

Extinction Risk of *Ipomopsis sancti-spiritus* in Holy Ghost Canyon With and Without Management Intervention

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Abstract: Small populations are threatened with deterministic and stochastic events that can drive the number of individuals below a critical threshold for survival. Long-term studies allow us to increase our understanding of processes required for their conservation. In the past 7 years, the population of the federally endangered Holy Ghost ipomopsis (*Ipomopsis sancti-spiritus*) in Holy Ghost Canyon has fluctuated widely from 2047 to 372 plants. Meta-population analysis of average Leslie matrices suggested that *I. sancti-spiritus* has a high probability of extinction; 60 percent of the demographic transects have negative growth rates. Transects with the greatest likelihood of remaining occupied, the highest λ values, and the greatest source of new propagules for maintaining the species in Holy Ghost Canyon are in the sunny lower part of the canyon. In comparison, transects at the top of the canyon have fewer individuals and lower probability of remaining occupied. With management intervention to disperse propagules from more fecund to less fecund areas of the canyon, meta-population modeling indicated decreased (but still a high) risk of extinction within the next 50 years. Thus, although seed augmentation and habitat improvement can improve the chances for *I. sancti-spiritus* persistence in Holy Ghost Canyon, the species remains at high risk of extinction.

Small populations are threatened with deterministic and stochastic events that can drive the number of individuals below a critical threshold for survival (Shaffer 1987, Holsinger 2000). Climatic variation, habitat changes, impacts of exotic species, and inherent reproductive limitations have dramatic and exaggerated impacts on small populations. Through long-term studies of small populations, we can increase our understanding of the processes required for their conservation.

The federally endangered Holy Ghost ipomopsis (*Ipomopsis sancti-spiritus* Wilken & Fletcher) is threatened by events that plague all small populations. Believed to be a newly derived taxa having arisen within the last 10,000 years (Wolf et al. 1991), it was first described in 1988 (Wilken and Fletcher 1988) and very little was known about its biology. Growing along a 1.3 mile stretch of road cut through mixed conifer forests of Holy Ghost Canyon (elevation 2350–2500 m) in northern New Mexico, Santa Fe National Forest, *I. sancti-spiritus* seems to be an early successional species, like many of its congeners. Nearly 80 percent of the population grows on west-facing steeply cut Terro limestone slopes along the road in the canyon. It is associated with open areas with low densities of ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), quaking aspen (*Populus tremuloides*), Gambel oak (*Quercus gambelii*), mountain mohogany (*Cercocarpus montanus*), Woods'

rose (*Rosa woodsii*), poison ivy (*Toxicodendron rydbergii*), Indian hemp (*Apocynum cannabinum*), western yarrow (*Achillea millefolium*), white ragweed (*Hymenopappus newberryi*), and *Erigeron speciosa*. It does not co-occur with grasses.

In 1991, Robert Sivinski of New Mexico Forestry and Resources Conservation Division estimated the *I. sancti-spiritus* population size to be between 1250 and 2500 individuals. It was listed as endangered in 1994 (U.S. Fish and Wildlife Service 1994). Because the majority of the population occurs along cut and fill slopes of one road, it was hypothesized that management practices, which eliminated natural disturbances (i.e., fire and erosion), shifted the dependence of the species to man-made disturbance for suitable habitat. Inursions of exotic grasses smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*) may have excluded *I. sancti-spiritus* expansion within the canyon. The extremely narrow geographic distribution of the species and its lack of competitive ability make it extremely vulnerable to activities related to road maintenance, exotics, and activities that suppress moderate disturbance (U.S. Fish and Wildlife Service 1994).

In 1994, I established long-term demographic plots in Holy Ghost Canyon to assess the population viability of the endangered species. I treated the demographic plots as a metapopulation—a system of local populations connected by dispers-

ing individuals and gene flow, where colonization and extinction play significant roles in the dynamics and persistence of the species (Hanski 1998). Examining an entire corridor where the species occurred allowed me to examine patterns of patch extinction and colonization. Thrall et al. (2000) have argued that a metapopulation approach to conservation biology is likely to provide one of the most useful tools for developing management strategies that optimize among-population processes critical for the persistence of many natural systems.

