ex situ* conservation and found the following: Initial banking of a seed is estimated at $8 per seed, compared to $25 to $200 per tissue culture specimen. Yearly maintenance of an accession in a seed bank is estimated to range from $.05 to $10, whereas alternative banking methods (tissue banking, in vitro culture, and field gene banks) can range from $1 to $100 per accession per year. Living plants conserved *ex situ* in a botanical garden can cost up to $400.

Seed banks are the most common and economical method of *ex situ* conservation for vascular, seed-bearing plant taxa. There are over 1,300 seed banks around the world (Laliberté 1997), and there are 421 institutions that bank seeds of wild plants in 97 countries (O'Donnell and Sharrock 2015). The majority of seeds stored long-term in a conventional seed bank are orthodox seeds, or seeds that maintain viability after undergoing desiccation and freezing temperatures. These seeds are dried to 3-7% moisture content (Linington 2003) and stored at -18°C ±3°C in an environment of 15 ±3% relative humidity (FAO 2014). There are, however, vascular plant taxa that do not produce orthodox seeds and thus cannot be conserved in traditional seed banks. These are referred to as “exceptional," a term coined by Dr. Valerie Pence (Pence 2011). Furthermore, Pence (2011) calculated that there are roughly 30,000 total threatened taxa in the world, 16.7% of which fall into the "exceptional" category.

Currently, there is no comprehensive and generally agreed-upon definition of "exceptional" as it pertains to the conservation of vascular, seed-bearing plants. For example, exceptional taxa might produce recalcitrant seeds, which cannot tolerate loss of some percentage of their moisture, and/or they cannot be subject to below-freezing temperatures without losing viability. They can also be plant taxa that have environmental, reproductive, or genetic barriers to producing seeds and therefore reproduce clonally. Another example of exceptional taxa could be plants that produce few seeds, have infrequent or non-viable seed production, or are located in an area or produce seed at a time in which it is impossible for people to collect their seeds. Still others might have deeply dormant seeds or their seeds can only be banked for a short period of time. Alternative methods must be employed for successful *ex situ* preservation and propagation of exceptional taxa (Pence 2011). Some alternatives to seed banking are: pollen banking; long-term storage of plant tissue such as woody stems, roots, and tubers; cryopreservation of plant tissues such as excised embryos, dormant buds, somatic embryos, or shoot tips; living field gene banks; and living plant collections.

Data Sharing

In addition to the need for conservation of threatened plants, there is a growing need for the sharing of conservation data. Target 3 of the GSPC requires that research, information, and methods that inform the implementation of the GSPC be developed and shared (CBD 2010d). Similarly, Target 19 of the Aichi Biodiversity Targets requires that knowledge relating to biodiversity be widely shared (CBD 2010c). However, many institutions may not be aware that they hold exceptional taxa in their collections. Further, the valuable information they hold on these taxa may not be easily accessible or readily available to others who could support efforts to research and preserve them. An easily-accessible, "comprehensive resource" is necessary to identify threatened exceptional plant taxa so that conservation measures can be prioritized (Global Trees Campaign 2014a).

Research Objectives

The goals of this research are to refine the definition of "exceptional" as it pertains to vascular, seed-bearing plant taxa, assign seed storage behaviors to the threatened plant taxa of the United States and Canada, and provide preliminary interpretation of the data in order to determine high-priority targets for plant conservation efforts.

This research will help to satisfy Target 8 of the GSPC and Target 12 of the Aichi Biodiversity Targets, by determining which threatened, vascular, seed-bearing plant taxa in the United States and Canada are also exceptional. It will also help to satisfy Target 3 of the GSPC and Target 19 of the Aichi Biodiversity Targets, by creating a resource for documentation of these taxa.

Chapter 2

MATERIALS AND METHODS

Human Subjects Review Board

The protocols for the two surveys included in this research were reviewed and determined to be exempt from applicable federal regulations by the University of Delaware Human Subjects Review Board (Appendix A).

Survey: Characterization of Exceptional Plant Taxa

To refine the definition of "exceptional" as it pertains to vascular, seed-bearing plant taxa that cannot be seed-banked, a survey was sent to professionals in the field of plant conservation throughout the world. The majority of the recipients practice plant conservation in the United States and Canada. The total number of surveys sent via email was over 3,500.

The survey was distributed via email to major botanic garden plant conservation networks in North America including the American Public Gardens Association (APGA) Plant Conservation Professional Section, the Botanic Gardens Conservation International (BGCI) network including the Exceptional Plant Species Advisory Group (EPSAG), the Botanical Society of America (BSA), the Center for

Plant Conservation (CPC), targeted members of the National Academy of Sciences (NAS), and targeted employees of the United States Department of Agriculture (USDA).

The survey was structured to characterize the respondents' relationships with plant conservation via questions about their institutions and job positions, refine the definition of "exceptional" plant taxa, and to identify researchers to assess a list of potentially exceptional plant taxa from the United States (U.S.) and Canada.

Within the survey, survey recipients were asked to provide their professional position and to provide general characteristics of their institution.

The survey respondents were asked to review the characteristics of exceptional taxa, as previously suggested by the EPSAG of BGCI in a meeting held in October of 2013 and to choose from these the characteristics they felt best represented qualities of exceptional plant taxa. Respondents also could suggest new categories. See Appendix B for an unpublished summary of the meeting.

The selections were:

- produces recalcitrant seeds (seeds that do not survive drying and freezing in *ex situ* conservation)
- produces few or no seeds
- seeds are not easily accessible for collection when mature (if at all)
- produces poor-quality and non-viable seeds
- produces seeds infrequently

- produces seeds with deep dormancy
- produces seeds that can survive short-term banking (10 years of conventional storage or less with approximately 20% or greater viability loss) but not long-term banking (greater than 10 years of conventional storage with less than 20% viability loss)
- cannot be easily propagated by seed (with current knowledge/protocols)

See Appendix C for the complete survey. All survey recipients were informed that if they assisted with the preliminary list, their participation would result in formal acknowledement when this research is published.

All responses in which selections were made for the definition of "exceptional" were included in the data analysis. The responses for those that did not make any selections to help refine the definition were considered incomplete and therefore not included. All complete responses were given equal importance.

Information Request: Community Input for Threatened, Exceptional Plant Taxa in the United States (U.S.) and Canada

This request for information targeted those who had, in the survey, expressed willingness to look at a preliminary list of threatened, exceptional plant taxa. The request was also sent to all members of two specific groups: members of the Center for Plant Conservation (CPC) and the members of the Exceptional Plant Species Advisory Group (EPSAG) of BGCI. These two specific groups were chosen because many members of each group work with exceptional plants and have expertise in *ex situ* plant conservation.

Generation of Initial List of Exceptional Plants

In 2012, before this thesis research began, a list of North American threatened plant taxa was compiled from data held in NatureServe's databases (NatureServe 2015b). This list was narrowed down into a list of taxa preliminarily assigned "exceptional statuses" based on known *ex situ* holdings in BGCI's PlantSearch database (BGCI 2015). The list included angiosperms (flowering plants that produce seeds enclosed in fruits), gymnosperms (plants with unprotected seeds), and pteridophytes (vascular plants that produce spores rather than seeds). Overall, 117 threatened, native taxa were assigned an exceptional status of "exceptional", 106 taxa were assigned a "questionable" exceptional status, and 66 taxa were assigned a status of "suspected" to be exceptional. This list, which totals 289, though not definitive, will henceforth be referred to as the "Known Status" list and was compiled by Ben Morgan, a Ph.D. Candidate at Northwestern University, Dr. Valerie Pence of the Cincinnati Zoo & Botanical Garden, and Dr. Andrea Kramer of the Chicago Botanic Garden. For more detailed information on how these exceptional statuses were assigned, see Appendix D for this incomplete and unpublished summary of the effort. There were also many threatened native taxa that did not have holdings in *ex situ* collections. These 5842 taxa also became a list, henceforth called the "Unknown Status" list.

The Known Status and Unknown Status lists were then further refined for this thesis research. The plant taxa Latin names, native countries, native states and provinces, and global threat statuses were sourced from NatureServe Explorer (NatureServe 2015b). See Table 1 for definitions of these statuses. The plant families were sourced from the Taxonomic Name Resolution Service (iPlant Collaborative 2014). Habit information, including tree, shrub, subshrub, forb/herb, graminoid, vine, and combinations of two or more of these habits, was pulled from the USDA Plants database (USDA 2015). For some taxa, habit information was not available from the USDA Plants database. Habitat or ecosystem type for each taxon was not analyzed because there was no readily available, comprehensive source from which to compile such information.

All of the above data was included in the two lists and placed into a larger Excel® Workbook with five spreadsheets. The Known and Unknown lists were kept unlocked so that they could be sorted based on features that might most closely match the recipients' realm of familiarity.

Table 1: NatureServe Global Conservation Status Ranks (NatureServe 2015c)	
A **G-rank** reflects an assessment of the condition of the *species*' global conservation status ranks across its entire range. A **T-rank** is the status of an *infraspecific taxon* (subspecies or variety). The T-rank follows the species' global rank. Rules for assigning T-ranks follow the same principles outlined for G-ranks. For example, the global conservation status of a critically imperiled subspecies of an otherwise widespread and common species would be G5T1.	
Basic G- and T-ranks	**Conservation Status Description**
GX/TX	**Presumed Extinct -** Not located despite intensive searches and virtually no likelihood of rediscovery.
GH/TH	**Possibly Extinct -** Missing; known from only historical occurrences but still some hope of rediscovery.
G1/T1	**Critically Imperiled** - At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors.
G2/T2	**Imperiled -** At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.
G3/T3	**Vulnerable -** At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
G4/T4	**Apparently Secure -** Uncommon but not rare; some cause for long-term concern due to declines or other factors.
G5/T5	**Secure -** Common; widespread and abundant.
When there is some uncertainty of the degree of global conservation status, a **Variant** rank is assigned.	
Variant Rank	**Variant Rank Description**
G#G#/T#T#	**Range Rank -** A numeric range rank (e.g., G2G3) is used to indicate the range of uncertainty in the status of a species or community. Ranges cannot skip more than one rank (e.g., GU should be used rather than G1G4).
GU/TU	**Unrankable -** Currently unrankable due to lack of information or due to substantially conflicting information about status or trends. Whenever possible, the most likely rank is assigned and the question mark qualifier is added (e.g., G2?) to express uncertainty, or a range rank (e.g., G2G3) is used to delineate the limits (range) of uncertainty.
GNR/TNR	**Unranked -** Global rank not yet assessed.
When there is a question as to the validity of a global conservation status rank, a Rank **Qualifier** is assigned.	
Rank Qualifier	**Qualifier Description**
?	**Inexact Numeric Rank -** Denotes inexact numeric rank (e.g., G2?)

Q	**Questionable taxonomy -** Taxonomic distinctiveness of this entity at the current level is questionable; resolution of this uncertainty may result in change from a species to a subspecies or hybrid, or the inclusion of this taxon in another taxon, with the resulting taxon having a lower-priority conservation priority.
C	**Captive or Cultivated Only -** At present extant only in captivity or cultivation, or as a reintroduced population not yet established.

Excel® Workbook

The first spreadsheet was entitled "Read Me" and was an explanatory spreadsheet that described the project, gave the definition of "exceptional" plant taxa based on the results of the survey, explained that any input they could give was valuable, and gave data entry instructions (Appendix E). This spreadsheet was password locked so respondents could not edit it.

The second spreadsheet was entitled "Key to Columns" and contained sources and explanatory text for the informational columns, and instructional and explanatory text for the columns in which the researchers were asked to input information (Appendix F). This spreadsheet was password locked so that the recipients could not alter it.

The third spreadsheet was entitled "Examples" and gave examples of ways in which the researchers could input information. This spreadsheet was password locked so respondents could not alter it.

The fourth spreadsheet was entitled "Known Status" and the fifth spreadsheet was entitled "Unknown Status," and are described above and are included in Appendix G and Appendix H, respectively.

The entire workbook was sent via email to the aforementioned conservation experts. The columns in the Known Status and Unknown Status spreadsheets that the recipients were asked to fill in were entitled:

- "Your Name and Institution".
- "Your Proposed Exceptional Status" - here, recipients were asked to code their proposed exceptional status as "E" for exceptional, "N" for not exceptional, and "U" for unknown, per taxon.
- "Brief Justification for Your Proposed Status" - recipients were asked to include a few words explaining why a particular taxon should be assigned their proposed exceptional status.
- "Research Status (Past/Current), and Investigators and Publications" - here, recipients were asked to cite publications or describe anecdotal evidence to further explain why a particular taxon should be assigned their proposed exceptional status.
- "Comments and Notes" - recipients were also asked to include non-related conservation aspects for a taxon, corrections to any information given to them in the spreadsheet, and any other comments they might have about a taxon.

The participants were then asked to return the workbook with their inserted information, or contact the researcher via phone or email to discuss.

Data Analysis

In some cases, participants' proposed seed storage behavior did not concur with their justifications and/or comments. In these cases, changes may have been made to the participants' proposed seed storage behaviors. The final seed storage behavior was determined based on participants' justifications and comments as well as their proposed seed storage behavior.

