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A set of simple decision matrices for prioritizing collection of rare plant species for ex situ conservation

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ABSTRACT

Because it is virtually impossible to collect seed or tissue for ex situ conservation banks from every known population of rare plant species, it is important to rank populations systematically in terms of their priority for collection. The New England Wild Flower Society, which maintains a regional seed bank, developed a set of three complementary decision matrices in spreadsheet form by which to prioritize all occurrences of all state-listed rare plant species in New England in terms of their urgency and feasibility for collection. Data on 4333 occurrences, spanning 456 taxa, were collated from six state Natural Heritage Programs. The first decision matrix ranked taxa in terms of their amenability to storage or propagation at ex situ institutions, and determined whether any known New England occurrences were reproductive. The second matrix further ranked taxa in terms of their global and regional rarity and the viability and genetic and geographic representation of collections already present in the bank. The third matrix scored individual occurrences within each taxon in terms of the presence of imminent threat, reproductive status, vigor, protection status, potential genetic distance from other occurrences, availability of landowner permission, and their current status in the bank. Occurrences were then sorted in ascending order by total matrix score; those with low scores were at the top of the list for collection priority. 3743 occurrences were deemed eligible for collection. Scores ranged from 14.5 to 182, and were influenced most strongly by the number of occurrences per taxon. Clear breakpoints were apparent in the distribution of scores, with clusters of uncommon taxa at the low end of the scale and a long tail created by taxa with more numerous occurrences in New England. These breakpoints could potentially be used to prioritize groups of occurrences that should receive the first attention for collection, while postponing collection of higher-scoring groups. Fewer than 1% of occurrences were misclassified, according to post hoc inspection. This simple set of decision matrices can be adapted by a wide range of institutions involved in ex situ conservation.

1. Introduction

The continual loss of wild plant populations demands a range of conservation solutions, including both in situ protection and restoration and ex situ banking of seeds, spores, and tissue. These efforts must go hand in hand to assure success (Hamilton, 1994; Guerrant et al., 2004). Organizations charged with collecting plant material for ex situ storage and

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propagation face challenges in optimizing their collections given limitations in funding and the size and technological sophistication of their facilities (Maunder et al., 2001, 2004). Thus, it is increasingly important to develop coherent, systematic strategies for targeting plant populations to maximize capture of genetic diversity and potentially adaptive alleles. Population genetic theory and data on in situ genetic diversity in natural populations inform these efforts (Hamrick and Godt, 1989; Falk and Holsinger, 1991; Brown and Marshall, 1995; Neel and Cummings, 2003; Schaal and Leverich, 2004; Goodall-Copestake et al., 2005), and several useful rules of thumb have been developed for estimating the numbers of populations, individual plants, and seeds that should be sampled (Brown and Briggs, 1991; Hawkes et al., 2000; Lawrence, 2002; Guerrant et al., 2004). Several large-scale collection programs such as the national Center for Plant Conservation now focus on meeting at least the minimum criteria for sample size needed to represent the genetic diversity of a species and to offset loss of alleles through attrition or artificial selection (Dixon, 1994; Smith et al., 2003; Cochrane, 2004).

Less attention has been paid, however, to prioritizing which populations should be sampled. When rare plant species are represented by five or fewer extant populations, collection is recommended for all populations that would not be harmed by such activity (Guerrant and Pavlik, 1998; Havens et al., 2004). Other taxa, particularly those that are regionally, rather than globally, rare may have more numerous populations. In building an ex situ bank for these taxa, given a limited capacity for storage, it is necessary to select a subset of populations that will be genetically representative and amenable to propagation for potential reintroduction or augmentation efforts. Such a challenge also presents itself in designing reserves and prioritizing populations to be protected in order to maximize allelic diversity (Neel and Cummings, 2003; Groves, 2003).

Such prioritization schemes should make use of all available data on the genotypic variability within and among populations, but this information is frequently lacking. In practice, phenotypic variance is sometimes used as a proxy for genetic differentiation. Draper et al. (2003), for example, recently developed a GIS-based method for identifying populations that span a broad range of habitats, surmising that genetic diversity will be maximized when collections take place from distinct "ecogeographical units" within a taxon's distributional range. This spatially-explicit approach can be applied readily in making collection decisions, but it does not take into account elements of a taxon's life history that may influence whether geographically separate populations are likely to be genetically isolated and thus divergent. Spatial data are one component of an integrated expert system that brings together information on geographic distribution, phenotypic variance, breeding systems, and relative rarity to rank taxa and populations in terms of their significance for ex situ conservation. In the analogous case of reserve design, expert opinion regarding these variables is frequently used; however, concordance between experts selecting populations has been shown to vary depending on the emphasis different experts place on conservation criteria (Neel and Cummings, 2003). Thus, it is important to develop a set of criteria that can be consistently applied among populations and taxa, and that can be used by a range of conservation professionals. Here, we describe a simple but comprehensive set of decision methods designed to enable conservation banks to prioritize rare taxa and their constituent populations for collection.

The New England Wild Flower Society maintains the largest bank of seeds of rare plant species in the northeastern United States for its conservation collaborative, the New England Plant Conservation Program (NEPCoP). Its purpose is to preserve the genetic diversity and reintroduction potential of the 450+ species of state-listed and/or globally-listed plant species of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut (New England Wild Flower Society, 1992; Brumback et al., 1996). Ex situ activities involving seedbanking, propagation, and maintenance of living collections for public education in our botanic garden (Garden-in-the-Woods, Framingham, Massachusetts) complement in situ efforts in habitat protection, volunteer monitoring of rare plant populations, research, and outreach to the general public (New England Wild Flower Society, 1992). To date, the NEPCoP seed bank encompasses 391 occurrences of 205 regionally rare taxa of the New England flora. In creating the following decision models, we have sought to fill the gaps in the range of taxa maintained in the bank and to develop a practical protocol by which to identify and prioritize wild populations for future collection. The methods we have developed have enabled us to select and rank 456 taxa for collection. Within these taxa, we have ranked occurrences to target those are most in need of collection, most suitable for collection, and maximally representative of the phenotypic diversity present in the region (in the absence of direct information on genotypic variance). We posit that these decision methods can serve as models for other seed or germ plasm banks that are devising their own optimal strategies for collection.