Methods

To determine population viability of the *I. sancti-spiritus*, I established ten 13 X 5 m randomly selected transects numbered 1 through 10 from the top of Holy Ghost Canyon to the bottom. All transects had adult *I. sancti-spiritus* present in 1994. I tracked location, plant size, reproductive output, and survival of individuals in plots each year from 1994 through 2000.

In each transect, I measured the amount of light with a photometer to determine PPFD (photosynthetic photon flux density) and estimated the total hours of solar radiation received by plants in each transect.

Using RAMAS Metapop (Akçakaya 1998), I modeled population viability analysis of all 10 transects in Holy Ghost Canyon. Three stages were represented in the model: seedling, rosette, and adult. I generated a Leslie matrix for each transect from the means and variances of the past 6 transition years. I calculated reproductive values by dividing the number of seedlings by reproductive adults in each transect in each transition year, then derived the mean and variance for the 6 transition years. I assumed that populations had ceiling Allee density dependence with carrying capacities 1.5 times greater than population numbers seen in the last 7 years. I assumed that dispersal of seeds would be most likely to be unidirectional from the top of the canyon to the bottom. Transects separated by < 0.1 mile (0.16 km) had higher probabilities of dispersal than transects separated by > 0.5 mile (1.2 km). I assumed demographic and environmental stochasticity and included parameters in the model.

There were local and regional level catastrophes during the 7 years of monitoring. In some transects, local "catastrophes" were created by vehicles crushing plants, gophers burying plants, and erosion or landslides eliminating sections of a plot. I estimated the probabilities for local catastro-

phe by reviewing the evidence of disturbance in the plots over the past 7 years. For example, disturbance in 1 out of 7 years yielded a probability of 0.14 of a local catastrophe for that plot. Regional level catastrophes due to climatic conditions affected all plots. I assigned a probability of 0.14 for regional catastrophe, because severe drought has occurred once in the past 7 years of monitoring. The model ran 50 replicates for 100 years.

To examine whether management intervention could help conserve the species, I tested the impact of increasing dispersal throughout Holy Ghost Canyon on persistence of the species. The second model simulates moving seeds uphill and dispersing to all transects. I assumed dispersal of 5 percent of seeds in any given year to all uphill transects. The model ran 50 replicates for 100 years.

Results

The majority of seedlings required 1–3 years to achieve reproductive maturity. Although the range was between 1 and 6 years, mean maturation time was 1.86 years. Seeds often germinated with the onset of monsoon rains and had several true leaves by September.

The lower portion of the canyon received significantly more sun and had more fecund populations with greater numbers of individuals than the upper portion of the canyon. Upper transects 1–4 received approximately 2 hours of sunlight. The filtered sunlight was approximately 20 percent of full sun. Transects at the lowest part of the canyon received approximately 10 hours of full sun, with less than 5 percent shading.

There was significant variation in survival and reproduction across years. Most transects experienced good seedling establishment in 1996. In contrast, the lowest population numbers occurred in 1995, 1999, and 2000, which were comparatively dry years (Table 1). I observed no extinction within transects, although some transects consistently maintained few individuals (Table 1).

Population viability analysis of mean Leslie matrices over 6 transition years indicated that 40 percent of the transects have positive growth rates ($\lambda > 1.0$, Table 1 and 2), whereas 60 percent have negative growth rates ($\lambda < 1.0$). Not surprisingly, metapopulation analysis indicated that occupancy of *I. sancti-spiritus* in any transect has a probability of zero within 44 years (Figures 1 and 2) and that within the next 10 years only 2 of the 10 transects will be occupied. The model estimated a median of 16.8 years for the numbers of individuals in all

Table 1. Total number of individuals in each transect for the 7 years of monitoring. Mean λ values were determined from the average of six matrices. Total individuals in all transects are indicated for each year in the bottom row.