To determine the relationships between plant families that contain exceptional taxa, an image of the phylogenetic tree of flowering plant and gymnosperm orders was extracted from the Angiosperm Phylogeny Website (Stevens 2001). The families with exceptional taxa were matched to their orders.

As there are many different combinations of NatureServe global conservation threat status ranks, analysis based on each unique combination is complex. To simplify analysis, each incidence of a T-rank was considered a unique occurrence, and when paired with a G-rank, the G-rank was ignored since it represents the species as opposed to the subspecies or variety. Additionally, each incidence of a G-rank was considered a unique occurrence except for those cases where it was paired with a T-rank as stated in the previous sentence. The rank qualifiers (?, Q, and C) were ignored. For example, one taxon might have a status of "G2G3Q." In this example, this taxon was counted as "1" for G2 and "1" for G3. The rank qualifier of "Q" was ignored. In another example, a taxon with a status of G4T1T3? was counted as "1" for T1 and "1" for T3. The G4 and rank qualifier of "?" were ignored. Because taxa with more than one G- or T-rank was counted several times, the number of taxa are inflated.

There are also many taxa that are listed with several habits. In the Threatened list, the habit listed first for a taxon indicates the habit in which it is most commonly found in nature. Only this first-listed habit for each taxon was used in analysis.

A chloropleth map of the number of exceptional and extinct exceptional taxa and their native states and provinces was made with QGIS 2.4.0-Chugiak (QGIS 2015). The base maps for Canada and the U.S. were obtained from DIVA-GIS (Hijmans, Guarino, and Mathur 2014). Because some taxa span more than one state or province, the numbers appear inflated.

Chapter 3

RESULTS

Definition of Exceptional

In order for a list of plant taxa to be analyzed for their seed storage behaviors, there needed to be effective communication about the definition of "exceptional" as it pertains to plant taxa. The first step in achieving this was to gather input via a survey from the scientific community about the best definition of "exceptional."

In total, 178 complete responses from 147 different institutions, 70% of which have conservation in their missions, were included in the analysis (Appendix I). Since the primary purpose of the survey was to refine the definition of "exceptional," responses that did not include "exceptional" definition parameters were determined to be incomplete and therefore removed from analysis.

Six of the eight definition parameters offered to survey recipients had 60% or higher "yes" responses, indicating that these parameters should be included in the definition of exceptional. See Figure 1. Two other definition parameters, with the lowest number of "yes" responses (below 53%) were taken out of the final definition of exceptional. This was in part due to the low number of "yes" responses, but also because of the following: the definition parameter "Produces seeds that can survive short term banking but not long term banking" refers to the seeds' abilities to be seed-banked, and therefore is in conflict with the definition of exceptional. In addition, "Produces seeds with deep dormancy" can be incorporated into the more general definition parameter "Cannot be easily propagated by seed."

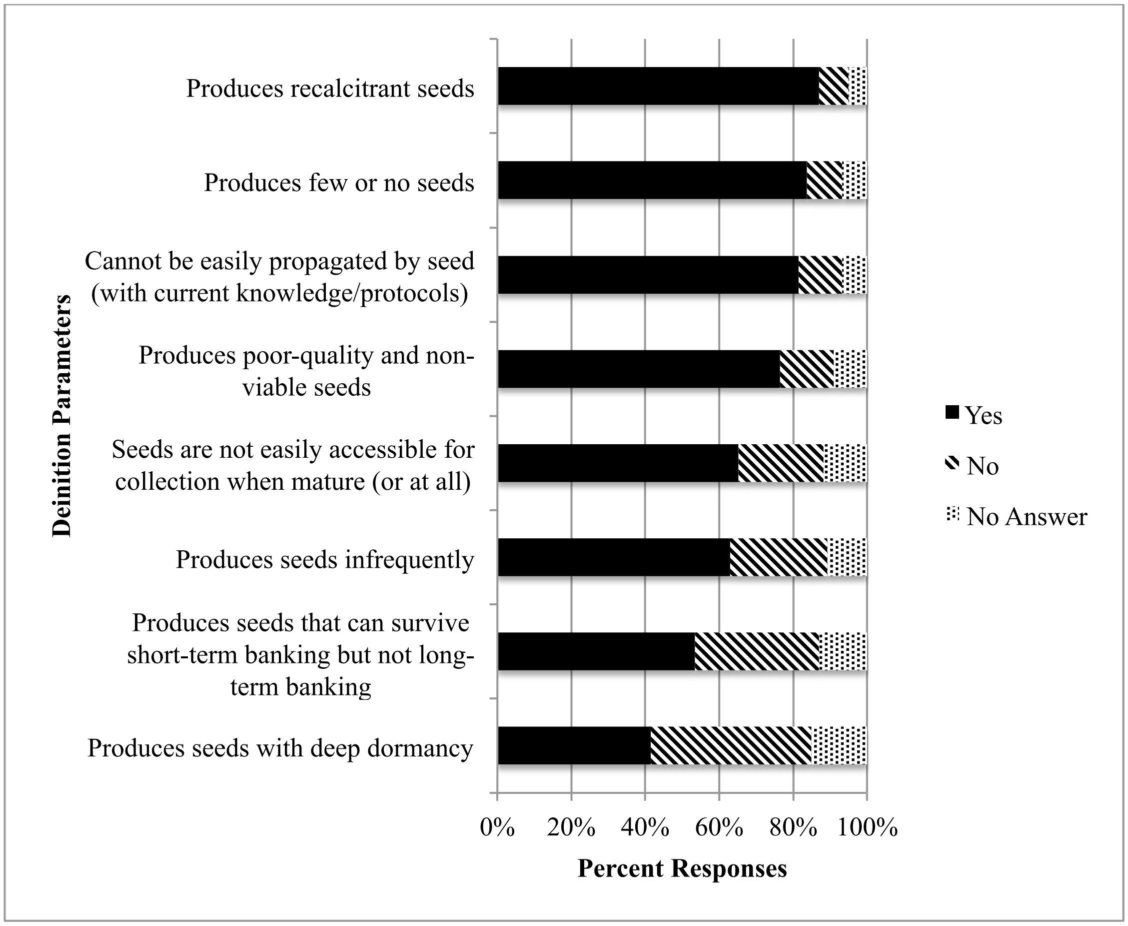

Figure 1: **Percentage of Responses to "Exceptional" Definition Parameters**. Two definition parameters, "Produces seeds that can survive short-term banking..." and "Produces seeds with deep dormancy" were not included in the final definition.

Based on survey results, the definition of an "exceptional" plant taxon is as follows:

An exceptional plant taxon is a species, subspecies, or variety of vascular, seed-bearing plant which cannot be seed-banked because the seed biology or availability satisfies one or more of the following conditions: produces recalcitrant seeds, produces few or no seeds, cannot be easily propagated by seed, produces poor-quality or non-viable seeds, seeds are not easily accessible for collection when mature (or at all), or produces seeds infrequently.

Known and Unknown Status List Input

Twenty-two recipients responded with input into the lists. See Table 2 for a complete list of the research contributors' institutions and method of participation. The contributors supplied vital information regarding exceptional status of threatened, U.S. and Canadian taxa.

Table 2: Institutions and Methods of Participation of Research Contributors Who Gave Input into Known, Unknown, and Suggested Additions Lists. All respondents were involved in plant research and/or conservation.	
Institution	**Method of Participation**
Memorial University of Newfoundland Botanical Garden	Spreadsheet
Lyon Arboretum Seed Conservation Laboratory	Spreadsheet
The Botanic Garden of Smith College	Email; Spreadsheet
New England Wild Flower Society	Spreadsheet
University of South Florida Herbarium	Spreadsheet
Montgomery Botanical Center	Spreadsheet
Chicago Botanic Garden	Email
BGCI-US	Spreadsheet
Lyon Arboretum Seed Conservation Laboratory	Spreadsheet
U-Paris-Sud	Email; Spreadsheet
Rancho Santa Ana Botanic Garden	Email
Waimea Valley	Spreadsheet
Cincinnati Zoo & Botanical Garden	Spreadsheet
Bok Tower Gardens	Spreadsheet
ICF International	Email; Spreadsheet
Minnesota Landscape Arboretum	Spreadsheet
Southeastern Oklahoma State University	Email
Lyon Arboretum Micropropagation Lab	Spreadsheet
USDA-ARS National Center for Genetic Resources Preservation	Email
Royal Botanic Gardens Kew, Millennium Seed Bank	Email
Oahu Army Natural Resources Program (OANRP)	Spreadsheet
Longwood Gardens	Email

Adjustments to Known and Unknown Status Lists After Response Collection

In order to standardize the information supplied by the research contributors so that the data could be analyzed, it was necessary to make adjustments in the Known Status and Unknown Status lists. Those adjustments are as follows:

Suggested Additions

The research contributors suggested adding twenty-two plant taxa to the Known Status list. These remain on a separate list and are in Appendix J. Names of research contributors have been removed.

Pteridophytes

The Known Status and Unknown Status lists sent to the research contributors contained ferns and other vascular, spore-producing plants (pteridophytes). Because pteridophytes do not produce seeds, they were taken out of the Known Status and Unknown Status lists, and remain on a separate list. See Appendix K for the entire list of pteridophytes from the original Known Status and Unknown Status lists including any comments made by the research contributors. Names of research contributors have been removed.

Additional Comments

Many of the research contributors also made comments regarding the lists that were outside the scope of the existing rows or columns. See Appendix L for these comments.

Seed Storage Behavior

After analysis of each of the research contributors' proposed exceptional statuses for the taxa, justifications for the proposed exceptional statuses, research statuses, and comments and notes, three columns were added to standardize comments and proposed exceptional statuses. They are: "Final Seed Storage Behavior," "Final Seed Storage Behavior Justification," and "Final Seed Storage Behavior Notes." To eliminate confusion, the term "exceptional status" was not used in these columns. Although "seed storage behavior" is used to refer to the specific categories of: orthodox, recalcitrant, and intermediate in Royal Botanic Gardens, Kew's Seed Information Database (Royal Botanic Gardens Kew, 2015), for the purposes of this research, final "seed storage behavior" refers to the following:

Final Seed Storage Behavior

Based on comments by the research contributors, each taxon commented on was given a final seed storage behavior. These are:

- Exceptional (E)
- Non-Exceptional (N)

- Unknown (U)
- Congeners Exceptional (CE)
- Congeners Non-Exceptional (CN)
- Extinct Exceptional (XE)
- Extinct, Congeners Exceptional (XCE)
- Extinct Non-Exceptional (XN)
- Extinct, Congeners Non-Exceptional (XCN)
- Extinct Unknown (XU)

Final Seed Storage Behavior Justifications

In order to standardize the seed storage behavior input from the research contributors, a column entitled "Final Seed Storage Behavior Justifications" was created. The following explains the reasoning behind final seed storage behavior justifications given.

Exceptional (E) or Extinct Exceptional (XE)

The final justifications for the taxa given an exceptional (E) or extinct exceptional (XE) seed storage behavior are one or more of the definition parameters of exceptional:

- Produces recalcitrant seeds
- Produces few or no seeds

- Cannot be easily propagated by seed
- Produces poor-quality and non-viable seeds
- Produces seeds infrequently
- Produces seeds that are not easily accessible by humans when mature

Congeners Exceptional (CE) or Extinct, Congeners Exceptional (XCE)

The final justification for the taxa given a congeners exceptional (CE) or extinct, congeners exceptional (XCE) seed storage behavior is based on the fact that they share a genus with a taxon that is exceptional.

Non-Exceptional (N) or Extinct Non-Exceptional (XN)

The final justification for the taxa given a non-exceptional (N) or extinct non-exceptional (XN) seed storage behavior is:

- Seeds non-exceptional - these taxa are the opposite of *all* of the parameters of exceptional

Congeners Non-Exceptional (CN) or Extinct, Congeners Non-Exceptional (XCN)

The final justification for the taxa given a congeners non-exceptional (CN) or extinct, congeners non-exceptional (XCN) seed storage behavior is based on the fact that they share a genus with a taxon that is non-exceptional.

Unknown (U) or Extinct Unknown (XU)

The final justifications for the taxa given an unknown (U) or extinct unknown (XU) seed storage behavior, which indicates the need for further research, are:

- Conflicting justifications - two or more research contributors gave two or more proposed seed storage behaviors to these taxa
- Congeners exceptional and non-exceptional - taxa share a genus with both a taxon that is exceptional and a taxon that is non-exceptional
- Justification is incomplete - justification not given, or justification does not satisfy one of the definition parameters of exceptional, or cannot be categorized as non-exceptional, congeners exceptional, or congeners non-exceptional

Final Seed Storage Behavior Notes

In the "Final Seed Storage Behavior Notes" column, there are two standard notes. These notes do not justify the final seed storage behavior of the taxa, but they can serve as a guide to next steps into research of these taxa. They are:

- Further contact suggested - this indicates that in the original input by the research contributors, an organization or individual name and/or contact information has been provided as a possible source of information regarding the taxon.

- Taxonomy Issue - this indicates that there has been some question as to the proper taxonomy of the given taxon.

Unranked Taxa

There are many taxa on the Known list and Unknown list that were not commented on by the research contributors or given final seed storage behaviors. These are considered to be unranked.