2. Methods

We obtained detailed information from all six New England Natural Heritage Programs (scientific bodies charged with monitoring of state-listed organisms) on the status of all extant element occurrences of 456 plant taxa that are state-listed (as S1, S2, S3 and/or Endangered, Threatened, or Special Concern) and tracked in one or more New England states. The term "Element Occurrence" *sensu* NatureServe (2002) is used preferentially to "population" by the Natural Heritage Programs (and throughout this paper), to mean the "full, occupied habitat that contributes... to the persistence of a species at [a given] location." In practice, "Element Occurrences" (EOs) may encompass populations or metapopulations that are "typically separated from each other by barriers to movement or dispersal, or by specific distances for each element defined by unsuitable habitat or suitable but apparently unoccupied habitat" (NatureServe, 2002). The total data set encompassed 4333 separate extant EOs with sufficient information to permit coding within the decision matrices. These data were analyzed according to a set of three decision matrices that enabled us to rank taxa for collection and, within taxa, to prioritize occurrences for sampling. The types of data recorded by North American

Natural Heritage Programs are analogous to those maintained in biodiversity atlases by the UNEP World Conservation Monitoring Centre, the Australian Department of the Environment and Heritage, and other conservation agencies throughout the world.

We used Microsoft Excel 2000 to construct a set of three worksheets, each corresponding to a separate decision matrix. Excel was selected because it is a widely distributed and user-friendly software package that can be employed by a wide range of organizations without additional purchases of proprietary software (and its spreadsheets are usable in OpenOffice and other open source applications); in principle, any spreadsheet may be used. Decision matrices were conceptualized as a series of questions regarding each taxon and each occurrence. The "answers" to each question were entered as quantitative values in the Excel spreadsheet, with columns corresponding to each variable ("question") and rows corresponding to a taxon (in decision matrices 1 and 2) or a separate occurrence (decision matrix 3). The types of questions asked in the decision matrices corresponded to many of the issues surrounding ex situ collections considered by the Center for Plant Conservation (Brown and Briggs, 1991), including: degrees of endangerment of the taxon and each occurrence; capacity of our seedbank facility to store propagules and to propagate plants successfully; putative genetic isolation among EOs; size of occurrences; and temporal frequency and reliability of reproduction.

3. Overall logic of the decision matrices

Fig. 1 diagrammatically summarizes the overall structure of the three decision matrices. The first and second decision matrices allowed us to evaluate and rank taxa according to three basic considerations: (1) the feasibility of collection and storage based on NEWFS capacity, current in situ reproduction, and availability of collectable material; (2) the global and regional rarity of the taxon; and (3) the status of existing collections. After passing through these decision matrices, taxa were ranked in ascending order, with those receiving lower overall scores accorded a higher priority for collection consideration. Certain taxa were also eliminated from further consideration if they could not be stored or propagated successfully or if in situ reproduction or vigor was insufficient to permit collection. Generally, questions in these matrices could be answered with a "yes" (assigned a score of "1") or a "no" (assigned a score of "2"). For certain questions that addressed levels of global or regional rarity, numbers of existing EOs, and the numbers of existing collections in the NEPCoP seedbank, a range of scores from 0 to X were used (where X corresponds to the absolute value of each variable). These scores exerted a larger numerical influence on overall ranking of taxa than the binary scores above, reflecting the relative importance we placed on these factors.

We then carried over the taxonomic ranking to the third decision matrix, in which we ranked each known extant EO

