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SETTING PRIORITIES FOR REGIONAL PLANT CONSERVATION PROGRAMS

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ABSTRACT

Because plant conservationists have such an enormous task facing them, criteria for setting conservation priorities must be developed. In this paper I suggest a set of criteria for determining species conservation priorities based on three independent factors: (1) likelihood of persistence, (2) taxonomic distinctiveness, and (3) potential economic or ecological importance. Species with the highest priority for conservation will be those that are unlikely to persist without intervention, are taxonomically distinct and are economically or ecologically important. There are also a set of practical criteria that must be considered in setting priorities: What are the chances that the proposed conservation program will succeed? Could the program endanger existing natural populations? How expensive will the effort be? Regional plant conservation programs have something important to offer. Just as it makes sense to justify a regional plant conservation program for New England with reference to the distinctive characteristics of its flora, it makes sense to define regions within New England towards which our conservation programs are directed. Not only will regional plant conservation programs make a significant contribution to conserving our natural heritage, but their development will lead to new insights that can be applied to conservation on a much broader scale.

Key Words: Rarity, endangered species, conservation, conservation priorities, *ex situ* conservation, integrated conservation strategies

INTRODUCTION

The magnitude of the task facing plant conservationists on a global or national scale has been widely recognized. Raven (1987) guessed that nearly one-quarter of the 250,000 species of vascular plants will go extinct before the middle of the next century. Of course, most of the species at risk are found in the tropics, but the task facing conservationists in the temperate zone is also frightening, even on a local or regional scale. In Connecticut, for example, nearly one-fifth of the roughly 1600 native species of plants are endangered or threatened on a statewide level or are regarded as species of special concern. For 117 of these species it may already be too late; they are now known only from herbarium records (Mehrhoff, pers. comm.). The situation is similar throughout New England. In fact, there are so many species in imminent danger of extinction that we must make difficult choices as we design a program for plant conservation in New England. Some species will be objects of concern early in this program's life, but others must wait. How do we make these choices? What criteria are appropriate for setting priorities? How do we tell when one species is a better choice for our efforts than another?

SETTING CONSERVATION PRIORITIES

To develop criteria for setting conservation priorities we must first decide what it is we are trying to conserve and why we are trying to conserve it. To accomplish this task we must recognize that conservation efforts can be directed either toward the conservation of species, especially rare and endangered ones, or toward conservation of the functional and structural attributes of important ecosystems. These aspects of conservation are often complementary, but they need not be. Plant species that are regarded as high conservation priorities are sometimes found in habitats that are otherwise unremarkable. Protecting the habitat for Furbish's lousewort (*Pedicularis furbishiae*), for example, also protected a unique and valuable watershed, but protecting the habitat for Texas wild rice (*Zizania texana*) will involve nothing more than protecting a drainage ditch near San Marcos, Texas. Furthermore, managing the dynamics of common species is likely to be more important in maintaining the structure and function of a distinctive ecosystem than is protecting the rare species within it.

Thus, the first task facing any conservation program is to define its mission, to decide whether it is directed at saving threatened and endangered species or at conserving examples of unique habitats and ecosystems. Although I focus on plant species conservation in this paper, we must remember that species conservation is only part of the story. Protecting and conserving significant ecosystems deserves an equal emphasis, even if the ecosystems involved have few high priority species. More importantly, the criteria appropriate for setting priorities in ecosystem conservation are likely to differ from those I develop here (Daniels et al., 1991).

Likelihood of Persistence

One criterion for setting priorities is obvious. Since we are concerned with conserving species, i.e., preventing their extinction, those species that are most likely to go extinct deserve higher priority than those that are less threatened. The problem, of course, rests in determining how likely extinction is. The International Union for the Conservation of Nature (IUCN) uses five categories to reflect the degree of threat: Extinct, Endangered, Vulnerable, Rare, and Indeterminate (IUCN, 1988). The Nature Conservancy uses a numerical scale from 1 to 5, ranking species separately at the global, national, and subnational levels (Nature Conservancy, 1988; Master, 1991). Both schemes combine qualitative judgments about the threat to populations with data on the number of separate occurrences. Similarly, legal protection is often based on qualitative assessments about the threat to populations and the number of occurrences.