Seed Storage Behavior List

There are 734 vascular, seed-bearing plant taxa from the original Known Status and Unknown Status lists on which comments were made by the research contributors. These were combined with 1,356 taxa that are congeneric with taxa given a final seed storage behavior of E or N, for a total of 2,090 taxa. This list of 2,090 taxa is known as the Seed Storage Behavior list. See Appendix M for the complete Seed Storage Behavior list.

The numbers of each of the final seed storage behaviors for the taxa on the Seed Storage Behavior list are:

- 154 exceptional (E)
- 574 congeners exceptional (CE)
- 141 non-exceptional (N)
- 887 congeners non-exceptional (CN)

- 316 unknown (U)
- 2 Extinct, exceptional (XE)
- 7 Extinct, congeners exceptional (XCE)
- 0 Extinct, non-exceptional (XN)
- 3 Extinct, congeners non-exceptional (XCN)
- 6 Extinct, unknown (XU)

Changes in Seed Storage Behavior

Based on research contributors' responses, the final seed storage behavior for many taxa differed from their original seed storage behavior given to them by Morgan, Pence and Kramer. See Table 3. All seed storage behavior of taxa with an original seed storage behavior of Questionable (Q) and Suspect (S) from the Known Status and Unknown Status lists have changed since these were not options for the final seed storage behavior on the Seed Storage Behavior list.

Table 3: Percent of Taxa for which the Seed Storage Behavior Remained the Same or Changed. The original seed storage behavior is from the list created by Morgan et al. (2013)

Original Seed Storage Behavior	Final Seed Storage Behavior	Percent
E	E or XE	32.2%
	CE or XCE	17.8%
	N or XN	6.7%
	CN or XCN	12.2%
	U or XU	21.1%
	Unranked	10.0%

Q	E or XE	28.6%
	CE or XCE	10.5%
	N or XN	28.6%
	CN or XCN	13.3%
	U or XU	17.1%
	Unranked	1.9%
S	E or XE	12.1%
	CE or XCE	51.5%
	N or XN	3.0%
	CN or XCN	10.6%
	U or XU	6.1%
	Unranked	16.7%
U	E or XE	1.6%
	CE or XCE	9.2%
	N or XN	1.8%
	CN or XCN	15.1%
	U or XU	5.0%
	Unranked	67.3%

Threatened List

All taxa on the Seed Storage Behavior list were combined with all unranked taxa to create the Threatened list (Appendix N).

Families and Final Seed Storage Behavior

A total of 139 families are on the Threatened list. Figure 2 shows the 40 families and 22 orders represented by all of the taxa on the list with a final seed storage behavior of E or XE. Appendix O shows the numbers of taxa with final seed storage behavior represented in each family on the Threatened list.

Figure 2: **Numbers of Exceptional Taxa per Family with Corresponding Orders**. The highest concentrations of exceptional taxa occur from Malphigiales to Apiales, which are more evolutionarily advanced orders. In addition, the exceptional taxa tend to occur in the orders that have shorter branching.

Habits and Final Seed Storage Behavior

Please note that when a habit is mentioned here, it is the habit in which the taxon is most commonly found in the wild. A comparison was made to determine if there is a correlation between habit of the threatened, exceptional taxa and severity of threat status. See Figure 3. Trees and shrub/subshrubs have higher numbers of E and

XE taxa with severe threat statuses combined (G1/T1 and G2/T2) than the taxa with other habits or habits for which data is not available.

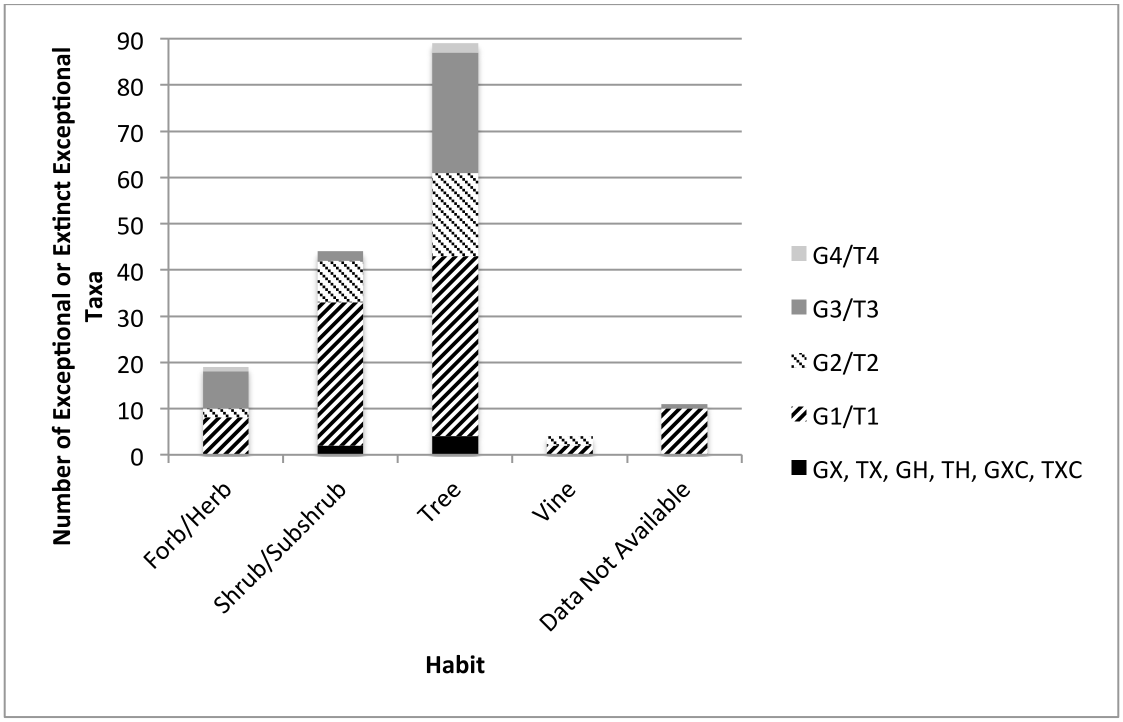

Figure 3: **Number of Exceptional and Extinct Exceptional Taxa with Corresponding Threat Status, by Habit.** The legend on right shows threat status top to bottom from lowest to highest degree of threat (See Table 1 for complete explanation of NatureServe threat statuses). Habit indicates the form of the taxa as they are most often found in nature. Because taxa with more than one G- or T-rank were counted several times, the number of taxa are inflated.

See Table 4 for the percentages of the habits on the Threatened and Seed Storage Behavior lists, and the percentage that have a final seed storage behavior of E or XE. Shrub/subshrub, vine, and habits for which data is not available are all fairly consistent in their percentages on the list, the percentages given a final seed storage behavior, and the percentage of exceptional taxa. The forb/herb/graminoids, however, make up 59% of the total taxa on the Threatened list, and account for 48% of all taxa given final seed storage behaviors, yet only 10% of all forb/herb/graminoid taxa are given a final seed storage behavior of E or XE. Conversely, trees make up only 7% of the total taxa on the Threatened list, and they account for 16% of all taxa given final seed storage behaviors, yet 53% of all tree taxa were given a final seed storage behavior of E or XE.

Table 4: Percentages of the Habits of the Taxa on the Threatened List, the Seed Storage Behavior List, and Those With a Final E or XE Behavior.

Habit most commonly found in nature	% Total on Threatened List	% Total on Seed Storage Behavior List	% Total with Final Seed Storage Behavior of E or XE
Forb/herb/graminoid	59%	48%	10%
Shrub/subshrub	23%	27%	27%
Trees	7%	16%	53%
Vine	3%	4%	3%
Data Not Available	8%	5%	7%

State/Province Nativity and Final Seed Storage Behavior

Appendix P contains the state/province nativity of the exceptional taxa identified within the Seed Storage Behavior list constructed through this research. Since many taxa span multiple states, the taxa totals appear inflated. Figure 4 shows a chloropleth map of the nativity of the exceptional and extinct exceptional taxa identified within this study. States of note are Hawaii with 132 exceptional taxa, Florida with 9 exceptional taxa, and Indiana with 4 exceptional taxa identified in this study. The rest of the states in the U.S. and provinces in Canada have 3 or fewer exceptional taxa identified in this study.

Figure 4: **Exceptional and Extinct Exceptional Taxa and Their Corresponding Native States/Provinces in the U.S. and Canada**. The states and provinces that have no shading have 0 taxa given an E or XE seed storage behavior. Hawaii has 132 exceptional or extinct exceptional taxa, and is the only state or province with greater than or equal to 10 taxa with an E or XE seed storage behavior identified by the research contributors.

Chapter 4

DISCUSSION

Background

It is becoming more and more scientifically accepted that our Earth is in its 6th great extinction, and that it is likely human-accelerated (Ceballos et al. 2015). It is a balancing act to support the human population and its needs in harmony with all other species' needs. As such, we devote resources to the conservation of plants that have agricultural, economic, cultural, and popular significance. Budgetary constraints and constraints on resources can limit conservation efforts, making it necessary for us to focus on those taxa that are most urgently in need of preserving before they succumb to extinction. Threatened plant taxa that are also exceptional should be given a greater conservation priority, since they have a double disadvantage of being threatened as well as being more difficult and costly to conserve (Smith et al. 2011; Pence 2011).

Knowing which threatened plants are exceptional will help direct efforts for both *ex situ* and *in situ* conservation. The information compiled in the Seed Storage Behavior list will help to achieve the goals set forth by the GSPC and Aichi Biodiversity Targets of improving and sustaining the conservation statuses of threatened species by 2020. The research from our study has furthered knowledge of the conservation needs of 2,090 threatened, vascular, seed-bearing plant taxa in the

U.S. and Canada. Now that we have a framework in place from this research, the gathering of information about additional taxa can be facilitated more efficiently.

This list is the first opportunity to share data on exceptional taxa. Royal Botanic Garden, Kew's Seed Information Database includes information on exceptional taxa, not using the term, "exceptional," but rather referring to a single definition parameter of exceptional: recalcitrance (Royal Botanic Gardens Kew, 2015). With the other definition parameters for exceptional now in place, there can be other valuable search parameters added to seed bank databases. Furthermore, adding seed storage behaviors, seed storage behavior justifications, and seed storage behavior sources to databases such as the Center for Plant Conservation's National Collection Plant Profiles (CPC 2015) would inform and prioritize efforts related to plant conservation and ecological restoration for the taxa listed. BGCI's PlantSearch database (BGCI 2015) would also benefit because it could show which threatened trees and plants held at botanic gardens are also exceptional, allowing for more purposeful management and planning of conservation-oriented living collections.

Definition of Exceptional

The definition of "exceptional" as it pertains to vascular, seed-bearing plant taxa was decided upon by majority opinion of respected individuals who work in plant conservation and related fields. Once this definition was established, we could then assign seed storage behaviors to the threatened taxa of the U.S. and Canada. Based on the seed storage behaviors assigned and our knowledge of the taxa beyond their exceptionality, we can now take a critical look at the data and provide preliminary interpretation of the characteristics and relationships of the taxa on the list.

Analysis of Exceptional Taxa

In the initial, unpublished study by Morgan et al. 2013, there were 90 vascular, seed-bearing plant taxa thought to be exceptional. Recall Appendix D. In this study, it was determined that 156 taxa are exceptional, only 29 of which were exceptional in the preliminary list. The difference in numbers of exceptional taxa can be explained by the fact that Morgan et al. 2013 categorized taxa as exceptional based on two parameters. One parameter was that the taxa were recorded as recalcitrant in Kew's Seed Information Database (Royal Botanic Gardens Kew 2015). Although this particular parameter is indeed used in our study, it is only one of the six definition parameters of exceptional that were agreed upon by a large group of experts in plant conservation and related fields. The second parameter was that the taxa were recorded as conserved in tissue culture and/or cryopreservation with no seed bank accessions known, according to BGCI's PlantSearch database (BGCI 2015). Though this is valuable storage information to include in the Seed Storage Behavior list, it does not necessarily identify seed storage behavior. As evidenced in the Seed Storage Behavior list, there are orthodox taxa conserved in tissue culture and/or cryopreservation collections, and/or are not seed banked.

Phylogenetic Relationships

Congeners

The final seed storage behavior of congener(s) exceptional (CE) and congener(s) non-exceptional (CN) were established after many of the research contributors who gave input to the lists recognized congenericity as a factor that may be significant. Walters et al. (2005) found that congeners in some genera share similar seed storage longevities, while congeners in other genera do not. Though this specific example is only related to one parameter of seed storage behavior, it does show that seed characteristics may be similar within some genera. Therefore, for the taxa that have not been assigned an exceptional (E) or non-exceptional (N) seed storage behavior, it may be helpful to know that they are congeneric with E taxa or N taxa.

There are some taxa that are congeneric with both E and N taxa; these were given an Unknown (U) seed storage behavior. Because these U taxa are congeneric with both E and N taxa, a logical next step for determining their seed storage behavior may be to examine the habitats of the E, N, and U taxa. For example, a U taxon that is a congener with both an E and an N taxon but shares a similar habitat with the E taxon might be more likely to also have an seed storage behavior of E. This would be an interesting future study and could help to quickly and easily categorize a number of the taxa that currently have a seed storage behavior of U.