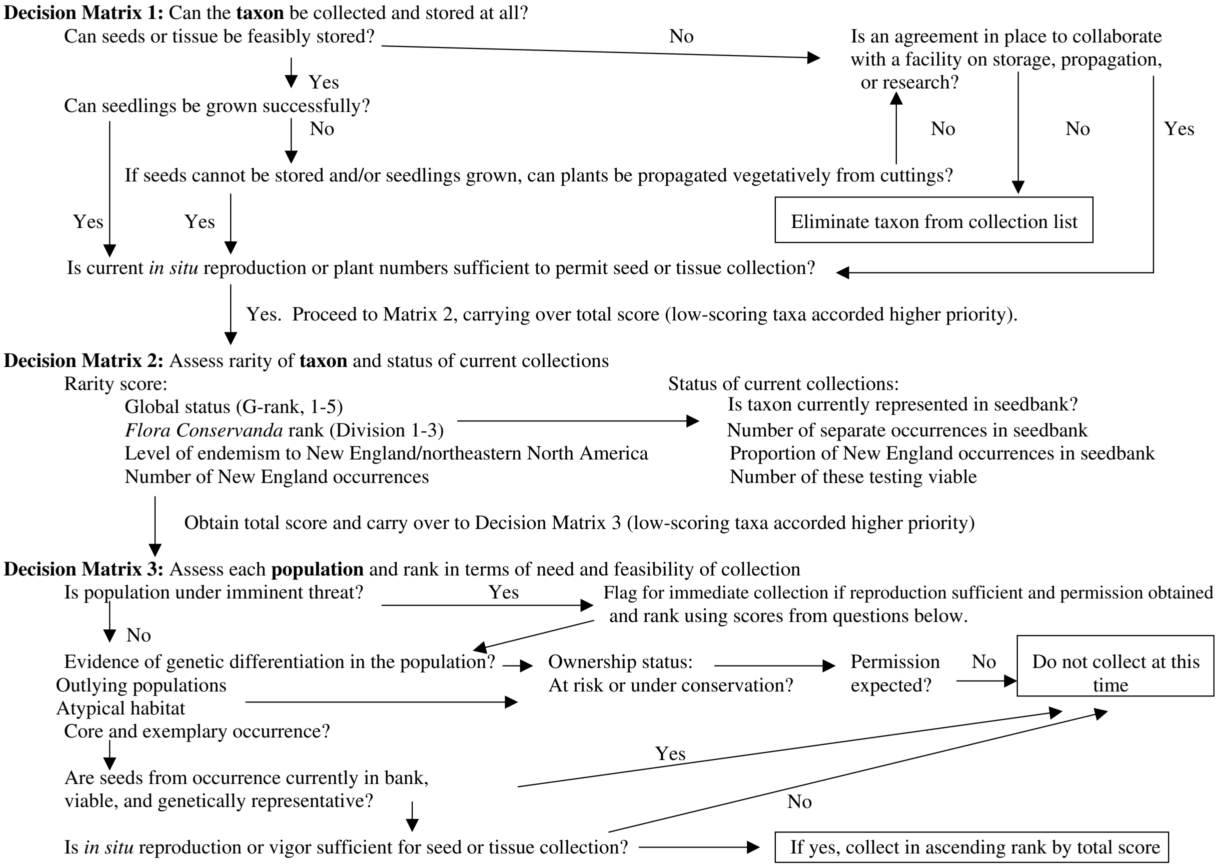

Fig. 1 – General topology and logic of decision matrices.

within each taxon in terms of its need and feasibility of collection. By transferring the taxon-level rank, we could ensure that EOs could be ranked within the context of the general status of the taxa; thus, the most precarious EOs of the rarest taxa would be ranked more highly for collection than similarly tenuous EOs of more secure taxa. As in the two matrices above, many questions were answered with a "yes" (assigned a score of "1") or a "no" (assigned a score of "2"). Questions regarding regularity of reproduction and land ownership status were answered with scores ranging from "0" to "1"; we intended these scores to have a lower influence on the ranking overall because there was more uncertainty on how to code the answers precisely (due to lack of data on specific occurrences). Certain EOs were eliminated from further consideration if their current status precluded collection, landowner permission was not possible to obtain, or a viable collection was already in place at NEWFS. The specific structure of each decision matrix is described in detail below.

4. Decision matrix 1

The first decision matrix (Table 1) enabled us to determine whether the constraints of life history and the capacity of our storage facility would permit collection of a target taxon. Affirmative answers to each question yielded a score of "1" while negative answers yielded a score of "2". We first asked whether the taxon produced desiccation-tolerant seeds or spores that can be stored in the NEWFS bank. Generally, taxa with desiccation-intolerant ("recalcitrant") seeds were regarded as problematic for collection due to limitations in the NEWFS storage infrastructure.

We then asked whether seeds could be germinated and seedlings successfully propagated at our facility. We answered this question based on prior experience (if available), the findings of other facilities, or data on related taxa that had similar life history and propagation requirements (Baskin and Baskin, 1998; USDA NRCS, 2004).

For the species with recalcitrant seeds and/or seeds that could not be germinated and propagated at NEWFS, we asked whether vegetative cuttings could be propagated at NEWFS. If seed storage and seedling establishment could be accomplished, the taxon received a score of "0" indicating that the category is not applicable. While vegetative propagation of cuttings is a less desirable preservation method than storage of seeds due to the risks of inadvertent artificial selection (Guerrant and Fiedler, 2004), we retained this option in the decision matrix to allow for collection of tissue from species (such as *Salix* spp. or orchid seeds with challenging mycorrhizal requirements) for which seed storage was impractical or seedling establishment was unsuccessful. If the answer was "no" to the first three questions, we relegated the taxon to a group that would be evaluated further only if a collaboration on storage, propagation, or research could be developed with an alternate institution (for example, the orchid species, *Isotria medeoloides*, was retained for collection consideration because NEWFS collects seeds for research and storage at the Smithsonian Institution). Taxa with no such agreements in place were dropped from further consideration. For the subset of taxa that we could successfully handle, we obtained a total propagation feasibility score summed from the scores of the first three questions above.

We then asked whether one or more EOs of the taxon were documented as producing seed in situ in New England, with a "yes" answer scored as "1" and a "no" answer scored as "2". In the absence of explicit information on seed production, we used recent observations of flowering in situ as a proxy. If no EOs of a given taxon were reproductive, collection was not possible, so taxa scoring "2" in this category were also excluded from further consideration.

Finally, we asked whether the taxa were represented by five or fewer EOs in the region ("yes" = 1, "no" = 2), in order to give priority to extremely rare taxa in New England.

The subset of taxa exhibiting positive storage or propagation capacity and evidence of in situ reproduction were ranked in ascending order according to the sum of the feasibility score and the rarity score (with a minimum total score of 3). Taxa with lower scores received a higher priority for collection than taxa with higher scores. We carried over the total score from the first decision matrix to the second matrix. Taxa passing positively out of the first decision matrix were then subjected to a series of questions in the second decision matrix, by which they could be ranked in terms of the urgency for collection.

5. Decision matrix 2

The second decision matrix (Table 2) first assessed the relative rarity of taxa according to NatureServe's global ranking system (NatureServe Explorer, 2005). By this system, all taxa in North America receive a rank based on the numbers of EOs known to exist worldwide. This conservation rank is indicated by a number from 1 to 5, preceded by a G (Global) prefix, where 1 = critically imperiled; 2 = imperiled; 3 = vulnerable to extirpation or extinction; 4 = apparently secure; and 5 = demonstrably widespread, abundant, and secure. Taxa falling intermediate in rarity between two G-ranks are designated G1G2, G2G3, or G4G5 by NatureServe. Our scoring for global rarity ranged from 1 to 5 based on G-rank, with a "1.5" score corresponding to a rank of G1G2, "2.5" to a rank of G2G3, and so on. The majority of listed plants in New England are regionally rather than globally rare (e.g. with ranks between 3 and 5); New England EOs typically constitute the northern, eastern, or southern edge of many species' ranges and many of these species are more secure in the heart of their ranges.