In Connecticut, for example, three categories are recognized under the state's endangered species law (1989). An endangered species is "in danger of extirpation throughout all or a significant portion of its range within the state . . . and [has] no more than five occurrences in the state. . . ." A threatened species is "likely to become an endangered species within the foreseeable future . . . and [has] no more than nine occurrences in the state. . . ." A species of special concern has "a naturally restricted range of habitat in the state, [is] at a low population level, [is] in such high demand by man that its unregulated taking would be detrimental to the conservation of its populations, or has been extirpated from the state."

Mace and Lande (1990) criticized the IUCN system because they think its categories are excessively subjective. Their criticism would apply equally well to most other systems. How are we to assess the "danger of extirpation"? How long is "the foreseeable future"? How can we tell when human demand for a species is "detrimental to the conservation of its populations"? Mace and Lande propose a new system of threat categories (Extinct, Critical, Endangered, and Vulnerable) defined in terms of explicit probabilities of extinction over a specified period (Table 1). To assess such probabilities accurately would require a formal population viability analysis, incorporating information from demography, genetics, and metapopulation dynamics (Shaffer, 1981; Gilpin and Soulé, 1986; Belovsky, 1987; Menges, 1990, 1991; Murphy et al., 1990; Shaffer, 1990). Since the data necessary for detailed population viability analyses will not be available for many species, they also propose a set of criteria that can be used to assign a

Table 1. Mace and Lande's classification of the threats species face (Mace and Lande, 1990).

Classification	Likelihood of Persistence
Extinct	Zero
Critical	50% probability of extinction within 5 years or 2 generations, whichever is longer
Endangered	20% probability of extinction within 20 years or 10 generations, whichever is longer
Vulnerable	10% probability of extinction within 100 years

species to its proper category without a formal population viability analysis.

This new system represents a significant conceptual advance over existing ones, integrating as it does the theory of population viability analysis with the practical problem of assigning species to categories of endangerment. Unfortunately, as Master (1991) pointed out, the data needed to decide when the objective criteria are met are not available for most species, and the qualitative criteria that can be assessed require the same degree of subjective judgment as current systems. For practical purposes it is reasonable to accept Mace and Lande's conceptualization of the categories, but we will continue to use subjective judgments about the degree of threat facing a particular species and data on its distribution in assessing the likelihood of persistence for the foreseeable future.

Taxonomic Distinctiveness

Although the degree of endangerment is obviously an important criterion in deciding which species to protect, it is not the only criterion we should use. There are several plant taxa in which the entire world's population consists of one or a few individuals, and in at least some of these cases extensive efforts to conserve them seem misplaced. Grave's Beach Plum (*Prunus maritima* var. *gravesii*), for example, is known from only a single individual plant growing on the Connecticut shore in the town of Groton. Despite intense collecting throughout coastal New England in the century since it was first described, no other plants have been collected. It appears to be a mutant individual of the common beach plum that has never existed as a self-reproducing population (Anderson, 1980). Similarly, *Betula murryana* is a fertile octoploid that combines the genomes of *B. allegheniensis* and *B.* ×*purpusii.* Since the only two trees known grow near their presumed parents, it seems likely that these are the only ones that have ever existed (Barnes and Dancik, 1988). Preserving cuttings of these taxa for horticultural or educational purposes may be worthwhile, but it seems obvious that conserving them is less important than conserving taxa whose populations have been severely reduced or threatened by human activities (Holsinger and Gottlieb, 1991).