Site	1994	1995	1996	1997	1998	1999	2000	Mean λ
1	38	54	65	38	81	52	77	1.24
2	79	66	112	43	34	39	45	0.788
3	12	4	4	12	12	9	16	0.562
4	21	13	15	26	18	10	12	0.973
5	34	21	70	24	22	14	6	0.901
6	34	27	42	106	99	69	40	0.791
7	76	59	453	247	213	144	52	1.312
8	53	27	321	141	104	38	12	1.513
9	142	54	243	140	57	15	7	0.908
10	130	89	722	566	530	206	105	1.265
Total	619	414	2047	1343	1170	596	372	

Table 2. Mean probabilities for stage transitions across 6 transition years at each transect.

Stage	Transects in Holy Ghost Canyon									
	1	2	3	4	5	6	7	8	9	10
Seedling–rosette	0.5	0.63	0.35	0.55	0.42	0.55	0.51	0.40	0.40	0.63
Seedling–adult	0.28	0.09	0.31	0.24	0.06	0.15	0.24	0.37	0.28	0.09
Rosette–rosette	0.46	0.42	0.22	0.44	0.26	0.29	0.24	0.22	0.17	0.32
Rosette–adult	0.24	0.35	0.32	0.35	0.41	0.39	0.33	0.38	0.44	0.37
Reproductive value	3.556	0.909	0.50	1.585	2.51	1.08	4.298	4.66	1.596	4.8

transects to fall to zero (Figure 2). Transects 1, 7, 8, 9, and 10 have the greatest likelihood of remaining occupied, have the highest λ values, have the highest variation of occupancy, and represent the greatest source of new propagules for maintaining the species in Holy Ghost Canyon (Figure 3).

The second model, which simulated the management intervention of dispersing seeds from lower canyon transects to upper canyon transects, showed a significant impact from dispersal; local occupancy of all transects increased dramatically (Figure 4). Most important, the upper range of time steps increased from < 15 steps to > 40 steps for transects 1–8. With human-aided uphill dispersal, the estimated time to extinction and the upper range of persistence increased (Figure 5), as did the metapopulation occupancy (Figure 6). Without uphill dispersal, the estimated occupation time for 10 transects was less than 5 years, whereas with uphill dispersal the estimated occupation time increased to 26 years (Figure 6). Uphill dispersal increased the probability of species persistence in the individual transects and in the entire canyon.

Discussion

Wide fluctuations of growth rates within the metapopulation of *I. sancti-spiritus* in Holy Ghost Canyon are endangering the species. During the past 7 years, *I. sancti-spiritus* experienced both favorable and unfavorable climatic conditions. Even though years with good precipitation produced good seedling recruitment, this did not translate to good adult survival and reproduction in subsequent years. Similarly, years when the numbers of adults were comparatively great did not yield good seedling establishment in subsequent years. Even stable or increasing populations will suffer decline with high year-to-year variability in population growth rate, regardless of whether the variation is caused by the environment or rare catastrophic events (Holsinger 2000).

The metapopulation analysis indicated that persistence of the species in Holy Ghost Canyon does not look promising without management intervention. Six of 10 transects are declining and have low solar exposure. The analysis predicted a high risk of extinction for the species. Holsinger (2000) admonished that populations with negative