If indeed it is determined that congenericity is significant and can be used to definitively categorize taxa, then there is much insight that can be gained into exactly where conservation efforts should be focused. As determined from this study, only 9%

of CE taxa are currently being maintained *ex situ*, leaving 91% that are not conserved *ex situ*. Conversely, there are 851 taxa on the list that are CN taxa and are not known to be conserved *ex situ*, but likely could be easily stored in a seed bank, with low cost and effort. Pritchard et al. (2014) said, "Even when there is no data on the species of interest, there may be information on a con-generic species or a perspective that can be gleaned from information across species in the same family."

Families

Hong, Linington, and Ellis (1996) show that there is a correlation between certain families and recalcitrance. According to Walters et al. (2005), in the 276 species within the USDA National Plant Germplasm System studied, some seeds that shared select plant families and/or select similar localities, also shared storage length characteristics. Present data and improved tests now show that seed longevity is evolutionarily related to seed structure as well as climate of origin (Probert, Daws, and Hay 2009). Though this previous evidence shows that species within the same family or order share certain seed biology characteristics and/or climate of origin, our study shows only select cases in which taxa sharing a family also share a seed storage behavior of E or N.

Two examples from our research are Rutaceae and Solanaceae. There are 61 Rutaceae on the list, 60 of which were given final seed storage behaviors. Of the 60 with final seed storage behaviors, 37% are E and share 3 genera, *Melicope*, *Zanthoxylum*, and *Platydesma*. All but one of these E taxa are located in Hawaii.

Further, 62% of those with final seed storage behaviors are CE taxa and are also found in Hawaii. This would be an ideal family to study further, as the majority are not only CE taxa, but they also share locality, and likely similar habitats. Within Solanaceae, there is both a wide range of seed storage behaviors and a wide range of localities, and therefore environment and habitat. Although only 20 out of 29 (69%) of the Solanaceae on the list were given final seed storage behaviors, there may be some interest in the outcome. Of the 20, three (15%) are E, are from Hawaii, and share the genus *Nothocestrum*, one (5%) is CE- also *Nothocestrum* and also from Hawaii, four (20%) share two genera and are N and from Hawaii. Seven (35%) are congeneric with these Hawaiian non-exceptional taxa but are located in California, Arizona, and Texas, and are therefore likely growing in dryer environments than their Hawaiian congeners. Five (25%) are unknown because they are congeneric with both E and N taxa. It would be interesting to study this family further as it would provide opportunity to draw specific conclusions about familial relationships as they relate to habitat and locality information.

Orders

There is evidence of an evolutionary relationship between seeds of taxa that share orders or families and their dormancy (Baskin, Baskin, and Li 2000). Pammenter and Berjak (2000) found that recalcitrance and orthodoxy arises in both primitive and advanced species. In our study, greater numbers of taxa with final seed storage behaviors of exceptional generally correspond to the more evolutionarily advanced taxa, and tend to be represented at the shorter branches. Recall Figure 2.

To gain a better understanding as to whether there may be a correlation between familial relationships and seed storage behavior, it would be necessary to know how many total taxa there are in each family. Schwartz and Simberloff (2001) found that, in the U.S. and Canada, the incidence of rare species is positively correlated with taxon size. If a taxon is large, it will have many rare species compared to a species-poor taxon, which has fewer than expected rare species. Knowing the total taxa in each family would help to test if there is a similar correlation between taxon size and seed storage behavior.

Threat Status

As stated above, the greater numbers of taxa with final seed storage behavior of E tend to be represented at the shorter branches of the order chart. Davies et al. (2011) found that for the species-rich Cape Region of South Africa, the more threatened species are found "within short branches at the tips of the phylogeny." It may not logically follow that exceptional taxa tend to have higher threat of extinction, but if there is a correlation, perhaps seed storage behavior should be a factor of threat status determination. For example, if a taxon with a NatureServe Imperiled (G2) threat status is determined to also be exceptional, this may warrant a threat status change to Critically Imperiled (G1).

Extinct Taxa on Seed Storage Behavior List

Although "extinct" does exist as a rank in the Threat Status column, it is helpful to include XE, XCE, XN, XCN, and XU as seed storage behavior options on the Seed Storage Behavior list. These storage behavior options lend validity to extinct taxa and help to assure that they will be given the same level of consideration for seed storage behaviors as the threatened, extant taxa. With the inclusion of extinct seed storage behavior options, if exceptional taxa on the list at some point become extinct and remain on the list, this information could provide researchers with increased knowledge of any correlation existing between seed storage behavior and threat status. In addition, if congenericity for example, is established to be a significant factor in determining seed storage behavior, the extinct taxa on the list could provide insight to future extinction risk of congeneric taxa. Lastly, if a plant on the list goes extinct in the wild, the list may have locations of the stored tissue of the plant so that it can be reintroduced when appropriate.

Habit

The inverse relationships of the percentages of E and XE forb/herb/graminoids and trees can be attributed to two possible factors. One option is that it is possible that the experts in the field are concentrating their efforts on trees more than any other habit. For example, The Global Trees Campaign is a partnership between BGCI and Fauna and Flora International, whose mission is to save the world's threatened trees (Global Trees Campaign 2014b). There is no known equivalent campaign for forbs and grasses. Or, assuming no habit-related bias in research, the data presented here shows that trees are more likely to be exceptional than any other habit, and forb/herb/graminoids tend to be non-exceptional. This is not surprising, since Hong, Linington, and Ellis (1996) show that climax vegetation is more likely to have recalcitrant seeds, and Tweddle et al. (2003) found that, in their study of 886 tree and shrub species that spanned climates, the highest frequency of desiccation-sensitive species are non-pioneer evergreen rainforest trees. Pritchard et al. (2014) found that species in families of large trees tend to more frequently have recalcitrant seeds.

State/Province Nativity

This study identified 132 threatened, exceptional, vascular, seed-bearing taxa in Hawaii, more than any other state in the U.S. or province in Canada. Relatedly, 54% of the Hawaiian exceptional taxa have a final seed storage behavior justification of "produces recalcitrant seeds." These findings are in keeping with Roberts and King (1980) who suggested that tropical seeds tend to be recalcitrant because they are adapted to high humidity and cannot tolerate drought. In addition, there are aggressive conservation programs in Hawaii since it is the U.S. state with a very rich endemism, as well as the highest percentage of species at risk and numbers of extinction (Stein 2002) (Weisenberger and Keir 2014). Because of this attention to Hawaii's threatened taxa, it is possible that much more is known about the seed biology and storage behaviors there than might be known about taxa in other states and provinces. As such, it is much more difficult to establish correlations between exceptional taxa and any other state or province locality. Perhaps if the other states and provinces allocated more resources to the conservation, protection, and study of threatened taxa, more would be discovered about taxa with exceptional traits.

Summary

This list of threatened, exceptional, vascular, seed-bearing plant taxa in the U.S. and Canada serves as a model for the global plant conservation community. It helps to address information challenges by compiling relevant information and standardizing the language used to communicate about these taxa. Having addressed these information challenges allows for easier identification of research priorities for effective and efficient conservation of plants and their ecosystems. Identifying research priorities allows the list to facilitate communication and organization for targeted conservation efforts and funding.

Future Opportunities

As has been shown, there is new taxa-specific knowledge that has come from this research. However, there is so much more that we don't know, and that we could know, by compiling and comparing our collective knowledge. The 156 exceptional taxa from this study make up 2.6% of the 5,923 taxa on the Threatened list of U.S. and Canadian taxa, which is much lower than the 16.7% that Pence (2011) estimated worldwide. This percentage gap indicates that much more research needs to be done regarding threatened, exceptional taxa.

Pteridophytes

Like seeds, spores have varied temperature- and moisture-related storage requirements for maximum viability. Furthermore, nearly all spores respond well to cryopreservation as a method of *ex situ* conservation. (Ballesteros et. al 2012). So as not to overlook this important group of plants, it would be beneficial to include pteridophytes in the Threatened list, and assign them "Spore Storage Behaviors" along with justifications for these behaviors.

Habitat

Although this study did not include analysis of habitat of the threatened taxa, this is certainly a subject that could warrant further investigation. A correlation could exist between seed storage behaviors of taxa and the habitats in which they are found. For example, tropical taxa whose seeds have never desiccated or been frozen may have a higher rate of exceptionality than tundra taxa whose seeds have evolved based on dry, frozen conditions, similar to a seed bank. This example only refers to recalcitrance; studying habitat in relation to other exceptional definition parameters could lead to valuable conclusions that will guide both *in situ* and *ex situ* conservation practices.

Unknown and Unranked

There is a large number of U.S. and Canadian threatened taxa that have been assigned unknown seed storage behavior. Communication with the research contributors and other conservation experts can help clarify the unknowns for which justification is incomplete, or for those that have conflicting justifications. Use of and acknowledgement of synonyms could help categorize those for which there are taxonomy issues, and understanding biological and ecological similarities and differences could help categorize the ones that share exceptional and non-exceptional congeners.

An even larger number of taxa are unranked (i.e. seed storage behaviors have not been assigned to them). This study utilized the expertise of 22 specialists; engaging greater numbers of experts in the field of plant conservation could very well increase the number of taxa assigned final seed storage behaviors.

Definition Refinement

The definition of "exceptional" as it pertains to vascular, seed-bearing plant taxa was determined by majority opinion of experts who work in plant conservation and related fields in the U.S. and Canada. There was input from others outside of the U.S. and Canada, but they made up a small fraction of the group. Whether or not this list is expanded to a global level, effort should be put into surveying individuals in plant conservation and related fields throughout the world, to determine if the definition of exceptional should remain as it is or if it can be refined further.

Expansion to Global List

Once the definition is confirmed, a larger global community should again be engaged to help contribute to a global threatened taxa seed storage behavior list. This would open up the doors to expanded opportunities for analysis of habit, phylogenetic relationships, threat status, habitat, and other not-yet-known attributes that may correlate to seed storage behavior. In addition, for this study, the threat statuses are based on NatureServe conservation ranks; for a global list, a combination of available international, national, and regional conservation lists should be utilized for assignment of threat status rankings. Another way to expand opportunities for analysis would be to assign all taxa- not just those that are threatened- with seed storage behaviors.

Seed Storage Behavior Rankings

A further step might be to establish a system of ranking the taxa with degrees of exceptionality. For example, a taxon that meets multiple exceptional parameters might be considered "more exceptional" than a taxon that meets only one parameter. Or perhaps one parameter, for example, seed recalcitrance, may be determined to be "more exceptional" than another parameter and therefore prioritized.

Database

A comprehensive, curated database of threatened U.S. and Canadian taxa could help catalog, consolidate, and disseminate seed storage behavior and related conservation information, and serve as a platform on which to create a global database.

A database would bring awareness to and justify funding for the targeted study and conservation of threatened, exceptional taxa. It would also be a portal where experts can access, add to, and share information regarding exceptional plant taxa. Of more altruistic importance, a database would help our efforts to conserve and maintain the Earth's threatened, exceptional plant taxa. It would provide a place to organize our understanding of conservation efforts of the non-seed-bankable taxa, which would in turn help us to know if we are on our way to satisfying Target 8 of the Global Strategy for Plant Conservation and Target 12 of the Aichi Biodiversity Targets.

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Appendix A

HUMAN SUBJECTS REVIEW BOARD EXEMPTION LETTER

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	November 12, 2014
TO:	Sara Helm Wallace, MS
FROM:	University of Delaware IRB
STUDY TITLE:	[683839-1] Characterization of Exceptional Plant Species
SUBMISSION TYPE:	New Project
ACTION:	DETERMINATION OF EXEMPT STATUS
DECISION DATE:	November 12, 2014
REVIEW CATEGORY:	Exemption category 2

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has determined this project is EXEMPT from the applicable federal regulations.

We will put a copy of this correspondence on file in our office. Please remember to notify us if you make any substantial changes to the project.

If you have any questions, please contact Maria Palazuelos at (302) 831-8619 or mariapj@udel.edu. Please include your study title and reference number in all correspondence with this office.

Appendix B

CONSERVING THREATENED EXCEPTIONAL PLANT SPECIES: STATEMENT OF NEED

December 3, 2013
Previously Unpublished

Background: A workshop on conserving threatened exceptional plant species was convened by Botanic Gardens Conservation International (BGCI) and the Cincinnati Zoo and Botanical Garden on October 21, 2013 as part of the 5th Global Botanic Gardens Congress in Dunedin, New Zealand. Workshop goals were to define key issues, priorities, and actions needed to effectively conserve threatened exceptional plant species.

Twenty-eight experts in cryopreservation, in vitro propagation, and *ex situ* conservation were invited to participate in the process as part of an Exceptional Plant Species Advisory Group (EPSAG), representing North America, Europe, Africa, Australia and New Zealand. Of these, seventeen individuals were able to attend the workshop and eleven provided consultation remotely. This Statement of Need summarizes outcomes of the workshop, as agreed by the EPSAG, and outlines next steps.

Defining exceptional plant species: Exceptional plant species cannot be conserved *ex situ* via conventional seed banking methods: they require more time- and resource-intensive approaches, including cryopreservation and *in vitro* propagation. We do not yet know how many species are exceptional, but initial estimates range from 10-25% of known plant species.