Hybrids that are self-reproducing or species that are of hybrid origin, on the other hand, are worthy of protection, especially when they have acquired new and distinctive features. The sunflower relative *Helianthus paradoxus,* for example, is a stabilized hybrid derivative of *H. petiolaris* and the common sunflower *H. annuus.* It has diverged from its parents in flowering time, secondary compound composition, leaf and phyllary shape, and the habitat in which it is found (Rieseberg, 1991). Whatever its origin, its distinctive characteristics mark it as a new species, and it is clearly worthy of the same degree of attention that any other rare sunflower would receive. Similarly, *Aster* ×*blakei* is a stabilized hybrid derivative of *A. nemoralis* and *A. acuminatus* (Pike, 1970). Its habitat, typically the edges of bogs, the shores of ponds, and the swampy border of woods, is intermediate between that of its parents (Brouillet and Simon, 1981), and it is intermediate in many morphological traits. Nonetheless, it reproduces vigorously by rhizomes and is often found growing without one or both parents. Clearly it is behaving as a distinct species and deserves the same attention that we would give to any other rare *Aster.*

These considerations suggest a second important criterion to be used in setting conservation priorities. Taxa that are taxonomically more distinctive deserve a higher priority than those that are less distinctive. Why? Because our objective in conserving species is to conserve as much of the remaining biological diversity as we can, and a taxon that plays a unique ecological role or that represents a unique evolutionary line contributes more to that diversity than does one that is just another variation on the same theme. This assumption is not to suggest that less distinctive taxa are unworthy of protection or unimportant. After all, it is not just the beauty of his themes but the brilliance of his variations that makes listening to Mozart such a wonderful experience. But think how much poorer the world would be if there were no Bach or Brahms, no Vivaldi or Puccini, no Debussy or Ravel. Similarly, the variety of sedges makes them a fascinating group, but to allow their variety to distract us from such distinctive species as Lizard's tail (*Saururus cernuus*) or Arethusa (*Arethusa bulbosa*) would be a grave mistake.

Taxonomic distinctiveness is probably the simplest and most accessible index of evolutionary and ecological uniqueness. Thus, we can use it as a guide in setting priorities. As a rule of thumb, I suggest that species in monotypic genera deserve greater attention than species in large genera, distinctive species deserve more attention than cryptic ones, and species deserve more attention than subspecies or varieties. Of course taxonomic judgments are notoriously variable from one group of plants to another, so this criterion must be applied cautiously. Within any particular group, however, taxonomic decisions tend to be made consistently, and taxonomic rank will quickly reveal when one taxon is more distinctive than another. In California about one-quarter of the taxa listed under the state's endangered species law are subspecies or varieties, suggesting that attention to minor categories has shifted the focus away from more important taxa (Holsinger and Gottlieb, 1991).

Economic or Ecological Importance

One reason we are trying to conserve biological diversity is that human beings may derive important benefits from it. Yields of major agricultural crops like corn, wheat, soybeans, tomatoes and potatoes have doubled or tripled in the last fifty years, for example, and nearly half this improvement is attributable to the use of genetic variation found in wild relatives of these crops (OTA, 1987). Use of these genetic resources has so far been limited by the need for reproductive compatibility between cultivated and wild species, but recent advances in molecular biology and genetics may make it possible to move genes coding for agronomically important traits into cultivated species from wild relatives that could not be included in a traditional crossing program. Similarly, the importance of plant products in the world's medicine chest is widely known. Nearly one-quarter of all prescriptions dispensed from community pharmacies in the United States contain active principles extracted from higher plants (Farnsworth and Morris, 1976). Taxol from the Pacific yew (*Taxus* *brevifolia*) and vincristine/vinblastine from the rosy periwinkle (*Catharanthus roseus*) are merely two recent examples. Thus, another important criterion in determining conservation priority concerns the potential direct benefits that we may derive from plant species. Those species economically important themselves or relatives of economically important plants deserve a higher priority than those that are not.

To limit our considerations of human benefit from plant species to the direct benefit that may be gained from their use would, of course, be too narrow a view. We derive enormous indirect benefits from the role that plants play in maintaining the structure and function of important ecosystems. Rare species, which are the primary focus of this paper, may play a less important role in maintaining that function than those that are common, but they can serve as indicators of a system under stress. Loss of rare species may alert us to the loss of a unique and valuable habitat. Development on coastal sand plains in Connecticut, for example, is reflected in the declining numbers of False beach-heather (*Hudsonia tomentosa*), just as loss of sphagnum bogs has led to decline of Arethusa (*Arethusa bulbosa*). Loss of rare species might also be the first sign of change in ecosystem structure. Thus, it is reasonable to accord ecologically important species a higher priority for conservation purposes than those that are less important.