Metapopulation occupancy

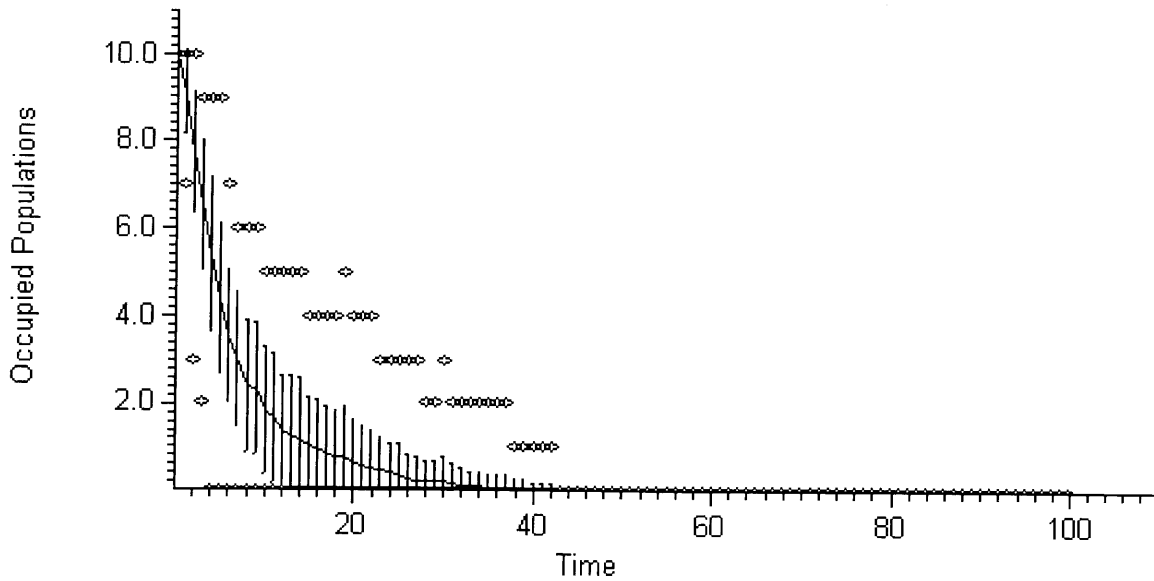


Figure 1. Summary of expected occupancy of *Ipomopsis sancti-spiritus* metapopulation through time. The average \pm standard deviation, minimum and maximum number of extant populations are indicated. The model used average matrices (indicated in Table 2) and assumed dispersal downhill only to adjacent transects.

Median \sim 16.8

Time to extinction

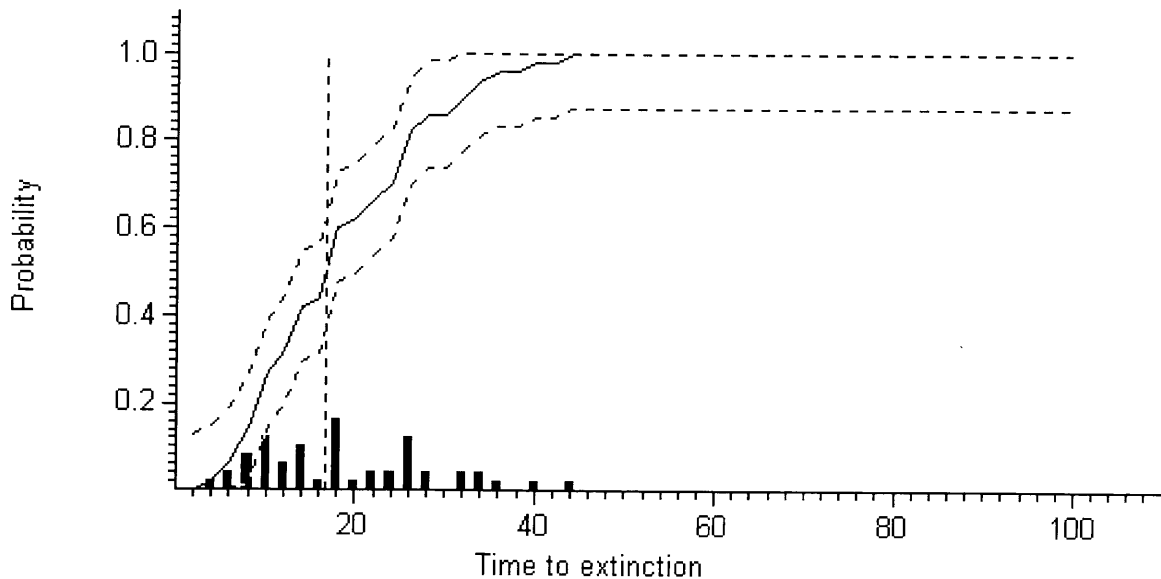


Figure 2. Time to extinction projected by the model using average matrices indicated in Table 2. The dotted vertical line indicates that the median of the distribution is 16.8 years. The histogram shows the probability that the metapopulation size will fall below or increase above zero exactly at the time step. The continuous line is the cumulative probability distribution. It shows the probability of the metapopulation falling below zero at or before a specific year; after 44 years the probability of extinction is 1.0. The model assumed dispersal downhill only to adjacent transects.