Any plant species that meets at least one of the following biological or environmental conditions may be considered exceptional:

- Produces recalcitrant seeds
- Produces few or no seeds
- Produces poor-quality or non-viable seeds
- Produces seeds infrequently
- Produces seeds with deep dormancy
- Produces seeds that survive short-term but not long-term banking
- Cannot be easily propagated by seed (with current knowledge/protocols)
- Are not accessible when seeds are mature

NEED 1: Address information challenges. We have incomplete information on which threatened plant species are exceptional, and which researchers and practitioners are currently working with threatened exceptional species. These are currently the most significant information barriers to effective conservation of threatened exceptional plant species, and therefore a priority for action.

As a first step, BGCI and CZBG will work with all 28 EPSAG members to create a first draft global list of threatened exceptional plant species and the individuals that are working with them. This will:

- Allow research and *ex situ* collection efforts to be prioritized
- Provide opportunities to better define and understand the biological and environmental features of exceptional species
- Provide examples for use in decision-making and advocacy efforts
- Identify experts already working with exceptional species
- Support coordination and collaboration

There are many logistical obstacles to compiling this list, but many resources were identified to manage them. These include:
OBSTACLE: Unresolved taxonomic issues. RESOURCE: BGCI's PlantSearch database and access to The Plant List via Kew's web services.
OBSTACLE: Lack of comprehensive global threatened species list. RESOURCE: The Red List as well as many other regional or national lists that the EPSAG is familiar with.
OBSTACLE: Limited access to information on seed production, storage, and germination behavior. RESOURCE: Kew's Seed Information Database, and input from the EPSAG working with individual species.

NEED 2: Identify research priorities. The biology of most threatened exceptional plant species is generally poorly understood and often species-specific. *In vitro* propagation and cryopreservation are currently the primary techniques to conserve threatened exceptional species *ex situ* and to produce propagules for reintroduction efforts, but specialized facilities and expertise is often required to develop protocols for these techniques, and they are often species-specific. Even under the best of circumstances, protocol development is often expensive, time-consuming, and unpredictable.

Research priorities identified include:

- Develop more formal and standardized protocols for identifying threatened exceptional plant species.
- Understand the basic biologies of threatened exceptional plant species, in relation to *ex situ* conservation needs and restoration potential.

- Understand the biology and improve the technology of cryopreservation and *in vitro* methods, in order to identify optimal and tolerance ranges of the protocols for species or groups of species, thereby improving efficiency and predictability of the methods.
- Facilitate more research coordination among cryopreservation, *in vitro* propagation, and seed banking efforts.
- Provide and promote research opportunities to university researchers and graduate students.
- Develop mechanisms for disseminating both successful and unsuccessful research on protocol development.
- Overcome barriers to technology transfer to exceptional species-rich developing countries.

There are many logistical obstacles to addressing these priorities, but many resources were identified to manage them. These include:
OBSTACLE: Technical challenges in approaching the research of improving *in vitro* and cryopreservation methods, due largely to the multiple factors affecting these systems. RESOURCE: The application of new research tools, such as statistical approaches (Design of Experiments), time-lapse photography, and others, that can facilitate the testing of multiple factors and significantly increase the quality and the quantity of scientifically sound information that can be gathered by small, resource-limited laboratories.
OBSTACLE: Limited research on the biology of wild, threatened plant species. RESOURCE: Engage more university researchers and graduate students to expand knowledge in this area.
OBSTACLE: Limited access to information on research that has already been done on threatened exceptional plant species, as it is often unpublished or in grey literature. RESOURCE: Listserves on plant tissue culture and plant propagation, in-country and international networks.

NEED 3: Address funding, communication and coordination challenges.
Conserving threatened exceptional plant species *ex situ* is more costly than traditional seed banking. In general, cryopreservation and *in vitro* propagation costs are difficult to quantify or standardize and species-specific, and results are unpredictable. Additional funding for research, outreach, and more effective communication and coordination among the global community working with these species, is needed. Potential avenues to secure funding to support research, outreach, and coordination include targeting major foundations, the corporate sector, and industry leaders.

Next steps: This workshop is only a first step in addressing threatened exceptional plant species conservation. BGCI and CZBG have funding to continue to coordinate this work through February 2014, and until then they will work with workshop participants to carry out the following next steps:

BGCI and CZBG will:

1. Synthesize and share priorities agreed on by workshop participants as a Statement of Need, incorporating input from workshop participants by **December 31, 2013**.
2. Work with EPSAG members to compile a draft global list of threatened exceptional plants species by **January 31, 2014**.
3. Compile list of useful resources on threatened exceptional plant species, with input from EPSAG members by **February 15, 2014**.
4. Update BGCI's Exceptional Species webpage (www.bgci.org/usa/exceptionalspecies) and post all relevant information (draft species list, statement of need, resources, & contacts) by **February 28, 2014**.
5. Consider funding approach(es) and options, and work independently and collaboratively to pursue funding that can support research, outreach, communication and coordination of exceptional plant species conservation efforts.

EPSAG members will:

1. Review and provide feedback on a draft Statement of Need by **December 31, 2013**.
2. Contribute to a draft global threatened exceptional plant species list being assembled by BGCI and CZBG by **January 31, 2014**.
3. Contribute to list of useful resources on threatened exceptional plant species by **February 15, 2014**.
4. Consider funding approach(es) and options, and work independently and collaboratively to pursue funding that can support research, outreach, communication and coordination of exceptional plant species conservation efforts.

Appendix C

SURVEY: CHARACTERIZATION OF EXCEPTIONAL PLANT SPECIES

You have received this survey because of your work with conservation of plants, including species that cannot be seed banked. Your feedback is essential in helping to create a list of threatened plant species that are native to Canada and the United States and are unable to be seed banked (referred to in this study as "threatened, Exceptional Plant Species").

This survey is being sent to members of: The Botanical Society of America (BSA) Botanic Gardens Conservation International (BGCI) NAS (National Academy of Sciences) USDA (United States Department of Agriculture) The Center for Plant Conservation (CPC) The American Public Gardens Association (APGA) Plant Conservation section If you are a member of several of these organizations, you may receive this survey more than once. Please fill out the survey only once.

The goals of this survey are:
1.) to refine the definition of "Exceptional Plant Species"
2.) to expand upon a core group who can contribute to a list of threatened Canadian and United States native plant species that fit these Exceptional characteristics.

Outcomes of this study will inform the creation of a global list of threatened, Exceptional Plant Species. For more information, and to learn how "Exceptional Plant Species" is currently defined, please see Pence, VC. 2011. Evaluating Costs for the in vitro propagation and preservation of endangered plants. In Vitro Cell. Dev. Biol. -- Plant 47: 176-187.

Here is the most pertinent section of the article:
"Both ex situ propagation and preservation are most efficiently accomplished using seed-based methods. However, a small percentage of species produce few or no seeds, or they may have seeds that are recalcitrant (desiccation sensitive). These "exceptional species" cannot be propagated by seed or stored using traditional seed banking technologies, and for many of these, in vitro, or tissue culture, methods can play a role in both propagation and preservation. Such methods are more expensive than using seeds, but may become acceptable as the threat to a species rises. Since resources 'for conservation are finite, allocation of funds needs to be guided by information both on the endangerment of the species and on an understanding of the costs involved in ex situ conservation."

Also feel free to contact me with any questions: Sara Helm Wallace, sara.helm.wallace@gmail.com, 717-203-8133

1. What is the name and address (country and postal code) of your institution?
   Name of institution
   Country
   Postal Code

2. Does the mission of your institution include conservation?
- ❍ Yes
- ❍ No

3. Which of the following describe the institution that you represent? Please select all that apply.
- ❑ Government Funded
- ❑ Nonprofit Conservation Organization
- ❑ Public/ Private Partnership
- ❑ Public or Private Garden
- ❑ University or College
- ❑ Other

3a. Please indicate whether your Government Funded institution is funded by federal, state/province, or municipality.
- ❍ 1- Federal
- ❍ 2- State/ Provincial
- ❍ 3- Municipality

3b. If you chose "Other" please explain what type of institution you represent.

4. What is your role in the institution?
- ❍ 1- Executive Director/ CEO/ President
- ❍ 2- Administrator/ COO/ Department Head
- ❍ 9- Curator/ Collections Manager
- ❍ 3- Conservation Scientist
- ❍ 6- Research Scientist
- ❍ 5- Other

4a. If you chose "Other" please explain your role in the institution.

5. Exceptional plant species cannot be conserved ex situ via conventional seed banking methods: they require more time- and resource-intensive approaches, including cryopreservation and in vitro propagation. To further refine this definition, please select one or more of the characteristics below that in your professional opinion accurately describe Exceptional Plant Species:

	Yes	No
Produces recalcitrant seeds (seeds that do not survive drying and freezing in ex situ conservation)..	❍	❍
Produces few or no seeds..	❍	❍
Seeds are not easily accessible for collection when mature (or at all).......	❍	❍
Produces poor-quality and non-viable seeds..	❍	❍
Produces seeds infrequently...	❍	❍
Produces seeds with deep dormancy..	❍	❍
Produces seeds that can survive short-term banking (10 years of conventional storage or less with approximately 20% or greater viability loss) but not long-term banking (greater than 10 years of conventional storage with less than 20% viability loss)..	❍	❍
Cannot be easily propagated by seed (with current knowledge/protocols)	❍	❍

5a. What characteristics not listed above identify a species as an "Exceptional Plant Species"? Do you have any further comments about Exceptional Plant Species?

6. The goal of this study is to generate a list and public database of threatened, Exceptional Plant Species native to Canada and the United States. A preliminary list of approximately 200 of these species has been compiled. Would you be willing to review the list and provide feedback in a future correspondence? Your participation will result in formal acknowledgement when this research is published.

- ❍ Yes
- ❍ No
- ❍ Maybe

6a. Would you like the compiled (anonymous) results of this survey?

- ❍ Yes
- ❍ No

6b. If you are willing to be contacted, please enter your name, institution name, phone number, and email address below.

First and Last Name

Institution

Phone Number

Email Address

Appendix D

IDENTIFYING EXCEPTIONAL SPECIES

A previously unpublished paper by Ben Morgan, Valerie Pence and Andrea Kramer

Ex situ conservation has become a critical component of plant conservation activities (Havens et al. 2006). Target 8 of the Global Strategy for Plant Conservation (GSPC), with a goal of 75% of threatened plant species in *ex situ* collections by 2020, highlights the importance of backing up vulnerable wild populations (CBD 2010). Seed banking is generally the most efficient and effective way to accomplish this (Godefroid et al. 2011, Li and Pritchard 2009, Maunder et al. 2004). It is likely that more than 90% of all threatened species have orthodox seeds (ask Valerie where she got this; Li and Pritchard 2009 say as many as 25%), which are adaptable to the protocols necessary for traditional seed banking. However, there is a smaller, but significant, number of threatened species for which seed banking is not an option, including recalcitrant (desiccation sensitive) seeds and those species producing few or no seeds.

It is estimated that there may be 5,000 – 10,000 threatened exceptional species worldwide (Pence 2011), and other methods such as embryo or tissue cryopreservation will be required for their long-term germplasm storage. Several labs have pioneered work with these species, but the resources of any one lab or even a combination of existing programs are not sufficient to meet the challenge of the number of species predicted to be in the exceptional category. Additionally, no definitive accounting of exceptional species, even at a region- or country- level, has been performed (although RBG Kew's SID database identifies more than a thousand recalcitrant species - CITE). Without a clear understanding of which species fall into the exceptional category, it is not possible to identify the extent of the conservation challenge they pose, nor is it possible to strategically allocate resources to tackle this challenge.

Methods for cryopreservation of non-seed tissues are more labor intensive and more costly than traditional seed banking. Some estimates suggest that banking all threatened exceptional species with adequate genetic representation would require more than $30 million USD (Pence 2011). In a world where economic pressures require the most efficient use of resources, the GSPC Target 8 of 75% of species maintained in *ex situ* collections could be accomplished entirely by directing available funds to orthodox species and bypassing the more difficult exceptional species. However, this would mean threatened species like oaks and magnolias would not be provided an *ex situ* safety net against extinction. This is an unacceptable situation, as the threats to even currently common species in these genera grows (for example, through the spread of invasive pathogens such as Sudden Oak Death; Kramer and Pence 2012).

To begin to address the challenge of conserving threatened exceptional species, we have we have examined the types of ex situ accessions maintained and reports of seed storage behavior for North American threatened taxa in order to generate the first comprehensive regional exceptional species list. This process serves as a model for developing exceptional species lists for other regions and for the global flora, and will help to prioritize future threatened plant conservation efforts.

Materials and Methods

Based on our definition of exceptional species as those that are both threatened and difficult to conserve *ex situ* by conventional methods (following Pence 2011), we first compiled a list of 8431 critically imperiled, imperiled, and vulnerable North American taxa from NatureServe databases, as defined by NatureServe's Global Conservation Status ranks of G1, G2, and G3 (or T1-T3 for infraspecific taxa). Our initial database contained 14,579 accessions of these taxa at 471 institutions affiliated with Botanic Gardens Conservation International's PlantSearch database (BGCI 2012).