Special Considerations for *ex situ* Conservation Programs

For conservation programs like the national collection of the Center for Plant Conservation or the regional collection being developed as part of the New England Plant Conservation Program, there are additional considerations that must come into play. These programs aim to provide an insurance policy against catastrophes that would eliminate or endanger existing natural populations by establishing off-site collections of imperiled species. For temperate zone plants the method of choice for off-site preservation is long-term storage in seed banks, though maintenance of living collections may be an option for some long-lived plants (Holsinger and Gottlieb, 1991). The *ex situ* component of conservation programs must focus on species in which it can contribute significantly to the integrated conservation effort (Falk, 1987). It would be an unconscionable waste of limited resources to spend our time and money on species for which the prospects of *ex situ* conservation are limited.

I have already alluded to one important criterion for determining conservation priority in the *ex situ* component of a program, namely, the ability to store the species long-term as seed. Many temperate zone plants, especially those whose seeds are resistant to drying, can easily tolerate long-term storage at subfreezing temperatures if the seed is properly dried (Eberhart et al., 1991). Although meristem culture and other forms of tissue storage show some potential, expense and expertise necessary for such programs will make them impractical for all except the most important species. Species with recalcitrant seed, e.g., orchids and many aquatics, pose a real problem for *ex situ* conservation programs. It may be useful to include such species for horticultural, educational or research purposes, but only rarely can we justify the effort necessary to use living collections of short-lived species for conserving genetic diversity off-site. The amount of expertise and labor required simply make it impractical to consider more than one or two of the most important species for such an effort (Holsinger and Gottlieb, 1991).

Another important criterion is that no *ex situ* conservation plan should be considered for a species in which the collections necessary to ensure its success would seriously endanger remaining natural populations. After all, the whole purpose of the *ex situ* part of a program is to ensure the species' survival *in the wild.* Conservation of existing natural populations is the surest way to prevent loss of the genetic diversity necessary for long-term persistence. There may be rare cases similar to that of the California condor in which the only chance for a species' survival is to increase its population size through an off-site breeding program, but such programs should be considered *only* as a last resort. The record of ecological transplant experiments shows that the chances of successful establishment are very small, even when we try to match the ecological characteristics of source and destination populations as closely as possible (Huenneke, 1991). This outcome is particularly important to remember when development threatens a natural population. We should consider establishing a new population for mitigation only if the alternative is extinction.

Some Conclusions

I suggest that the conservation priority which a particular species receives should be based on: (1) its likelihood of persistence,

(2) its ecological or evolutionary distinctiveness as evidenced by its taxonomic distinctiveness, and (3) its ecological or economic importance. For programs that include an *ex situ* component we must also decide how likely *ex situ* efforts are to succeed for the species in question. Indeed, for any conservation program there is another layer of criteria that must be considered: How expensive will the effort be to conserve this species? What are the chances of success? Answers to these questions are obviously critical to the implementation of any program, but it is important that we distinguish between two questions that must be answered: (1) Which species should be the highest priority targets for a conservation program? (2) For which of these species are conservation efforts most likely to be rewarded? I shall focus only on the answer to the first of these, since it is that question which the three criteria I suggested above can answer.

Perhaps the most important thing to recognize about these criteria is that they are largely independent of one another. A species that faces a grave threat to its existence, for example, need not be particularly distinctive taxonomically nor particularly important ecologically. Obviously the highest priority should be accorded to those species that score high on each scale, but how are we to resolve conflicts among the scales? Does a taxon that is taxonomically distinctive but found in relatively stable populations deserve a lower priority than one that is less distinctive but whose populations are in imminent danger, for example?

