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DEMOGRAPHIC MONITORING OF ASTRAGALUS SCAPHOIDES
AT TWO SITES IN MONTANA AND IDAHO
1992 Progress Report

Prepared for

USDI Bureau of Land Management
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INTRODUCTION

Passage of the Federal Endangered Species Act of 1973 and subsequent recognition of the value of conserving biotic diversity (Wilson 1988) have resulted in many government agencies becoming active in species conservation. Surveys to determine the location and size of populations of rare species are being conducted on public lands throughout the west. These surveys are necessary in any species conservation program; however, knowing the location and size of populations at any one point in time is only the first step in a long-term protection strategy (Sutter 1986). Extinction is a process requiring an understanding of population dynamics (Menges 1986). Periodic inventories can detect trends but will do little to determine causality or help generate predictive hypotheses (Palmer 1987). Long-term conservation requires a knowledge of many life history parameters including fecundity, recruitment, survivorship, age structure, and population flux. Demographic monitoring techniques can provide information on factors regulating population density and persistence (Palmer 1987). This information, in turn, provides an essential basis for management decisions.

Astragalus scaphoides (Jones) Rydb. (Bitterroot milkvetch) is endemic to a small area of east-central Idaho and adjacent Beaverhead County, Montana. It is a candidate for listing as a threatened or endangered species (C-2) by the U.S. Fish and Wildlife Service (USDI-FWS 1990). It is listed as sensitive in Idaho (Moseley and Groves 1990) and Montana (Lesica and Shelly 1991). Most populations of A. scaphoides in Montana are on public lands administered by the Bureau of Land Management and are subject to livestock grazing (Lesica and Elliott 1987).

Previous studies have indicated that inflorescence predation and seed predation by insects may be adversely affecting A. scaphoides fecundity (Lesica and Elliott 1987, 1989). Lowered fecundity is thought to be the cause of local rarity in a number of plant species (Greig-Smith and Sagar 1981, Hester and Mendelsohn 1987, Cabin et al. 1991). The purpose of this demographic monitoring study is to track population trends of Astragalus scaphoides in Montana and Idaho and gather life history information that will enable interpretation of these trends.

METHODS

Study Sites

The Sheep Corral Gulch population occurs in southern Beaverhead County, Montana on a gentle south-facing slope at 6,300 ft (T8S R12W S16). Mean July and January temperatures at Dillon, 20 miles to the northwest at 5,400 ft, are 66.2° and 20.1°F respectively. Mean annual precipitation is 9.5 in.

Vegetation is dominated by Artemisia tridentata and Agropyron spicatum. Aster scopulorum and Phlox hoodii are common forbs. The Haynes Creek population is in central Lemhi County, Idaho, approximately 30 miles west of Sheep Corral Gulch. It occurs on a moderate southeast-facing slope at 5,100 ft (T19N R23E S2). Mean July and January temperatures at Salmon, 15 miles northwest at 3,900 ft, are 61.3° and 19.8°F respectively. Mean annual precipitation is 9.93 in. Vegetation is dominated by Artemisia tridentata, Agropyron spicatum and Bromus tectorum.

Field Methods

Two permanent monitoring transects were subjectively located at each of the study sites in early July, 1986 following methods outlined in Lesica (1987). At each site the transects were parallel to each other and the slope and separated by ca. 30 ft. Procedures for reading the monitoring transects are outlined in Lesica and Elliott (1987) and Lesica (1987). Each transect consisted of 50 1-m² quadrats placed along the transect line. The position of each A. scaphoides plant encountered in the quadrats was mapped and classified for three traits: size, inflorescence production, and fecundity. The classification system and codes for these traits are as follows:

1) Size Classes:

- S Very small plants with 1-3 leaves
- J Plants with 4-6 leaves
- M Plants with more than 6 leaves

Plants that produced inflorescences were classified by the fate of the individual inflorescences as follows:

2) Inflorescence Production:

- A An inflorescence that produced no fruit
- P An inflorescence that was removed by predation
- I An inflorescence that produced at least one mature fruit

3) Fecundity: the total number of mature fruit

Plants that produced inflorescences were classified by using combinations of the classifiers followed by numerics. For example, a mature plant with 2 aborted inflorescences, 1 predated inflorescence, and 3 fruit-bearing inflorescences with 10 fruits would be recorded as A2-P1-I3-F10. A complete record of all plants recorded during the study is given in Appendix A. For the purpose of analysis "S" and "J" plants constitute a small size class, sterile "M" plants form the sterile size class, and all reproductive plants form the third size class. Transects were read on July 1-7, 1986-1992.

I found that some plants would go undetected for one to several years but reappear in subsequent years. These "underground" plants may have produced small leaves that had senesced and disappeared by early July; however, my observations in May and June suggest that most of them produced no vegetation on the years in question. The presence of underground plants can be inferred by comparing transect maps from the full sequence of years. Underground plants were placed in the small size class for analysis. The proportion of underground plants ranged from 1-23% with a mean of 10% in 1987-91. Plants have "disappeared" for as many as five years before reappearing. However, in 1986-92 at the two sites, 71% of the underground plants reappeared after one year, and 88% reappeared after two years. As a result, ca. 10% of the plants were undetected in the first and last of years of the study, 3% were undetected in second and second from last years, and ca. 1% were undetected on other years. Thus, I have chosen to eliminate the first and last years of the study from demographic analysis.