Because NEWFS' mission is to protect a regional (New England) flora, we also asked whether each taxon was considered regionally rare in New England. The data used to answer this question included the taxon's *Flora Conservanda* rank (Brumback et al., 1996), in which the taxa considered rare and tracked by Natural Heritage Programs in one or more New England state are categorized into five divisions (as with global ranks, state ranks of S1–S3 indicate rarity at the state level). Division 1 taxa (receiving a score of 1) are globally rare (with a G1–G3 NatureServe rank). Division 2 taxa (receiving a score of 2) are regionally rare, with fewer than 20 extant occurrences within New England. Division 3 taxa (receiving a score of 3) may be secure in a portion of New England,

Table 1 – Decision matrix 1 in Excel spreadsheet format, illustrating ranking of 11 sample taxa

A	B	C	D	E	F	G	H	I
Species	Are seeds or spores desiccation-tolerant? (1 = yes, 2 = no) Data from literature and previous experience	Propagation of cuttings possible? (1 = yes, 2 = no, 0 = N/A) Data from previous experience	Seedling growth possible after storage (seedbanking)? (1 = yes, 2 = no) Data from previous experience	Seed storage, research, or propagation scheduled with another facility? (1 = yes, 2 = no, 0 = N/A)	Initial storage feasibility total (= sum columns B–E)	Five or fewer populations in New England? (1 = yes, 2 = no) Data from EO records	Current reproduction sufficient? (1 = yes, 2 = no) Data from EO records	Total score (formula: if *H* = 2, score as 0, else score as sum of F and G)
Taxa moving to decision matrix 2								
Agastache nepetoides	1	0	1	0	2	1	1	3
Arctostaphylos alpina	1	0	1	0	2	1	1	3
Taenidia integerrima	1	0	1	0	2	2	1	4
Tanacetum bipinnatum	1	0	1	0	2	2	1	4
Tipularia discolor	1	0	1	0	2	2	1	4
Carex polymorpha	1	0	2	0	3	2	1	5
Betula minor	2	1	2	0	5	2	1	7
Taxa not moving to decision matrix 2								
Barbarea orthoceras	1	0	1	0	2	1	2	0
Hydrastis canadensis	2	2	1	2	7	2	1	9
Juglans cinerea	2	2	2	2	8	2	1	10
Sagittaria rigida	2	2	2	2	8	2	1	10

Taxa not moving to matrix 2 either cannot be stored or propagated or have insufficient in situ reproduction to permit collection.

Table 2 – Decision matrix 2 in Excel spreadsheet format, illustrating further ranking of taxa according to rarity and current representation in the NEPCoP seedbank

A	B	C	D	E	F	G	H	I	J	K	L
Species	Score from decision matrix 1	Grank	Flora conservanda rank	Range outside of NE? (yes = 1, endemic = 0)	Total # of EOs in New England	In NEPCoP seedbank? (1 = yes, 0 = no)	Number of separate EOs in seedbank	Proportion of NE EOs already in bank	Proportion of NE states represented	Proportion of accessions confirmed viable	Total score (= sum of columns B–K)
Agastache nepetoides	3	5	2	1	2	0	0	0.00	0.00	0.00	13.00
Arctostaphylos alpina	3	5	2	0.5	6	0	0	0.00	0.00	0.00	16.50
Betula minor	7	3.5	1	0.5	12	0	0	0.00	0	0	24.00
Carex polymorpha	5	3	1	1	17	1	3	0.18	0.8	0	31.98
Taenidia integerrima	4	5	2	1	12	1	1	0.08	0.50	1.00	27.58
Tanacetum bipinnatum	4	5	2	1	19	0	0	0.00	0.00	0.00	31.00
Tipularia discolor	4	4.5	2	1	7	0	0	0.00	0.00	0.00	18.50

but have one or more outlying or unusual occurrences that may be genetically isolated from other EOs or may represent ecological anomalies (e.g. an EO occupying a habitat that is atypical for the taxon as a whole). Division 3 also includes taxa for which a significant number of occurrences have demonstrably declined in one or more states. Division 4 ("historical" or "extirpated") taxa were not included in this analysis. Taxa whose *Flora Conservanda* rank is indeterminate due to paucity of information were given a score of "5" in this category. At this point, two groups of taxa were created, those in *Flora Conservanda* Divisions 1 and 2 and those in Division 3–5. The taxa in these two groups were scored based on the same questions described below. This grouping scheme also carried over to the EO level in decision matrix 3. It is important to note that the Division 3–5 taxa were not discounted or given a lower priority in the overall scheme (which would be erroneous, especially for Division 5 taxa for which little information exists); both sets of taxa were carried through the analysis.

We then scored the level of regional endemism exhibited by the taxon (taxa with all known occurrences restricted to New England received a score of "0"; those ranging only to adjacent states or Canadian provinces received a score of "0.5", and those with larger ranges were scored "1").

We also tallied the overall number of extant occurrences in New England. Note that some Division 3 taxa (those with declining populations in one or more New England state) would have a greatly inflated score if all New England occurrences were counted; thus, for these taxa, we counted only the number of outlying or anomalous occurrences or occurrences in states with declining EOs. Because Divisions 3 and 5 taxa were considered separately from Divisions 1 and 2 taxa, this scoring method did not bias the overall ranking toward more common taxa. Overall in this sector of the matrix, a low score (low G-rank, low *Flora Conservanda* rank, restricted geographic distribution, or small number of occurrences in New England) signified a high degree of rarity. Low-scoring taxa would therefore receive first attention for collection.