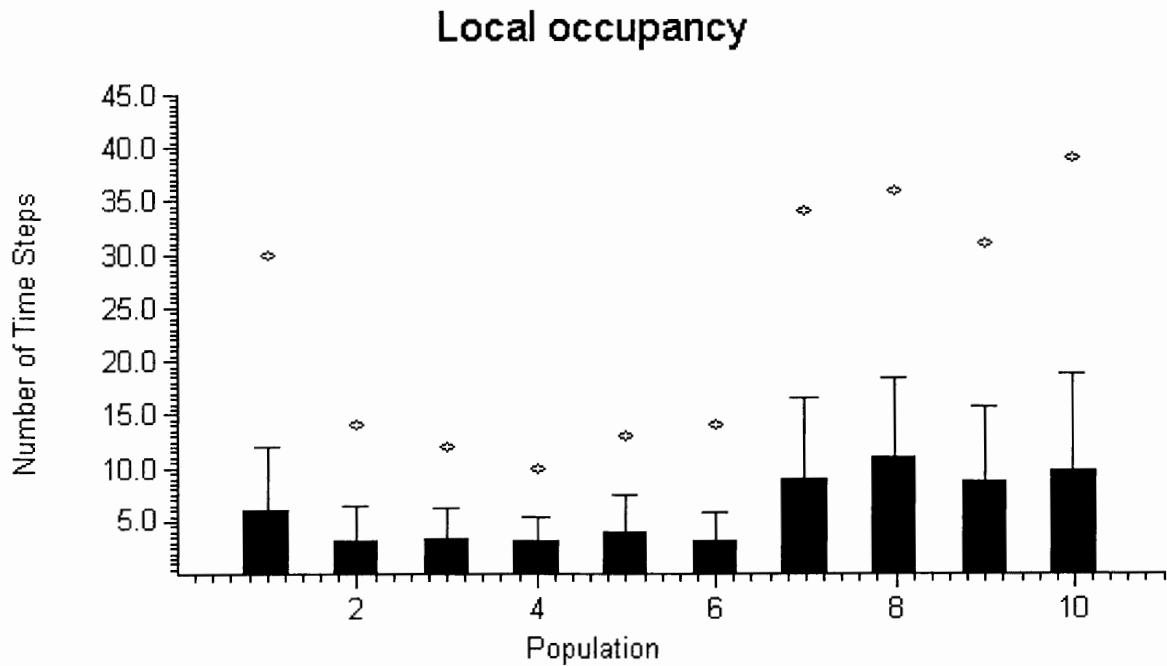


Figure 3. Statistical summary of the proportion of time that patches of *Ipomopsis sancti-spiritus* will remain occupied. The average \pm 1 standard deviation, minimum and maximum number of years that each population has remained extant is indicated. The model used average matrices (see Table 2) and assumed dispersal downhill only to adjacent transects.