Though I doubt that any general answer to these conflicts can be given, a rough priority scheme that ranks individual species in terms of their characteristics on three scales of measurement may be useful (Table 2). The priority scale I propose is divided into four categories: Very High, High, Medium, and Low. Species in the Very High category rank high on each of the three scales for conservation priority; those in the High category rank high on two; those in the Medium category in one; and those in the Low category rank low on every scale. Although the scheme presented in Table 2 treats each scale as a simple dichotomous variable, this treatment is done only to simplify the presentation. Likelihood of persistence, taxonomic distinctiveness and ecological or economic importance are all qualities that come in degrees, not absolutes. Thus, the categories suggested should also be regarded as points in a continuum, not as truly distinct categories.

The idea behind this scheme is a simple one: those species

Table 2. A scheme for setting conservation priorities.

Degree of Threat	Existing Populations Unlikely to Persist		Existing Populations Likely to Persist	
Taxonomic Distinctiveness	Very Distinct	Marginally Distinct	Very Distinct	Marginally Distinct
Ecological or Economic Importance				
Very important, good indicator species or close relative of economically important species	Very high priority	High priority	High priority	Medium priority
Less important, not a good indicator species and not a close relative of an economically important species	High priority	Medium priority	Medium priority	Low priority

deserving the highest priority for conservation efforts are those that are the most important in several different ways. Given a choice between a species that is both ecologically significant and taxonomically distinctive and another that is more immediately threatened but less significant ecologically and less distinct taxonomically, the first is a better candidate for conservation efforts, *all other things being equal.* Of course, all other things are rarely equal. This scheme and more elaborate ones, like the one proposed by Daniels (Daniels et al., 1991) which try to combine several measures of conservation priority must not be regarded as providing rigid rules for setting conservation priorities. Their usefulness, if they have any at all, comes primarily from their ability to clarify our thinking. They help us make sure that *all* aspects of the problem have been considered, but ultimately each case must be decided on its own merits.

APPLYING THE CRITERIA ON A REGIONAL SCALE

The first problem any regionally based plant conservation program must face is that of justifying its existence. For us the problem can be stated more specifically. Why should there be any efforts in New England at all when the number of species at risk pales in comparison with the tropics? Why should we regard elements of the New England flora as imperiled when the species that are considered rare here often occur throughout the area? The small whorled pogonia (*Isotria medeoloides*), for example, is extant in every New England state except Vermont, where it is known historically, and herbarium records exist from as far south as Georgia. In California, on the other hand, rare species are often found in only one or two populations covering only a few acres. The serpentine endemics *Layia discoidea* and *Streptanthus niger*, for example, are each found in only two or three populations in a small geographic area. There are at least three reasons why a plant conservation program is necessary in New England despite these questions.

First, the groups that are at risk in New England are often very different from those that are imperiled in California, Hawaii, Texas and Florida, the states with the highest concentration of plants on the Federal endangered species list. Our global concern for conserving biodiversity requires that we direct some attention to areas like New England lest we lose important parts of our biological heritage. Second, the threat facing rare and endangered species in New England often may be a result of human-induced changes to their environment, while western endemics often appear to be recently evolved taxa that have never been more widespread. Fiedler (1987), for example, showed that rarity in Californian mariposa lilies (*Calochortus*) is a result of specific adaptations to habitats that are rare, while the rarity of running buffalo clover (*Trifolium stoloniferum*) apparently reflects the effects of European settlement (Bartgis, 1985; Campbell et al., 1988). Thus, rare western taxa have often shown their ability to cope with the ecological and genetic consequences of rarity, by the mere fact of their continued persistence (Huenneke et al., 1986; Holsinger and Gottlieb, 1991). Rare eastern taxa, on the other hand, may have become rare only after European occupation and may still be suffering from the effects of reduced population size and habitat fragmentation. Third, although endangered species are not necessarily important to the structure and function of distinctive ecosystems, they are sometimes good indicator species. Furbish's lousewort (*Pedicularis furbishiae*) is the most famous example in New England, but decline of Arethusa (*Arethusa bulbosa*) and False beach-heather (*Hudsonia tomentosa*) in Connecticut that I referred to earlier are two others.

Just as it makes sense to justify a plant conservation program in New England with reference to the distinctive characteristics

Table 3. A preliminary scheme of floristic regions in New England.