A further set of questions in decision matrix 2 evaluated the status of the existing collections in the NEPCoP bank. Data on accessions, stored since 1986 in a BG-BASE Collection Management Software (BG-Base, Inc., Edinburgh, Scotland) database, were queried to determine the number of current, viable seed accessions. We first asked whether the taxon was represented by any collections in the NEPCoP bank. For each taxon, we then assembled data on the total number of separate element occurrences in the NEPCoP bank, and the proportion of total known New England element occurrences included in the bank. We also tabulated the number of New England states represented in the bank relative to the number of New England states from which the taxon is recorded (yielding a proportion from 0 to 1.0).

Finally, decision matrix 2 asked whether the available accessions had been tested for viability and/or germinability within the past 10 years, and the score reflected the proportion of accessions that were confirmed viable. Accessions for which this testing had not taken place or without viable seeds received a score of zero, contributing to a lowered overall score for the taxon (and hence increased priority for collection). A total score for decision matrix 2 was obtained from the sum of the scores for the above nine questions added to the starting score from decision matrix 1, and taxa were sorted according to score. A low total score indicated a high priority for collection. Taxon-level scores were carried over to decision matrix 3, retaining the overall ranking across species.

6. Decision matrix 3

Decision matrix 3 then assessed each EO within each taxon for its relative priority for collection (Table 3). We first asked whether the EO faced imminent threat of extirpation. We inferred the presence of imminent threat from the element occurrence records, ownership information, and management notes fields available from the Natural Heritage data. "Imminently threatened" EOs showed evidence of decline to 10 or fewer ramets or genets. This low numerical threshold was checked independently against the distribution of element occurrence ranks assigned to EOs by Natural Heritage Programs as an index of their size, condition, and quality of the landscape context (ranging from "A" meaning "excellent" to "D" meaning "poor"). EOs with fewer than 10 plants differed significantly from larger EOs in the frequency distribution of element occurrence ranks, with a median rank of "C"; by contrast, larger EOs had a median rank of "B" (G-statistic on frequencies of EO ranks = 451.9, $P < 0.0001$). Larger EOs that were noted as facing direct endangerment due to changing land use, or were noted as in poor condition, were also identified as "imminently threatened." Altogether, this designation encompassed 554 EOs (approximately 13% of the total EO count). The subset of EOs identified as imminently threatened were flagged to be considered for immediate collection pending acquisition of landowner permission to access the site and an in situ assessment of reproductive output. Because not all imminently threatened EOs could be collected immediately, this subset of EOs was also further ranked according to the answers to questions described below.

As with the previous two matrices, a low total score resulting from the set of questions in decision matrix 3 indicated a high priority for collection. We first asked whether the occurrence was disjunct from other EOs ("yes" = 1, "no" = 2). The outlying EOs were accorded priority because it was assumed they would be genetically isolated from other EOs and, in the absence of explicit genetic data, geographic isolation became a proxy for genetic distance. Only single EOs occurring at least 100 km (an arbitrary distance exceeding maximum pollinator flight distances) from clusters of other EOs in the core of the New England range were scored as outliers. Fig. 2 illustrates the method for identifying outlying EOs.

Second, we asked if the EO occurred in a typical or atypical habitat relative to the other occurrences in New England ("yes" = 1, "no" = 2). Occupation of atypical habitat was taken as an indication of potential genetic differentiation from other EOs.

Third, we asked if the EO appeared to reproduce regularly or whether it exhibited patterns of sporadic reproduction, indicating a need for opportunistic collection when seed was available ("reproduced regularly" = 1, "irregular reproduction" = 0). To determine this, we inspected the element occurrence data for information on frequency of flowering, fruiting, and/or seed production. We also used information on the basic biology of reproduction for certain species known to undergo periods of dormancy (e.g. orchids) or to be dependent on specific environmental conditions to induce reproduction (e.g. coastal plain pond species affected by temporal fluctuations in water levels).

Fourth, we asked whether the EO was situated within the core or stronghold of the taxon's range and was exemplary in terms of number of plants and their vigor ("yes" = 1, "no" = 2). We reasoned that collection from the largest and healthiest occurrences in New England would complement collections from severely imperiled EOs and enhance the overall vigor of the genetic stock across EOs. This was a relative score, developed by inspection and comparison of all EOs within a taxon. Generally, the largest EO of all occurrences was flagged, particularly if it had received an element occurrence rank of "A"; however, no EO with fewer than 50 plants or with fewer than 1% of individuals reproducing received this designation.

Fifth, the decision matrix asked if a EO occurred on a privately-owned site and thus was not assured of conservation protection. Occurrences on private land were assigned higher priority (a score of "0") because they were assumed to be at higher risk of extirpation than protected EOs. Occurrences on land owned by private, municipal, federal, or state conservation organizations were given a score of "1". If an EO occurred on property owned or managed by a private or public entity that was more likely to leave land undeveloped (e.g. power or water utility, Department of Transportation, United States military), an intermediate protection score of 0.5 was assigned. If ownership was uncertain, we assumed it was private and scored it as "0".