In order to determine the exceptional status of North American threatened taxa, we began by classifying the type of accession maintained by each institution in our database as one of: living collections, banked seed, tissue cultures, or cryopreserved tissue. Two institutions that maintain many types of accessions (Center for Plant Conservation and Wakehurst Place) were coded as "uncertain" to highlight taxa in only those collections for clarification if necessary. We coded the presence or absence of each accession type for all threatened taxa based on where they are being maintained, and used this data to make an initial assessment of exceptional status. Table 5 shows the exceptional status code used in our database, its meaning, and the accession-type criteria used to assign each taxon an exceptional status.

Next, we looked for records of the seed storage behavior of North American threatened taxa in Royal Botanic Gardens Kew's Seed Information Database (SID). Complete lists of taxa with known storage behaviors were downloaded from SID, and all threatened taxa with a species level match to a SID record were coded with the SID seed storage behavior (explained in table 6). We did not require infraspecific matching with SID records because NatureServe and Kew use different taxonomic systems and subspecific epithets were unlikely to be used consistently, however we have yet to account for the use of different synonyms at the species or genus level. There are conflicting reports as to the phylogenetic conservation of seed storage behavior (cf. Jayasuriya etal 2009, Berjak and Pammenter 2008). To explore the conservation of seed storage behavior at the genus level in our data set, we coded whether taxa were congeneric with recalcitrant, intermediate, or orthodox taxa recorded in the SID.

Table 5. Exceptional status codes and the criteria used to assign taxa to a status.	
Exceptional status	Criteria for assignment
Y - yes	Taxon is conserved in tissue/cryo culture and no seed bank accessions are known. Taxon is recorded as recalcitrant in SID.
N - no	Taxon is conserved in a seed bank. Taxon is recorded as orthodox in SID.
S - suspect	Taxon is not conserved as either tissue/cryo culture or in a seed bank, but is congeneric with taxa recorded as recalcitrant in SID.
Q - questionable	Taxon is conserved in tissue/cryo culture and seed bank. Taxon is conserved in tissue/cryo culture and is recorded as orthodox in SID. Other anomalous observations recorded in "notes" column.

Key preliminary findings
117 taxa have been identified as exceptional. Of these, 15 are considered by the SID to be recalcitrant or are congeneric with a recalcitrant species. 112 exceptional assignments have been determined ultimately by the institutions at which accessions are maintained.

66 taxa are suspected candidates for exceptional status on the basis of absence from current seed bank collections and being congeneric with recalcitrant taxa. Seven additional taxa meet these conditions, but are also reported in SID as orthodox, so they have been coded non-exceptional.

1567 taxa have been identified as non-exceptional, of which 1537 taxa are reported in seedbanks. The remaining 30 are conspecific with taxa considered to be orthodox by the SID.
Only one species indicated as seed banked in BGCI's PlantSearch database (*Aesculus parviflora*) is regarded as recalcitrant by SID. This anomalous hit is an inactive accession in the USDA ARS-GRIN germplasm collection of which materials are no longer available. Most of these taxa are probably of lower priority for this project, and can be considered in greater detail later on.

106 taxa are identified as questionable. These taxa warrant further investigation to determine why extraordinary conservation practices are being employed where evidence suggests that conventional seed banking is adequate to conserve these taxa.

6575 threatened taxa have not had an exceptional status assigned to them yet

There are 5219 G/T1-3 taxa for which there are no known accessions. Five of these taxa are referenced in the RBG Kew Seed Information Database (SID) as "recalcitrant" or "recalcitrant?" Regardless of exceptional status, these taxa should be of high priority for future collection and conservation efforts because of their threatened status and the absence of known collections.

No species in our database recognized as recalcitrant by the SID is congeneric with one recognized as orthodox. This holds across some genera, such as *Quercus*.

Without having made a direct comparison between the SID orthodox and recalcitrant species lists, our data reveals considerable overlap within genera of these behaviors. Thirteen North American threatened genera (predominantly *Coprosoma*, *Pittosporum*, *Salix*, and *Sideroxylon*) are reported to have both orthodox and recalcitrant species.

Table 6. Kew's Seed Information Database seed storage behavior coding. The left columns explain the codes for behavior, while the right columns explain the modifiers used to indicate the certainty of the assignment. It is possible in our database for a species to have multiple storage behavior assignments. If two sub-specific variants in the SID database have 'o' and 'op' respectively, that species will be labeled as 'oop' because infraspecific naming has been ignored in assigning storage behaviors.

Seed storage behavior		Certainty of assignment modifier	
r	Recalcitrant	None	Certain
i	Intermediate	p	Probable, but not absolutely certain
o	Orthodox	?	Likely, based on evidence

Next steps

Accounting for synonymy in comparing species information from different sources.
Share current lists of exceptional and questionable species with plant conservation community and solicit feedback to continue to refine list.

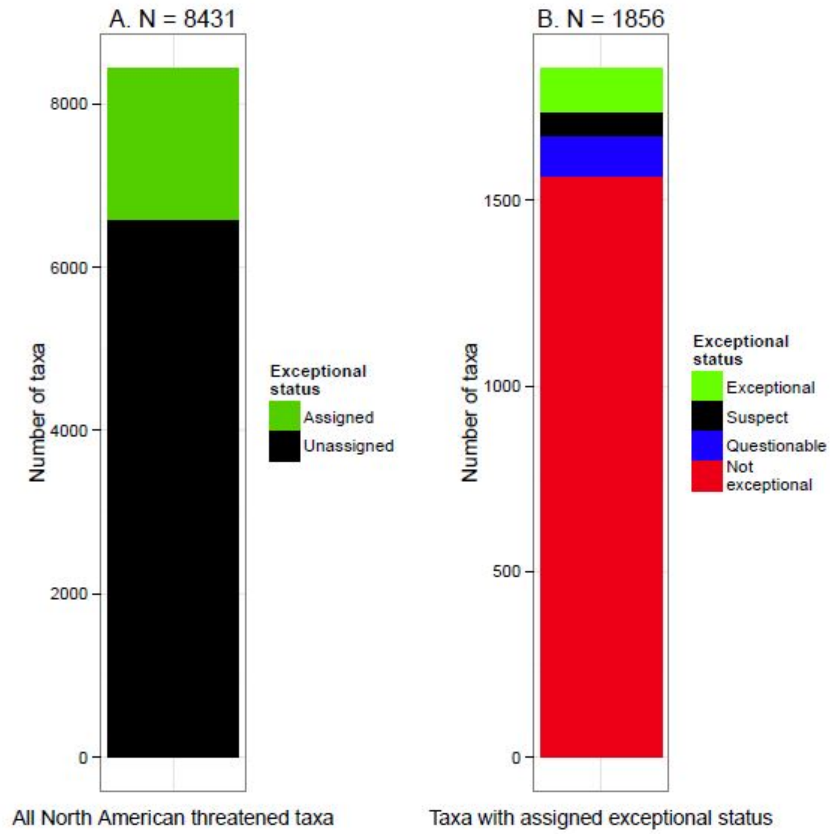

Figure 5: **Exceptional status assignments. A.** The number of taxa that have and have not been designated an exceptional status. Exceptional status designations are not possible based on the evidence used here for 78% (6675 taxa) of North American threatened plant taxa. **B.** The number of taxa assigned to each of four exceptional designations explained in table 1. 84% of taxa receiving a designation are considered to be "not exceptional."

Resources and references

Berjak, P and NW Pammenter. 2008. From *Avicennia* to *Zizania*: seed recalcitrance in perspective. Annals of Botany 101:213-228.

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Li, D.-Z., and H. W. Pritchard. 2009. The science and economics of *ex situ* plant conservation. *Trends in Plant Science* 14: 614-621.

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Pence, VC. 2011. Evaluating costs for the in vitro propagation and preservation of endangered plants. In Vitro Cell. Dev. Biol. – Plant 47: 176-187.
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Appendix E

TEXT IN "READ ME" SPREADSHEET

Community Input for Threatened, Exceptional Plant Taxa in the U.S. and Canada

About the Researcher and Research

My name is Sara Helm Wallace, and the aim of my Master's degree in the Longwood Graduate Program at the University of Delaware is to create a list of U.S. and Canadian threatened exceptional plant taxa. This will be a resource for the community to use in prioritization of conservation of these non-seed bankable species.

How you have contributed so far
In the fall of 2014, you were one of 178 conservation and botany professionals who took part in a voluntary survey, which helped generate a definition of exceptional plant taxa. Thank you.
As an outcome, the generally agreed-upon definition is as follows:

Definition:
An exceptional plant taxon is a plant species, variety, or subspecies whose seeds cannot be seed-banked for one or more of the following reasons:
-produces recalcitrant seeds
-produces few or no seeds
-cannot be easily propagated by seed
-produces poor-quality and non-viable seeds
-produces seeds infrequently
-produces seeds that are not easily accessible by humans when mature

Next steps
Now that we have a universally accepted definition, we can generate the list. Your input is requested to provide data supporting the exceptional status of threatened taxa native to the United States and Canada. The taxa in the following spreadsheets include known exceptional status, and unknown exceptional status. A wide range of plants are represented on these lists, and any information you can provide about seed behavior and/or ongoing conservation research is valued, whether it is anecdotal or has been referenced.

Instructions
The main idea is to fill in blue columns as much as possible in the "Known Status" and "Unknown Status" tabs below. There are five tabs in total. The first tab, "Read Me" is the one you are reading now. The second tab, "Key to Columns" gives you source information and explains any codes used in the columns. The third tab, "Examples" gives real examples of proposed exceptional statuses and their supporting documentation. The fourth tab, "Known Status" is a list of 289 threatened plant taxa native to the U.S. and Canada, which are likely exceptional, sorted alphabetically by Family. The fifth tab, "Unknown Status" is a list of 5855 threatened plant taxa native to the U.S. and Canada whose exceptional statuses are unconfirmed based on data available. This spreadsheet is also sorted alphabetically by Family. Any information you provide for a family, a genus, or lesser taxa on the list of "Unknowns" is very valuable.

Please Note
Even the smallest amount of information will be of tremendous importance to the research and conservation of exceptional taxa.

QUESTIONS? Please email shelmwal@udel.edu, sara.helm.wallace@gmail.com, or call: 717-203-8133

Appendix F

TEXT IN "KEY TO COLUMNS" SPREADSHEET

Family	Name	Habit	Native Country	Native State/ Province	Global Threat Status	Exceptional Status	Known Ex Situ Germplasm
Source: Taxonomic Name Resolution Service (TNRS) 2014 http://tnrs.iplantcollaborative.org/TNRSapp.html	Source: Natureserve 2014	Source: USDA Plants 2015	Source: Natureserve 2014	Source: Natureserve 2014	**G** = Global species status **T** = Infraspecific global status **GH or TH** = Possibly Extinct **GX or TX** = Presumed Extinct **G1 or T1** = Critically Imperiled **G2 or T2** = Imperiled **G3 or T3** = Vulnerable **G4 or T4** = Apparently Secure **G5 or T5** = Secure **G#G# or G#T# or T#T#** = Range Rank indicating some uncertainty of rank **GU** = Currently unrankable **GNR** = Rank not yet assessed **Q** = Questionable taxonomy that may reduce conservation priority **?** = Inexact numeric rank **C** = Captive or cultivated only Source: Natureserve 2015 http://explorer.natureserve.org/granks.htm	**E (Exceptional)** = Taxon is conserved in tissue/cryo culture and no seed bank accessions are known or taxon is recorded as recalcitrant in Kew's Seed Information Database. **S (Suspect)** = Taxon is not conserved as either tissue/cryo culture or in a seed bank, but is congeneric with taxa recorded as recalcitrant in Kew's Seed Information Database. **Q (Questionable)** = Taxon is conserved in tissue/cryo culture and is recorded as orthodox in Kew's Seed Information Database. **U (Unknown)** = Unknown exceptional status Source: BGCI Plant Search 2013 and Kew Seed Information Database, 2013	**L** = living plant collection **S** = seed bank **C** = cryopreservation **T** = tissue culture Source: BGCI Plant Search 2013 and Kew Seed Information Database, 2013

Appendix G

"KNOWN STATUS" SPREADSHEET

Please see supplemental electronic material submitted with this publication.

Appendix H

"UNKNOWN STATUS" SPREADSHEET

Please see supplemental electronic material submitted with this publication.