Coastal strand
Southern New England hardwood forest
Central New England transition forest
Northern New England mixed hardwood/coniferous forest
Northern New England coniferous forest

of its flora, it makes sense to define regions within New England toward which our conservation programs are directed. After all, rarity depends on the scale of observation (Harper, 1981; Rabinowitz, 1981; Kruckeberg and Rabinowitz, 1985). Side-oats grama-grass (*Bouteloua curtipendula*) is in no danger of extinction on a global scale; it is among the dominant grasses of the prairie in the central United States. In Connecticut, however, only a single population is known. Clearly, on that scale, it is a rare species. If our objective in designing a plant conservation program for New England is to preserve the diversity of its biological heritage, it behooves us to identify significant floristic regions or distinctive habitats within the area and to define rarity with reference to these regions. We should not define these regions too narrowly since we do not want to dilute our efforts, but defining them will help us to recognize rarities on a basis other than the artificial lines politicians have drawn. There are others far more qualified than I to suggest what these regions might be, but the scheme I suggest in Table 3 may serve as a basis on which to begin the discussion.

CONCLUSIONS

Many problems facing us as we design a program for plant conservation in New England are similar to those that have faced plant conservationists on a global or national level for years. The criteria I propose here, for example, are very similar to those developed by the Center for Plant Conservation for guiding the growth of its National Collection (CPC, 1991). It is not the criteria that are new, but the focus on a particular geographical region is new. This regional focus may allow us to accomplish two important tasks that more broadly based efforts have not. First, it helps us to knit together the sometimes competing objectives of species conservation and ecosystem conservation. At a global level, habitats of rare species may not be particularly significant, but at a regional level rare species often serve as indicators of unique and valuable habitats. Second, it helps us build the case for programs that are directed toward conservation of genetic diversity within widespread species. Rare and endangered species are a legitimate focus for many conservation efforts, but we must not forget that the evolutionary potential of common species may depend on the amount of genetic variation they can maintain (Millar and Libby, 1991), and it is common species rather than rare ones that have the most to lose by the fragmentation of natural habitat increasingly associated with land development in industrialized societies (Holsinger, 1992). Regional plant conservation programs, like the one being designed for New England, have much to offer. Not only will they make a significant contribution to conserving our biological heritage, but their development will lead to new insights which can be applied to conservation on a much broader scale.

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LITERATURE CITED

Anderson, G. J. 1980. The status of the very rare *Prunus gravesii* Small. Rhodora 82: 113–129.

Barnes, B. B. and B. P. Dancik. 1988. Characteristics and origin of a new birch species, *Betula murryana,* from southeastern Michigan. Canad. J. Bot. 63: 223–226.

Bartgis, R. L. 1985. Rediscovery of *Trifolium stoloniferum* Muhl. ex A. Eaton. Rhodora 87: 425–429.

Belovsky, G. E. 1987. Extinction models and mammalian persistence, pp. 35–57. *In:* M. E. Soulé, Ed., Viable Populations for Conservation. Cambridge Univ. Press, Cambridge, England.

Brouillet, L. and J.-P. Simon. 1981. An ecogeographical analysis of the distribution of *Aster acuminatus* Michaux and *A. nemoralis* Aiton (Asteraceae: Astereae). Rhodora 83: 521–550.

Campbell, J. J. N., M. Evans, M. E. Medley and N. L. Taylor. 1988. Buffalo clovers in Kentuchy (*Trifolium stoloniferum* and *T. reflexum*): historical records, presettlement environment, rediscovery, endangered status, cultivation, and chromosome number. Rhodora 90: 399–418.

CPC. 1991. Genetic sampling guidelines for conservation collections of endangered plants, pp. 225–238. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Daniels, R. J. R., M. Hedge, N. V. Joshi and M. Gadgil. 1991. Assigning conservation value: a case study from India. Conserv. Biol. 5: 464–475.

Eberhart, S. A., E. E. Roos and L. E. Towill. 1991. Strategies for long-term management of germplasm collections, pp. 135–145. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Falk, D. A. 1987. Integrated conservation strategies for endangered plants. Natural Areas J. 7: 118–123.