The next sector of the matrix evaluated the collection feasibility for each EO on the basis of two factors: landowner permission and reproduction. If the answer to either of these questions was "no," the collection feasibility was "0," and the EO was dropped from immediate consideration but held in a pool of EOs to be rechecked in subsequent years. We asked whether landowner permission to access the EO for collection purposes could be obtained (a score of "1" was given if yes, "0" if no). Collection would be impossible at sites for which such permission could not be secured. If no information was yet available, we assumed permission would be forthcoming. We also evaluated whether current in situ reproduction would allow for collection without undue harm to the genetic integrity of the EO ("yes" = 1, "no" = 0). "Nonreproductive" EOs included: those with only one genet present; those with 2–3 genets that were not noted as vigorous or reproducing in the element occurrence data; those not detected during the most recent survey and not noted as not vigorous during the previous survey; and those that observers failed to relocate during the past three surveys. Because collection would be contraindicated for these precarious occurrences, the subset of nonreproductive EOs was relegated to future reconsideration. We recommended that this nonreproductive subset of EOs be rechecked annually for reproduction for a total of 3

Table 3 – Decision matrix 3 in Excel spreadsheet format, ranking an illustrative sample of separate EOs within sample taxa from Matrix 2

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Species (state, EO #)	Score for taxon, decision matrix 2	Reproduction consistent year-to-year (yes = 1, no = 0)	Population outlier (1) or within center of NE range (2)?	Protection status (1 = conservation, 0.5 = intermediate, 0 = private)	Habitat typical? (yes = 1, no = 0)	Core of range, exemplary in condition (1 = yes, 2 = no)	Imminent threat?	Landowner permission expected? (1 = yes, 0 = no)	Collection possible given reproduction? (1 = yes, 0 = no)	Feasibility of collection (if 1, collection is possible)	Is EO already in seedbank and viable? (yes = 1, no = 0)	Is EO bank collection genetically representative? (yes = 1, no = 0)	Sum of factors to rank collection priority (if *K* = 1, sum of B, C, D, E, F, G, L, M)
Imminent threat													
Arctostaphylos alpina (NH,9)	16.5	1	2	0	1	2	1	1	1	1	0	0	22.50
Tipularia discolor (MA,8)	18.5	1	2	0	1	2	1	1	1	1	0	0	24.50
Taenidia integerrima (VT,7)	27.58	1	2	0	1	2	1	1	1	1	0	0	33.58
Carex polymorpha (CT,1)	31.98	1	2	0	1	2	1	1	1	1	0	0	37.98
Carex polymorpha (CT,4)	31.98	1	2	0	1	2	1	1	1	1	0	0	37.98
Secure and collectable													
Agastache nepetoides (CT,1)	13	1	1	0	1	2	0	1	1	1	0	0	18.00
Arctostaphylos alpina (ME,1)	16.5	1	1	0	1	2	0	1	1	1	0	0	21.50
Arctostaphylos alpina (NH,7)	16.5	1	2	0	1	2	0	1	1	1	0	0	22.50
Tipularia discolor (MA,10)	18.5	1	2	1	1	2	0	1	1	1	0	0	25.50
Tipularia discolor (MA,5)	18.5	1	2	1	1	2	0	1	1	1	0	0	25.50
Betula minor (ME,1)	24	1	1	1	1	2	0	1	1	1	0	0	30.00
Betula minor (NH,2)	24	1	2	1	1	2	0	1	1	1	0	0	31.00
Taenidia integerrima (CT,4)	27.58	1	1	0	1	2	0	1	1	1	0	0	32.58
Taenidia integerrima (VT,17)	27.58	1	2	0.5	1	1	0	1	1	1	0	0	33.08
Tanacetum bipinnatum (ME,34)	31	1	2	0	1	1	0	1	1	1	0	0	36.00
Tanacetum bipinnatum (ME,23)	31	1	2	0	1	2	0	1	1	1	0	0	37.00
Carex polymorpha (CT,5)	31.98	1	2	0	1	1	0	1	1	1	0	0	37.98
Carex polymorpha (MA,7)	31.98	1	2	1	1	2	0	1	1	1	0	0	40.98
Collection not feasible													
Agastache nepetoides (VT,1)	13	1	1	0	1	2	0	1	0	0	0	0	18.00
Betula minor (ME,2)	24	1	1	1	1	2	0	1	0	0	0	0	30.00
Taenidia integerrima (VT,4)	27.58	1	2	0.5	1	2	1	1	0	0	0	0	34.08