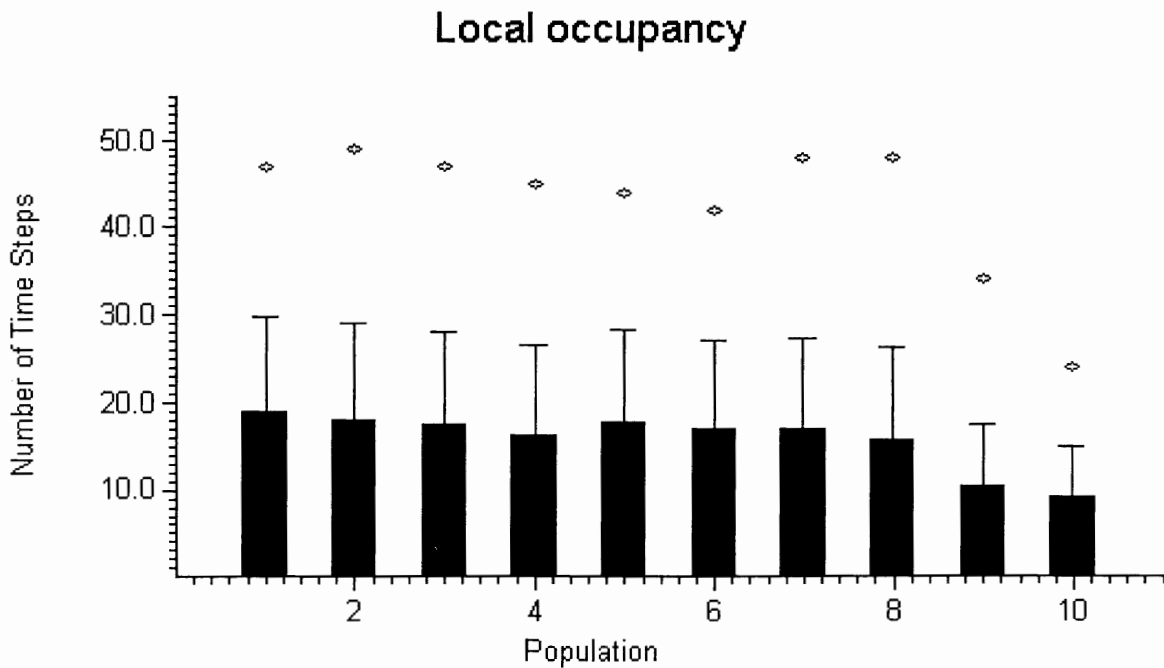


Figure 4. Statistical summary of the proportion of time that patches of *Ipomopsis sancti-spiritus* will remain occupied. The model used average matrices (indicated in Table 2) and assumed human-aided dispersal uphill to all transects. The average \pm 1 standard deviation, minimum and maximum number of years that each population has remained extant is indicated.

Median ~ 19.4

Time to extinction

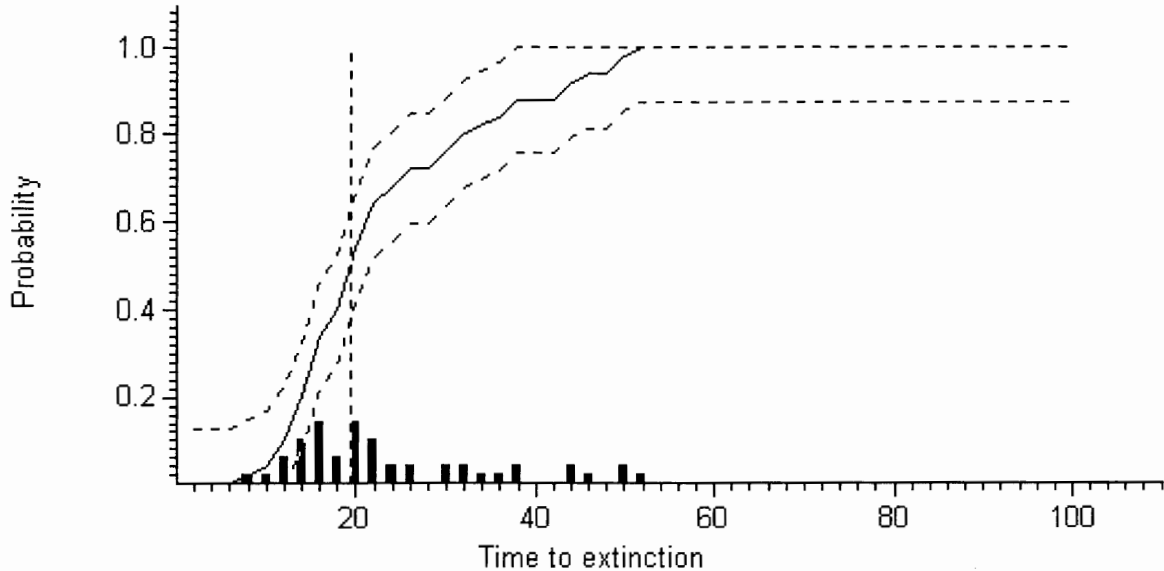


Figure 5. Time to extinction projected by the model using average matrices (indicated in Table 2) and assuming human-aided dispersal uphill to all transects. The dotted vertical line indicates that the median of the distribution is 19.4 years. The histogram shows the probability that the metapopulation size will fall below or increase above zero exactly at the time step. The continuous line is the cumulative probability distribution. It shows the probability of the metapopulation falling below zero at or before a specific year; after 52 years the probability of extinction is 1.0.