Farnsworth, N. R. and R. W. Morris. 1976. Higher plants—the sleeping giant of drug development. Amer. J. Pharm. Educ. 148: 46–52.

Fiedler, P. L. 1987. Life history and population dynamics of rare and common mariposa lilies (*Calochortus* Pursh: Liliaceae). J. Ecol. 75: 977–995.

Gilpin, M. E. and M. E. Soulé. 1986. Minimum viable populations: processes of species extinctions, pp. 19–34. *In:* M. E. Soulé, Ed., Conservation Biology: The Science of Scarcity and Diversity. Cambridge Univ. Press, Cambridge, England.

Harper, J. L. 1981. The meanings of rarity, pp. 189–203. *In:* H. Synge, Ed., The Biological Aspects of Rare Plant Conservation. Wiley, New York.

Holsinger, K. E. 1992. The evolutionary dynamics of fragmented plant populations. *In:* J. Kingsolver, P. Kareiva and R. Huey, Eds., Biotic Interactions and Global Change. Sinauer Associates Sunderland, MA (in press).

——— and L. D. Gottlieb. 1991. Conservation of rare and endangered plants: principle and prospects, pp. 195–208. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Huenneke, L. F. 1991. Ecological implications of genetic variation in populations, pp. 31–44. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

———, K. E. Holsinger and M. E. Palmer. 1986. Plant population biology and the management of viable plant populations, pp. 169–183. *In:* B. A. Wilcox, P. F. Brussard and B. G. Marcot, Eds., The Management of Viable Populations: Theory, Applications, and Case Studies. Center for Conservation Biology, Stanford, CA.

IUCN. 1988. 1988 IUCN Red List of Threatened Animals. IUCN, Gland, Switzerland.

Kruckeberg, A. R. and D. Rabinowitz. 1985. Biological aspects of endemism in higher plants. Annual Rev. Ecol. Syst. 16: 447–479.

Mace, G. M. and R. Lande. 1990. Assessing extinction threats: toward a reevaluation of IUCN threatened species categories. Conserv. Biol. 5: 148–157.

Master, L. I. 1991. Assessing threats and setting priorities for conservation. Conserv. Biol. 5: 559–563.

Menges, E. R. 1990. Population viability analysis for an endangered plant. Conserv. Biol. 4: 52–62.

———. 1991. The application of minimum viable population theory to plants, pp. 45–61. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Millar, C. I. and W. J. Libby. 1991. Strategies for conserving clinal, ecotypic, and disjunct population diversity in widespread species, pp. 148–170. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Murphy, D. D., K. E. Freas and S. B. Weiss. 1990. An environment-metapopulation approach to population viability analysis for a threatened invertebrate. Conserv. Biol. 4: 41–51.

Nature Conservancy. 1988. Natural Heritage Program Operations Manual. The Nature Conservancy, Arlington, VA.

OTA. 1987. Technologies to Maintain Biological Diversity. U.S. Government Printing Office, Washington, DC.

Pike, R. B. 1970. Evidence for the hybrid status of *Aster* × *blakei* (Porter) House. Rhodora 72: 401–436.

Rabinowitz, D. 1981. Seven forms of rarity, pp. 205–217. *In:* H. Synge, Ed., The Biological Aspects of Rare Plant Conservation. Wiley, New York.

Raven, P. H. 1987. The scope of the plant conservation problem world-wide, pp. 19–29. *In:* D. Bramwell, O. Hamann, V. Heywood and H. Synge, Eds., Botanic Gardens and the World Conservation Strategy. Academic Press, London.

Rieseberg, L. H. 1991. Hyrbridization in rare plants: insights from case studies in *Cercocarpus* and *Helianthus,* pp. 171–181. *In:* D. A. Falk and K. E. Holsinger, Eds., Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Shaffer, M. I. 1981. Minimum population sizes for species conservation. BioScience 31: 131–134.

———. 1990. Population viability analysis. Conserv. Biol. 4: 39–40.

State of Connecticut. 1989. Public Act 89-224: An Act Establishing a Program for the Protection of Endangered and Threatened Species. Available from State Publications Office, Hartford, CT.

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