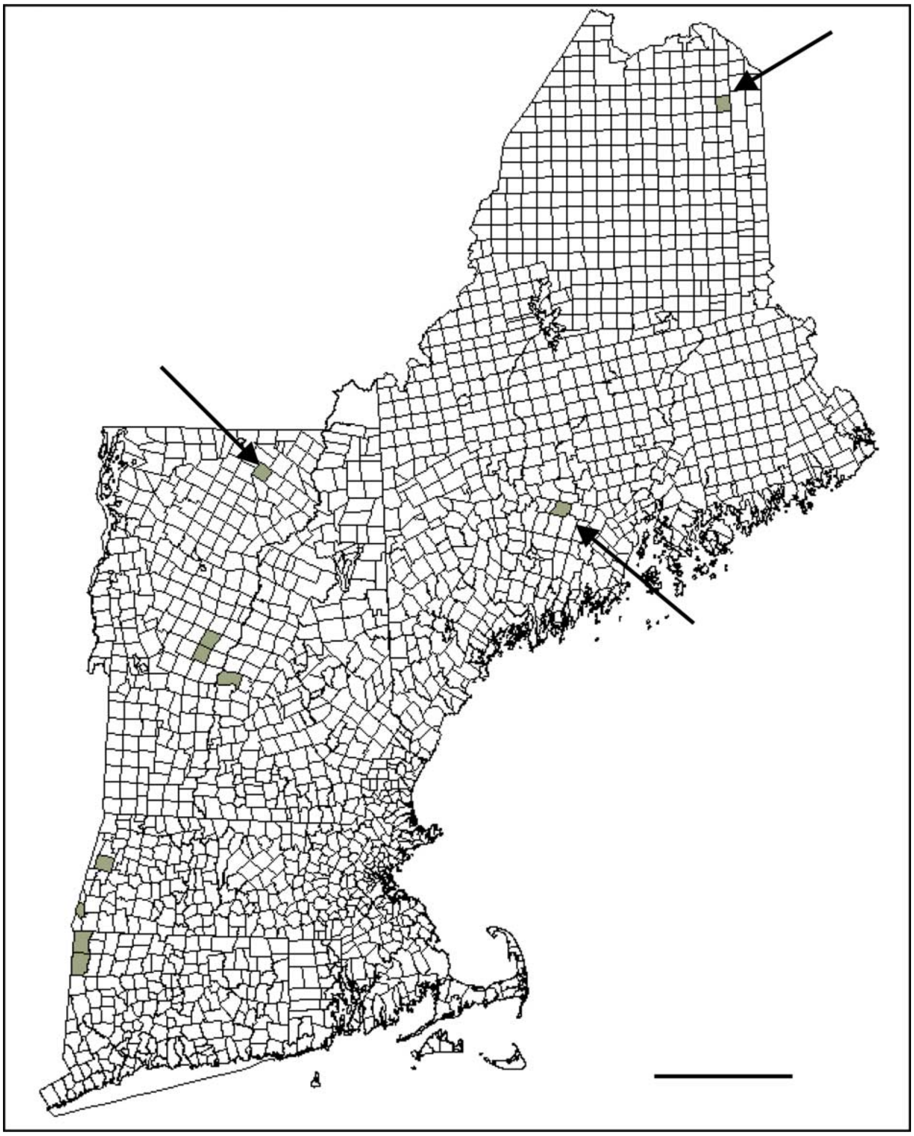

Fig. 2 – Sample map of New England demonstrating how GIS was used to map the region-wide distribution of a taxon in order to identify outlying or edge-of-range occurrences. The taxon mapped here is *Rhynchospora capillacea* (Cullina, 2002). Arrows highlight northern, eastern, and western populations that were widely separated from other populations. Scale bar equals 100 km.

years. If, after 3 years, the EO was still nonreproductive or too tenuous to allow collection, we advocated research into the causes of infertility and decline. Likewise, EOs on land without landowner permission would be reassessed in 3 years.

Regardless of collection feasibility, all EOs were subjected to the final round of questions in decision matrix 3. For both of these questions a "yes" answer received a score of "1" and a "no" answer received a score of "2." For each EO, we queried whether seeds from the EO were currently held in the NEWFS bank. Next, we inquired whether the current collection adequately represents the genetic diversity of the EO, consisting of all maternal lines up to a maximum of 50 and viable seeds numbering at least 1500 (per Guerrant et al., 2004). EOs satisfying both criteria were identified as low priorities for de novo collection, as current accessions were viewed as sufficient for conservation purposes.

7. Results

Four hundred and twenty two taxa (93% of the total starting pool of 456 taxa) passed positively through the first decision matrix, while 34 taxa were found to be either uncollectable or without storage or propagation capacity. This small pool of taxa will be flagged for future research on reproduction and ex situ conservation methods.

Of the EOs analyzed in the third decision matrix, 510 (12% of the original 4333 occurrences) were given a "0" collection feasibility score, based either upon their current in situ reproduction or the unavailability of landowner permission. These EOs will be reevaluated for collection in future years.

Eighty EOs (of the remaining 3283 occurrences, 2.4%) were determined to be already covered by viable and genetically representative accessions in the NEPCoP seedbank, highlighting the need for expanded collections of many more EOs in New England.

Total scores of taxa emerging from the decision matrices ranged between 14.5 and 184 (Fig. 3), with a mean score of 50.9 (±1.2 [95% CI]). The frequency distribution of total scores for EOs emerging from the decision matrices showed strong kurtosis (4.08) due to a long tail of larger scores. A concentrated cluster of normally-distributed scores appeared between 14.5 and 55. A clear break in scores occured between 40 and 55, and between 90 and 135. Because the magnitude of scores was most heavily influenced by the number of element occurrences in New England, these breaks reflected suites of species that vary in rarity in the region. Species with the largest scores, (hence those ranked lowest in collection priority) included taxa with more numerous occurrences, such as *Liatris scariosa* var. *novae-angliae*, *Amelanchier nantucketensis*, *Arethusa bulbosa*, *Lupinus perennis*, and *Sabatia kennedyana*. However, several of these species are largely restricted or endemic to New England (NatureServe Explorer, 2005) and thus receive considerable conservation attention from state Natural Heritage Programs. Therefore, they will continue to be monitored and considered for ex situ collection, particularly if individual EOs are observed to decline. Conversely, the EOs receiving the highest priority for collection included a range of taxa with comparatively few occurrences in New England, many of which are rare throughout their range. These included *Carex mitchelliana* (with one New England occurrence); *Platanthera leucophaea* (with a highly disjunct EO in Maine); *Hybanthus concolor* (which reaches the northern edge of its range in Vermont); *Echinodorus tenellus* (declining throughout its North American range and known only from two sites in the region); *Sclerolepis uniflora* (reaching its range limit with two occurrences in New England); and *Desmodium humifusum* (a G1G2 species with restricted global range).

The subset of 554 EOs identified as imminently threatened were further analyzed using decision matrix 3. Of this group, 316 EOs (57%) were deemed eligible for collection given observed levels of reproduction and pending landowner permission.