Metapopulation occupancy

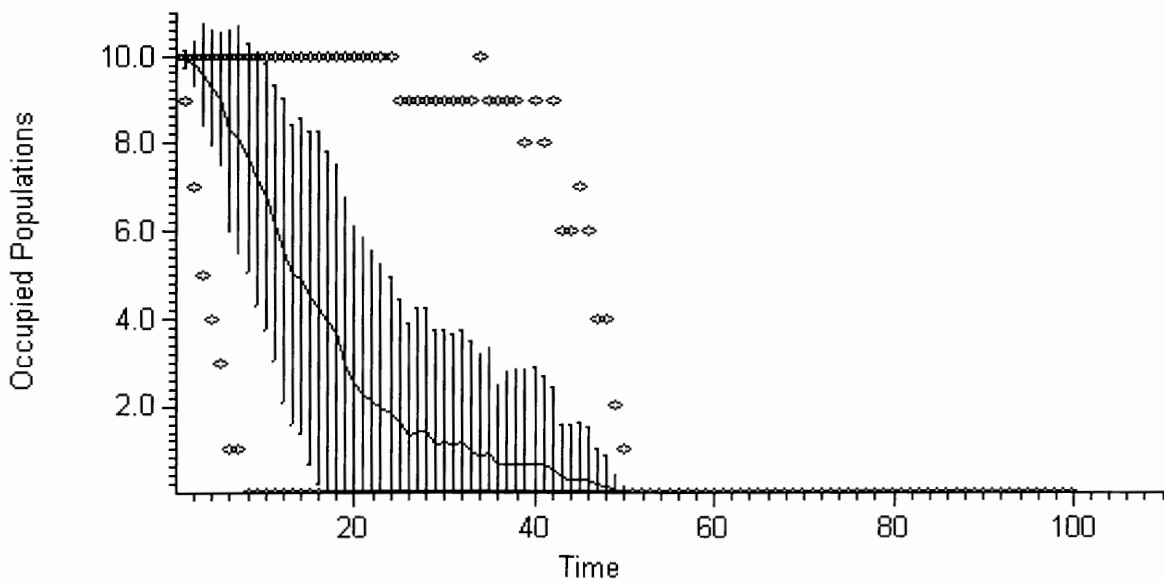


Figure 6. Statistical summary of the proportion of time that patches of *Ipomopsis sancti-spiritus* will remain occupied. The average ± 1 standard deviation, minimum and maximum number of years that each population has remained extant is indicated. The model used average matrices (see Table 2) and assumed human-aided dispersal uphill to all transects. Note the greater variance and range than in Figure 3.

long-term growth rates will require constant management and frequent supplementation to prevent their extinction. Because all populations are ultimately ephemeral, colonization processes must be preserved for any species to have a long-term future (Thrall et al. 2000). Colonization is naturally limited by the canyon topography; therefore any action that would increase options for dispersal and colonization would help preserve the species. This is supported by the metapopulation analysis, which indicated that species preservation would be favored with uphill dispersal. Therefore, a potential management strategy for conserving the species is to disperse seeds from transects 7, 8, 9, and 10 to uphill transects. However, there is a cost for dispersing seeds away from the "best" transects. The uphill dispersal model indicated that removing 45 percent of the seeds from transect 10 would decrease its longevity (Figure 4). A better option for preserving the Holy Ghost metapopulation would be to augment transects from *ex situ* seed sources, including the common garden currently being cultivated by Robert Sivinski, New Mexico Forestry and Resources Conservation Division, in Santa Fe, New Mexico.

A second management strategy is to increase light and decrease competition where *I. sancti-spiritus* grows. Although the amount of sunlight reaching the ground is constrained by topography in the upper canyon, selective timber harvest could open up canopies and favor *I. sancti-spiritus* establishment there. Manual exclusion of aggressive herbaceous competitors could also favor *I. sancti-spiritus* establishment throughout the canyon.

Even with these management actions, *I. sancti-spiritus* remains a species with a high risk of extinction in Holy Ghost Canyon. Recovery actions

underway to establish populations in new locations certainly are supported by these analyses.

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