Appendix I

INSTITUTIONS REPRESENTED BY SURVEY RESPONDENTS

Alaska Botanical Garden
Albany Medical College
Alta Vista Botanical Gardens
Appalachian Mountain Club, Research Dept.
Auburn University Museum of Natural History
Auburn University/Davis Arboretum
Augustana College (IL)
Bok Tower Gardens
Botanic Garden Meise
Brooklyn Botanic Garden
California Academy of Sciences
California State Polytechnic University, Pomona
California State University Fullerton
Chicago Botanic Garden
Christopher Newport University
Cincinnati Zoo and Botanical Garden
Colorado Mesa University
Conservation Biology Research
Cornell University
Delaware Technical Community College
Denison University
Denver Botanic Gardens
Desert Botanical Garden
Desert Legume Program
Division of Forestry and Wildlife
Don Harrington Discovery Center
Donald Danforth Plant Science Center
Duke University
Eastern Kentucky University
Fellows Riverside Gardens
FIU
Garfield Park Conservatory

Ghent University
Haleakala National Park
Hawaii Department of Natural Resources, Division of Forestry and Wildlife
Hawaiian Ecosystems at Risk project (HEAR)
Holden Arboretum
Hoyt Arboretum
Huntington Botanical Gardens
Indiana University
Indiana University Southeast
Institute of Botany
IUCN
Longwood
Lyon Arboretum
Malama O Puna
Meadowbrook Farm
Mecklenburg County Park and Recreation
Memorial University of Newfoundland Botanical Garden
Miami University
Michigan State University
Michigan Technological University
Minnesota Landscape Arboretum
Missouri Botanical Garden
Montana State University-Northern
Montgomery Botanical Center
Mt. Cuba Center
National Park Service
National Tropical Botanical Garden
Natural Resources Canada
New England Wild Flower Society
New Mexico State University
North Carolina State University
Northeastern University
Northwest Trek Wildlife Park
Oahu Army Natural Resources Program
Ohio State University
Ohio University
Old Dominion University
Oregon State University
Ornamental Plant Germplasm Center

Plant and Food Research
Polly Hill Arboretum
Quarryhill Botanical Garden
Rancho Santa Ana Botanic Garden
Rio Grande Botanic Garden
Royal Botanical Gardens
Rutgers University
Saint Louis University
San Antonio Botanical Garden
San Antonio College
San Diego Botanic Garden
Scott Arboretum
SDSU
Sister Mary Grace Burns Arboretum of Georgian Court University
Smithsonian Gardens
Smithsonian National Museum of Natural History
Southeastern Oklahoma State University
Springfield Central High School
Sunshine Farm & Gardens
SUNY-Fredonia
Syracuse University
Taltree Arboretum & Gardens
Texas Discovery Gardens
The Arboretum at Flagstaff
The Arnold Arboretum
The Australian Botanic Garden
The Botanic Garden of Smith College
The Botanic Gardens at Kona Kai Resort
The Gardens of Fanshawe College and the A. M. Cuddy Gardens
The Holden Arboretum
The Living Desert
The Morton Arboretum
The University of Texas
U.S. Fish and Wildlife Service
U.S. National Arboretum
Univ. of Victoria
Universidad de Chile
Universidad Nacional Autonoma de Mexico, Instituto de Biologia
Universidad Rey Juan Carlos
Universidade Estadual de Maringá

Universidade Estadual do Norte Fluminense Darcy Ribeiro
Université Paris Sud
University of Alaska Fairbanks
University of Alberta Devonian Botanic Garden
University of California
University of California Botanical Garden
University of Canterbury
University of Cincinnati
University of Debrecen
University of Florida
University of Hawai`i
University of Illinois
University of La Verne
University of Minnesota
University of Minnesota Duluth
University of Nebraska
University of Nebraska at Lincoln
University of Nebraska at Omaha
University of Oklahoma
University of Ottawa
University of South Florida
University of Tennessee
University of Texas at El Paso
University of Washington
University of Washington Botanic Gardens
University of Washington Herbarium, Burke Museum
University of Wisconsin Madison
University of Wyoming
U.S. Forest Service Research, Rocky Mountain Research Station
USDA Forest Service
USDA National Center for Genetic Resources Preservation
USDA-ARS
Washington State University
Western Illinois University
Wichita State University
Woodland Park Zoo

Appendix J

SUGGESTED ADDITIONS

Please see supplemental electronic material submitted with this publication.

Appendix K

PTERIDOPHYTES

Please see supplemental electronic material submitted with this publication.

Appendix L

ADDITIONAL PARTICIPANT COMMENTS

Comment	Date
One thought I did have...I can think of several species where we utilize tissue culture for species that we do not consider to be exceptional. We do it for reasons such as mass propagation for outplanting for species that are easier to maintain and clone in tissue culture than living collection in the nursery. Or species where we collected immature fruit (because of timing at a difficult to access area- not because they do not produce mature fruits) and had to send to tissue culture rather than germinate in our seed bank. Prior to 2000, and for several years after for some people, we did not think seeds from native plants could store, so everything went to tissue culture. Over the years we have definitely re-prioritized...but it's a slow process. But I will make these indications in the notes if that is ok.	3/30/15
We made a list of taxa in 2012 that we identified as 'species of conservation importance', ie in need to ex situ storage. But we only have around 800 taxa identified at the time and not all of them were considered rare. Would you be able to tell me how you came up with your list? I think often we underestimate rarity because it is so relative...with so many species with so few plants, we often think species are secure if there are hundreds of plants when in other states they would be considered very rare!	3/30/15
I looked over the checklist of exceptional plant species. I would like to recommend a species that is not on your list, either of known or unknown status. The species is Alnus maritima, the seaside alder, which consists of Delmarva, Oklahoma, and Georgia subspecies. It consists only of these subspecies, each of which consists of only a few small populations. If you wish to know more, please contact me. My understanding is that FWS is now considering it for listing as an endangered species, although the had a big backlog and had not yet, when I last contacted them, begun work upon it.	4/17/15
All ferns lack seeds, and thus the strict definition of "exceptional" will be met by all spore-producing plants (true ferns, lycophytes etc). In the case of Schizaea pusilla, my previous advisor has been propagating an old spore collection for many years now. I think you can get around it by changing "seed" to "propagule"? But this won't fully get around the Kew-based seed criterion.	4/21/15

I've filled in the unknown taxa that I have personally studied. However, I should note that, in general, it is pretty safe to assume that any annual (Forb/herb) species in California has orthodox seeds. Rainfall in California is "predictably unpredictable," and annual species have evolved various seed dormancy/germination cue mechanisms to survive drought periods. Many chaparral shrubs (Arctostaphylos, Ceanothus) produce seeds that require fire as a germination cue, so they can also be presumed to have orthodox seeds.	4/23/15
I don't know how extensive the response to your survey has been, but all the of the major botanical gardens in California have an active research program on propagating and/or preserving seeds of plants of conservation concern. There is a lot of data available, and I hope that they have responded to your survey.	4/23/15
Do you have guidance regarding the ferns? Do you want us to indicate the fern species? Should replace the word 'seed' in the exceptional criteria with 'spore'?	4/29/15
I don't have specific information on these [California] oaks and whether they are recalcitrant, but generally they frequently produce many seeds that are viable and easily propagated. None are inaccessible, although the island species are a little more difficult to get to.	5/4/15
Rorippa subumbellata appears to produce orthodox seeds. See: Ingolia, M., T. P. Young, and E. G. Sutter. 2008. Germination ecology of Rorippa subumbellata (Tahoe yellow cress), an endangered, endemic species of Lake Tahoe. Seed Science and Technology 36(3): 621-632.	5/4/15
We found it really difficult and the longer we looked at it, the more we felt that the rarity of these species would tend to suggest classification as Exceptional rather than Not Exceptional, even though the species had seeds that were orthodox. But it is all relative and subjective, and with so many rare species, I think we initially leaned towards being less conservative and classifying species as N, when maybe if we would have thought more in a global context we would have listed many more species as E! You will see a lot of caveats and notes and '?' and we feel that if we revisit the list in the future that we would make changes.	5/8/15
Please note that we did make notes in the comments regarding taxonomy - there were many name changes that have not made it yet to the national list (maybe you pulled from NatureServe?). There are also notes regarding additional taxa and I added a few lines on the Unknown Status worksheet that are highlighted in a peachy color. We did not spend a lot of time on this and there are likely many more taxa to be added. Those were just a few I caught. I also put in the notes for species I have living collections or seed collections of that were not listed in your "Known Ex Situ Germplasm" column but I did not edit that column. Lyon staff included a spreadsheet of their seed bank and tissue culture collection as a reference for you to update this information if you wish (also attached).	5/8/15
In the long list of 'unknown' threatened species, I would have liked to clarify that Quercus, Pouteria, and Aesculus are not capable of standard seed bank storage and require other conservation options.	5/11/15

I'll provide a couple of suggestions from my experience, but first hope that you will forgive a little criticism of the approach. In working through your key and rationale I was stuck by the use of combined criteria used to assess 'exceptional' status and I became a little concerned that the conservation options resulting from the individual evidence streams routinely become obscured with a single overall category being assigned. If we are to help conservation managers to make decisions about the value of collecting seed or meristem samples from an endangered plant at any one time, I would have preferred to have compiled and evaluated evidence against the seven criteria separately. Maybe I have mis-understood the application of the study in helping north American partners to deliver GSPC target 8, but for example, from assessment of other members of the Genus, Asclepias meadii on the 'known' list would be 100% predicted to have storable (orthodox) seeds, and so land managers would be advised to optimise seed set by investigating breeding system, pollination and predation in order to secure the most valuable ex situ germplasm sample for this species.	5/11/15
Below is our information from GRIN on the species you asked about. The database describes the propagule that was collected, but does not specify form that it is maintained. You can make inferences about form maintained based on the primary site. If it is an SOS sample, it is most likely at Pullman and may/may not be grown for evaluation and regeneration based on curator interest or BLM funding. Anything from the Pullman, Ames or Forest Service will be maintained as seeds and samples at Corvallis or National Arboretum will most likely be planted in orchards.	5/13/15
For years Waimea has always focused on vegetative propagation to perpetuate our wild collections – mainly of native Malvaceae. Only recently have we started (first with sedges and grasses) seed collections from our cult. plants. We hope to work more with Seed Lab at Lyon and are grateful that she can share plants from her germination trials.	5/15/15
Platanthera leucophaea – can't propagate and seed believed to be short lived in storage (probably the same could be said for many terrestrial orchids!)	5/15/15
Many cacti are very slow to propagate	5/15/15
You might talk with our grad student, [name removed], who is looking at G3 taxa that are uncommon in the nursery trade…there may be overlap between your lists! She is cc'd. You also might ask [name removed] to forward to the Botanical Soc. of America members if you need more input.	5/15/15
I have looked at your spreadsheet, primarily focusing on the unknown status tab. I referenced the Flora Novae-Angliae, published in 2011 by Arthur Haines, as well as data from gobotany.newenglandwild.org, our online interactive flora for the region. I note some taxonomic disparities (especially in Rubus taxa), and also looked at Baskin and Baskin (Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination, 2001) for information on these and congeneric taxa.	4/2/15
I couldn't address the vast majority of your list, since most of your species hail from well outside New England. Hope the limited information I offered is helpful to you. Good luck with your project.	4/2/15

Appendix M

SEED STORAGE BEHAVIOR LIST

Please see supplemental electronic material submitted with this publication.

Appendix N

THREATENED LIST

Please see supplemental electronic material submitted with this publication.

Appendix O

FINAL EXCEPTIONAL STATUS BY FAMILY

Family	Total taxa from Threatened List	Number of taxa given final seed storage behaviors	Final Exceptional Status									
			E	CE	N	CN	U	XE	XCE	XN	XCN	XU
Acanthaceae	16	4	1	0	0	0	3	0	0	0	0	0
Adoxaceae	1	0	0	0	0	0	0	0	0	0	0	0
Aizoaceae	1	0	0	0	0	0	0	0	0	0	0	0
Alismataceae	5	0	0	0	0	0	0	0	0	0	0	0
Amaranthaceae	59	41	4	3	9	22	1	0	0	0	0	2
Amaryllidaceae	49	8	1	6	0	0	1	0	0	0	0	0
Anacardiaceae	1	1	1	0	0	0	0	0	0	0	0	0
Annonaceae	3	3	3	0	0	0	0	0	0	0	0	0
Apiaceae	116	11	0	0	2	6	3	0	0	0	0	0
Apocynaceae	42	22	9	0	1	11	1	0	0	0	0	0
Aquifoliaceae	1	0	0	0	0	0	0	0	0	0	0	0
Araceae	1	0	0	0	0	0	0	0	0	0	0	0
Araliaceae	16	16	4	10	0	0	2	0	0	0	0	0
Arecaceae	21	21	1	0	1	1	18	0	0	0	0	0
Aristolochiaceae	6	0	0	0	0	0	0	0	0	0	0	0
Asparagaceae	51	16	2	4	9	0	1	0	0	0	0	0
Asteliaceae	2	2	1	1	0	0	0	0	0	0	0	0
Asteraceae	892	206	9	40	18	59	77	0	0	0	0	3
Berberidaceae	3	1	0	0	0	0	1	0	0	0	0	0
Betulaceae	1	0	0	0	0	0	0	0	0	0	0	0
Bixaceae	1	0	0	0	0	0	0	0	0	0	0	0
Boraginaceae	228	35	0	4	8	21	2	0	0	0	0	0