8. Discussion

In summary, the three decision matrices yielded a ranked set of 3743 EOs across 404 taxa that were recommended for collection, narrowed from an original data set of 4333 EOs and 456 taxa. Over 86% of the EOs we analyzed were eventually scored as collectable, indicating that our methodology eliminated only a small subset of occurrences from consideration. This reflects our optimism about our capacity to store or propagate material, which caused us to carry 93% of our starting pool of taxa from decision matrix 1 to decision matrix 2 (Fig. 1, Table 1). We also hesitated to ignore occurrences for which we had little information on potential landowner permission or current reproductive status or Division 5 (indeterminate) taxa. In fact, even taxa or occurrences temporarily "eliminated" from consideration for the current collection round will be reconsidered in future years as the technological capacity for storage improves or as conservation needs warrant. The effectiveness of our scoring scheme depended on the high quality of detailed occurrence data that we were able to assemble. Our objective was to produce a set of metrics that would be applied consistently to all taxa (i.e. would produce similar results when applied by multiple "experts," cf. Neel and Cummings, 2003) using the best available data. The means of scoring individual categories will differ among users of these decision matrices based on their

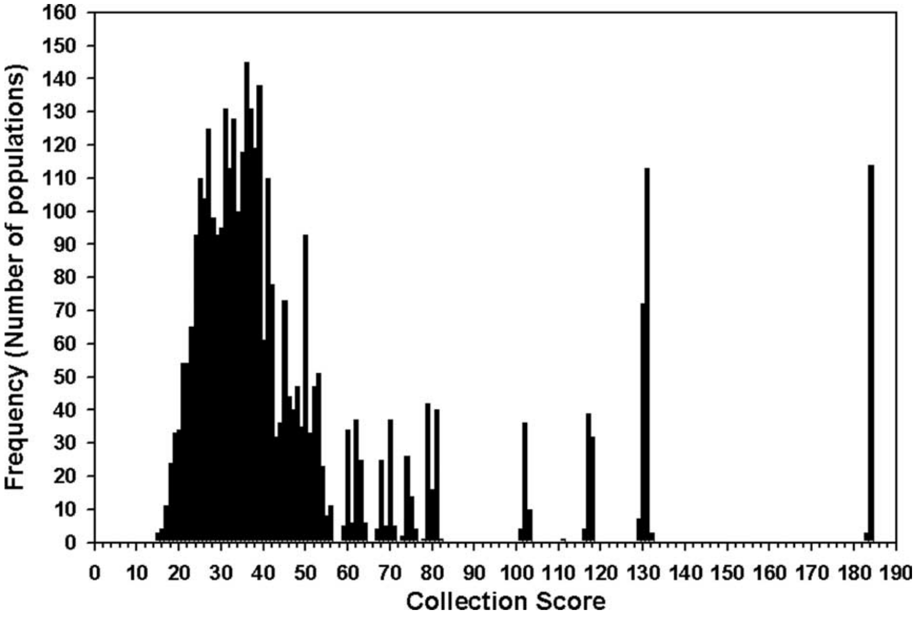

Fig. 3 – Histogram of total score frequencies for populations passing through all decision matrices.

conservatism in eliminating taxa or EOs and on the quality of data.

The distribution of scores we obtained shows interesting and potentially informative breakpoints, which might allow us to postpone collections on certain clusters of high-scoring EOs (Fig. 3). Without tests on a range of data sets, we cannot determine whether break points are general mathematical properties of the structure of the decision matrix system. The multi-modal distribution may simply reflect the influence of numbers of New England EOs on the scores from decision matrix 2, which in turn influenced final scores; EO number explained more than 97% of the variance in matrix 2 scores (Pearson product-moment $r = 0.985$, $P < 0.0001$). As the most reliable indicator of regional rarity, number of EOs was permitted to exert a comparatively large influence on the final score. We have high confidence in the number of occurrences in the region based on the intensity of population monitoring that occurs in New England. Other variables for which uncertainty was higher were purposely designed to exert less influence on final scores.

Overall, we found the prioritization of EOs reasonable, given our prior knowledge (through our own monitoring) of the status of many of these occurrences. That is, there were few instances (15 EOs, less than 1% of occurrences) in which EOs ranked unusually high or low in our estimation. The few exceptions raise issues about how to code taxa whose level of “rarity” may not strictly reflect the number of EOs present. For example, a few taxa restricted almost entirely to montane, alpine habitats in New England (e.g. *Arctostaphylos alpina* and *Veronica wormskjoldii*) are recorded from only a few localities in the region and thus were accorded a high priority for collection. However, these EOs, which can consist of large numbers of plants and largely occur on protected land, are considered generally secure and may not warrant collection at this time. Arguably, however, it may be advisable to collect material from even these secure EOs given that projected climatic warming may threaten their populations in the long-term (Kutner and Morse, 1996).

Likewise, a few species are represented by many very small and tenuous EOs (e.g. *Liparis liliifolia*; Mattrick, 2004). These taxa might receive a disproportionately low priority score for collection, were it not for the fact that many of their EOs were individually scored as “imminently threatened” on the basis of element occurrence data. This mechanism of assigning threat is labor-intensive, but critical for detecting EOs whose absolute scores might not elevate them in the ranking for collection.

Although a major goal of ex situ collections seeks to maximize the representation of genetic diversity across populations (Guerrant et al., 2004), our model could not incorporate many biologically-based variables that would result in genetically diverse sampling. We do not have detailed information on the genetic or even phenotypic diversity among populations, and this information is difficult to infer from existing habitat and descriptive data from element occurrence records. Moreover, breeding systems and levels of potential selfing are understood for only a very small set of rare plant taxa; thus, we are reluctant to extrapolate information on breeding systems among even closely-related species. Therefore, we developed proxies for genetic differentiation based on geographic distances among EOs and notes regarding unusual habitats occupied by certain, presumably divergent EOs. These are imperfect substitutes for actual data on genetic distances, but must suffice until such data are systematically gathered.

The challenges of coding particular variables, and the need to make occasional “judgment calls” regarding reproductive status, degree of threat, and capacities for storage, point to the need for more detailed field data on rare plant EOs. We were able to alleviate some uncertainty in coding by ensuring that multiple users (the authors of this paper) independently inspected the data for quality-control and consistency. However, our coding decisions could only be as reliable as the data collected during field visits. Precise and consistent documentation, particularly of numbers of extant plants, reproductive activity, and threats present, are critical for a better understanding of population trends and the urgency of collection. Notwithstanding these caveats, we have produced a simple model expert system that we believe can be adapted by a range of organizations involved in ex situ plant collections.

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