Family	Total taxa from Threatened List	Number of taxa given final seed storage behaviors	Final Exceptional Status									
			E	CE	N	CN	U	XE	XCE	XN	XCN	XU
Brassicaceae	376	139	0	0	30	107	2	0	0	0	0	0
Burmanniaceae	1	0	0	0	0	0	0	0	0	0	0	0
Cactaceae	131	4	0	0	0	0	4	0	0	0	0	0
Calycanthaceae	1	0	0	0	0	0	0	0	0	0	0	0
Campanulaceae	172	140	33	98	2	0	5	0	2	0	0	0
Cannabaceae	1	0	0	0	0	0	0	0	0	0	0	0
Caprifoliaceae	10	0	0	0	0	0	0	0	0	0	0	0
Caryophyllaceae	116	73	0	0	12	57	2	0	0	0	2	0
Celastraceae	2	0	0	0	0	0	0	0	0	0	0	0
Cistaceae	9	0	0	0	0	0	0	0	0	0	0	0
Cleomaceae	7	0	0	0	0	0	0	0	0	0	0	0
Colchicaceae	1	0	0	0	0	0	0	0	0	0	0	0
Commelinaceae	6	0	0	0	0	0	0	0	0	0	0	0
Convolvulaceae	51	2	0	0	0	0	2	0	0	0	0	0
Cornaceae	1	1	0	0	0	0	1	0	0	0	0	0
Crassulaceae	41	23	0	0	0	23	0	0	0	0	0	0
Crossosomataceae	7	0	0	0	0	0	0	0	0	0	0	0
Cucurbitaceae	16	13	0	0	2	11	0	0	0	0	0	0
Cupressaceae	2	0	0	0	0	0	0	0	0	0	0	0
Cyperaceae	128	84	0	0	2	81	1	0	0	0	0	0
Diapensiaceae	4	0	0	0	0	0	0	0	0	0	0	0
Dioscoreaceae	1	0	0	0	0	0	0	0	0	0	0	0
Droseraceae	1	0	0	0	0	0	0	0	0	0	0	0
Ebenaceae	1	1	1	0	0	0	0	0	0	0	0	0
Elatinaceae	2	0	0	0	0	0	0	0	0	0	0	0
Ephedraceae	2	0	0	0	0	0	0	0	0	0	0	0
Ericaceae	80	1	0	0	0	0	1	0	0	0	0	0
Eriocaulaceae	4	0	0	0	0	0	0	0	0	0	0	0
Euphorbiaceae	91	70	0	0	4	59	7	0	0	0	0	0
Fabaceae	493	232	4	215	3	3	6	1	0	0	0	0
Fagaceae	28	27	0	24	0	0	3	0	0	0	0	0

Family	Total taxa from Threatened List	Number of taxa given final seed storage behaviors	Final Exceptional Status									
			E	CE	N	CN	U	XE	XCE	XN	XCN	XU
Frankeniaceae	2	0	0	0	0	0	0	0	0	0	0	0
Garryaceae	1	0	0	0	0	0	0	0	0	0	0	0
Gentianaceae	31	0	0	0	0	0	0	0	0	0	0	0
Geraniaceae	15	4	0	0	1	0	3	0	0	0	0	0
Gesneriaceae	56	56	3	0	2	0	51	0	0	0	0	0
Goodeniaceae	5	0	0	0	0	0	0	0	0	0	0	0
Grossulariaceae	15	0	0	0	0	0	0	0	0	0	0	0
Gunneraceae	2	1	1	0	0	0	0	0	0	0	0	0
Haloragaceae	2	0	0	0	0	0	0	0	0	0	0	0
Hamamelidaceae	1	0	0	0	0	0	0	0	0	0	0	0
Hydrangeaceae	13	1	0	0	0	0	1	0	0	0	0	0
Hydrocharitaceae	5	0	0	0	0	0	0	0	0	0	0	0
Hypericaceae	4	0	0	0	0	0	0	0	0	0	0	0
Iridaceae	20	0	0	0	0	0	0	0	0	0	0	0
Joinvilleaceae	1	1	1	0	0	0	0	0	0	0	0	0
Juncaceae	18	5	0	0	1	0	4	0	0	0	0	0
Juncaginaceae	1	1	0	0	0	0	1	0	0	0	0	0
Lamiaceae	169	80	4	10	4	54	7	0	0	0	1	0
Lauraceae	5	1	1	0	0	0	0	0	0	0	0	0
Lentibulariaceae	3	0	0	0	0	0	0	0	0	0	0	0
Liliaceae	51	13	1	6	1	5	0	0	0	0	0	0
Limnanthaceae	1	0	0	0	0	0	0	0	0	0	0	0
Linaceae	19	0	0	0	0	0	0	0	0	0	0	0
Loasaceae	31	30	0	0	1	29	0	0	0	0	0	0
Loganiaceae	18	16	3	11	0	0	2	0	0	0	0	0
Lythraceae	3	0	0	0	0	0	0	0	0	0	0	0
Malvaceae	72	29	3	0	4	15	1	1	5	0	0	0
Martyniaceae	1	0	0	0	0	0	0	0	0	0	0	0
Melanthiaceae	21	5	0	0	0	0	5	0	0	0	0	0
Melastomataceae	3	3	0	0	1	2	0	0	0	0	0	0
Montiaceae	39	1	0	0	0	0	1	0	0	0	0	0

Family	Total taxa from Threatened List	Number of taxa given final seed storage behaviors	Final Exceptional Status									
			E	CE	N	CN	U	XE	XCE	XN	XCN	XU
Myricaceae	1	0	0	0	0	0	0	0	0	0	0	0
Myrtaceae	5	2	2	0	0	0	0	0	0	0	0	0
Nartheciaceae	2	1	0	0	0	0	1	0	0	0	0	0
Nyctaginaceae	35	2	0	0	0	0	2	0	0	0	0	0
Nymphaeaceae	3	0	0	0	0	0	0	0	0	0	0	0
Oleaceae	7	2	1	0	0	0	1	0	0	0	0	0
Onagraceae	87	0	0	0	0	0	0	0	0	0	0	0
Orchidaceae	60	8	1	1	0	0	6	0	0	0	0	0
Orobanchaceae	112	1	0	0	0	0	1	0	0	0	0	0
Oxalidaceae	3	0	0	0	0	0	0	0	0	0	0	0
Papaveraceae	30	9	0	2	1	6	0	0	0	0	0	0
Parnassiaceae	5	0	0	0	0	0	0	0	0	0	0	0
Passifloraceae	1	0	0	0	0	0	0	0	0	0	0	0
Pentaphylacaceae	1	1	0	0	0	0	1	0	0	0	0	0
Phrymaceae	59	0	0	0	0	0	0	0	0	0	0	0
Phyllanthaceae	6	2	0	1	0	0	1	0	0	0	0	0
Picrodendraceae	1	0	0	0	0	0	0	0	0	0	0	0
Pinaceae	4	0	0	0	0	0	0	0	0	0	0	0
Piperaceae	20	20	0	0	0	20	0	0	0	0	0	0
Pittosporaceae	10	10	2	7	0	0	1	0	0	0	0	0
Plantaginaceae	150	10	0	0	3	7	0	0	0	0	0	0
Poaceae	189	21	1	7	2	4	7	0	0	0	0	0
Polemoniaceae	136	31	3	25	0	0	3	0	0	0	0	0
Polygalaceae	15	0	0	0	0	0	0	0	0	0	0	0
Polygonaceae	243	178	0	0	1	177	0	0	0	0	0	0
Pontederiaceae	1	0	0	0	0	0	0	0	0	0	0	0
Portulacaceae	6	7	1	0	0	1	5	0	0	0	0	0
Potamogetonaceae	8	0	0	0	0	0	0	0	0	0	0	0
Primulaceae	65	41	4	17	1	19	0	0	0	0	0	0
Ranunculaceae	89	24	1	0	2	16	5	0	0	0	0	0
Rhamnaceae	40	4	0	0	0	0	4	0	0	0	0	0

Family	Total taxa from Threatened List	Number of taxa given final seed storage behaviors	Final Exceptional Status									
			E	CE	N	CN	U	XE	XCE	XN	XCN	XU
Rosaceae	214	56	0	0	2	28	25	0	0	0	0	1
Rubiaceae	101	64	7	23	4	14	16	0	0	0	0	0
Rutaceae	61	60	22	37	0	0	1	0	0	0	0	0
Salicaceae	11	10	1	8	0	0	1	0	0	0	0	0
Santalaceae	24	17	4	7	0	0	6	0	0	0	0	0
Sapindaceae	6	5	3	2	0	0	0	0	0	0	0	0
Sapotaceae	8	2	1	1	0	0	0	0	0	0	0	0
Sarraceniaceae	8	0	0	0	0	0	0	0	0	0	0	0
Saxifragaceae	47	1	0	0	0	0	1	0	0	0	0	0
Schisandraceae	1	0	0	0	0	0	0	0	0	0	0	0
Scrophulariaceae	2	0	0	0	0	0	0	0	0	0	0	0
Smilacaceae	3	0	0	0	0	0	0	0	0	0	0	0
Solanaceae	29	20	3	1	4	7	5	0	0	0	0	0
Stemonaceae	1	0	0	0	0	0	0	0	0	0	0	0
Styracaceae	5	0	0	0	0	0	0	0	0	0	0	0
Taxaceae	1	0	0	0	0	0	0	0	0	0	0	0
Theaceae	1	0	0	0	0	0	0	0	0	0	0	0
Thymelaeaceae	12	0	0	0	0	0	0	0	0	0	0	0
Tofieldiaceae	1	0	0	0	0	0	0	0	0	0	0	0
Urticaceae	14	8	5	3	0	0	0	0	0	0	0	0
Verbenaceae	9	0	0	0	0	0	0	0	0	0	0	0
Violaceae	30	29	1	0	3	22	3	0	0	0	0	0
Xyridaceae	8	0	0	0	0	0	0	0	0	0	0	0
Zygophyllaceae	2	0	0	0	0	0	0	0	0	0	0	0

Appendix P

SEED STORAGE BEHAVIOR BY STATE/PROVINCE NATIVITY

State or Province	Total Taxa from Threatened List	Number of taxa with input from survey respondents	Final E Status	Final CE Status	Final N Status	Final CN Status	Final U Status	Percentages of Taxa on the Threatened List that were commented on by survey respondents
Canada								
Alberta	28	4	0	0	0	0	0	14%
British Columbia	93	15	0	0	1	0	1	16%
Manitoba	14	4	1	0	0	0	0	29%
New Brunswick	19	7	0	0	0	0	6	37%
Newfoundland and Labrador	26	4	1	0	0	0	3	15%
Nova Scotia	24	11	1	0	0	0	9	46%
Northwest Territories	50	9	0	0	0	0	0	18%
Nunavut	21	4	0	0	0	0	0	19%
Ontario	43	17	2	0	1	1	7	40%
Prince Edward Island	7	4	0	0	0	0	3	57%
Quebec	51	20	1	0	0	0	11	39%
Saskatchewan	19	4	1	0	0	0	0	21%
Yukon Territory	73	10	0	0	0	1	0	14%
TOTAL	**468**	**113**	**7**	**0**	**2**	**2**	**40**	
United States								
Alabama	248	52	1	2	5	2	12	21%
Alaska	137	19	0	0	0	1	0	14%
Arizona	645	137	2	2	0	3	3	21%
Arkansas	76	24	2	1	1	4	4	32%
California	1900	457	0	18	63	50	8	24%
Colorado	282	90	0	2	0	1	3	32%
Connecticut	37	25	1	0	0	0	24	68%
Delaware	33	12	0	0	1	0	7	36%
District of Columbia	16	7	0	1	1	0	3	44%

United States (continued)								
Florida	431	96	9	0	3	1	33	22%
Georgia	286	67	1	2	4	2	13	23%
Hawaii	946	420	132	48	81	62	97	44%
Idaho	201	58	0	0	1	0	2	29%
Illinois	38	15	3	0	2	1	3	39%
Indiana	43	13	4	0	4	1	4	30%
Iowa	18	6	1	0	1	0	3	33%
Kansas	31	10	0	0	2	0	3	32%
Kentucky	68	24	3	0	5	2	5	35%
Louisiana	87	16	0	1	1	1	4	18%
Maine	32	24	1	0	0	0	23	75%
Maryland	48	13	0	0	1	0	7	27%
Massachusetts	38	26	1	0	3	0	22	68%
Michigan	41	13	2	0	1	0	6	32%
Minnesota	16	6	3	0	0	0	2	38%
Mississippi	105	20	0	1	1	1	5	19%
Missouri	59	16	2	0	2	1	4	27%
Montana	138	31	0	0	0	0	1	22%
Navajo Nation	83	1	0	0	0	0	1	1%
Nebraska	18	5	0	0	0	0	2	28%
Nevada	556	184	0	1	4	5	3	33%
New Hampshire	21	15	1	0	0	0	14	71%
New Jersey	48	24	0	1	2	0	17	50%
New Mexico	402	80	2	0	0	3	2	20%
New York	62	29	1	0	1	0	24	47%
North Carolina	198	20	0	0	3	1	16	10%
North Dakota	10	2	0	0	0	0	0	20%
Ohio	36	14	1	0	3	1	4	39%
Oklahoma	71	18	0	0	1	3	3	25%
Oregon	335	85	0	1	10	4	3	25%
Pennsylvania	47	17	0	1	2	0	14	36%
Rhode Island	13	9	0	0	0	0	9	69%
South Carolina	173	46	0	2	2	1	13	27%
South Dakota	11	2	0	0	0	0	0	18%
Tennessee	124	42	3	0	5	1	7	34%
Texas	484	90	3	7	0	7	8	19%
Utah	603	198	1	3	1	5	3	33%
Vermont	28	19	1	0	0	0	17	68%
Virginia	113	37	1	0	2	1	15	33%
Washington	163	27	0	0	1	0	1	17%
West Virginia	60	18	0	0	2	2	7	30%
Wisconsin	29	12	2	0	2	0	6	41%
Wyoming	187	53	0	0	0	1	2	28%
TOTAL	**9875**	**2744**	**184**	**94**	**224**	**168**	**492**	