On years when fruit production was adequate, I collected 50 randomly selected mature fruits from at least 25 plants. I opened the pods, counted the intact seeds, and recorded whether the fruit contained weevil larvae.

Data Analysis

Population growth for year t is the percent change in the size of the sample population between year $t-1$ and year t . It is calculated by $PG = (N_t - N_{t-1})/N_{t-1}$. Mortality rate is the ratio of the number of plants dying between years $t-1$ and t to the number surviving in the same period. Recruitment rate is defined as the ratio of new plants observed in year t to the number of plants surviving from year $t-1$ to year t .

I compared survival rates of uneven-age cohorts present at the start of the study between the sites using the nonparametric logrank test (Pyke and Thompson 1986, Hutchings et al. 1991). Survivorship curves were constructed following methods outlined in Hutchings et al. (1991).

Fecundity is the number of fruits per plant. The effects of site and year on fecundity were analyzed using analysis of variance (ANOVA). The interaction term was not significant ($F=0.7$, $P=0.56$) and was deleted from the final model. The dependent variable was log-transformed before analysis to conform to the assumptions of the test.

I used correlation analysis to explore relationships between climate variables and *Astragalus scaphoides* mortality, recruitment and proportion of reproductive plants at Sheep Corral Gulch. Climate data are from Dillon, the closest recording station. Mean monthly deviation from the 30-year normal for

temperature and precipitation were calculated for each year up to and including the spring when demography data were collected (data from National Oceanic and Atmospheric Administration). Take 1991 for example, summer included June, July and August, 1990; fall included September, October and November, 1990; winter included December, 1990 and January and February, 1991; and spring included March, April and May, 1991. Entries for each site and each year were used in the analyses. These analyses have small sample sizes, and the results must be viewed as tentative.

I also used correlation analysis to explore the relationships between the proportions of aborted, predated and fecund inflorescences and the total number of inflorescences produced. In order to use both sites in the same analysis, I relativized the variables at each site to the site means. Probability values were not corrected for multiple tests.

I surveyed a large Astragalus scaphoides population at Hayden Creek, Idaho in late May, 1990 for inflorescence predators. Insects observed girdling stems were collected and sent to the Montana State Entomology Lab in Bozeman for identification.

RESULTS

Population Growth

The number of Astragalus scaphoides plants in the monitoring transects increased in 1987-91 at both sites (Fig. 1). The increase was small at Haynes Creek but more appreciable at Sheep Corral Gulch. At both sites population growth rate was negative in only one year out of four (Fig. 2): 1988 at Sheep Corral Gulch and 1990 at Haynes Creek. In 1988 the Haynes Creek population displayed the highest population growth, while the Sheep Corral Gulch population had its lowest growth during the recording period. Trends in population growth were similar at the two sites for the other three years of the study (Fig. 2).

Survivorship

Survivorship curves of the 1986 uneven-age Astragalus scaphoides cohort were similar in shape for the two populations (Fig. 3). Mortality was higher during the first 1-2 years and then leveled off to a gradual, even rate. The Haynes Creek survivorship curve is steeper than at Sheep Corral Gulch, and this difference is significant (log-rank test; $LR=5.45$, $P=0.02$). The curves suggest that the majority of A. scaphoides plants live to be greater than six years old.

Mortality rate ranged from 5-22% at the two sites and was somewhat higher at Haynes Creek when all four years are taken together (Fig. 4). However, the temporal pattern of mortality

Figure 1. Number of Astragalus scaphoides plants in three size classes at two study sites in 1987-91.

Sheep Corral Gulch

Haynes Creek

Figure 2. Growth rate of Astragalus scaphoides populations in 1988-91 at two study sites.

Figure 3. Percent of Astragalus scaphoides plants in the 1986 uneven-age cohort surviving from 1986-91.

was exactly opposite at the two sites. 1987-88 and 1990-91 were the years of highest mortality at Sheep Corral Gulch, but mortality was lowest in these years at Haynes Creek (Fig. 4).

Recruitment

Astragalus scaphoides recruitment rate ranged from 6-59% and was similar at the two sites when all four years are taken together (Fig. 5). Recruitment at Haynes Creek was highest in 1987-88, but was lowest at Sheep Corral Gulch in this same year. During the last three years of the study the pattern of recruitment rate was similar at the two sites with slightly higher values at Sheep Corral Gulch (Fig. 5).

Reproduction

Reproductive effort of Astragalus scaphoides varied among years and between the two sites (Figs. 1,6). At Sheep Corral Gulch flower and fruit production was strong in 1986, 1989 and 1991 and was virtually nonexistent in the other four years. At Haynes Creek appreciable flower and fruit production occurred in 1986, 1988, 1990 and 1991. The proportion of reproductive plants ranged from 0-36% and was higher at Haynes Creek all seven years of the study (paired-sample t -test; $t=5.72$, $P=0.001$).

Number of fruits per reproductive plant varied among years and sites (Table 1). Number of fruits per plant did not differ significantly between the two sites but did vary significantly among years.

Mean number of seeds per unpredated Astragalus scaphoides fruit ranged from 9.4 to 16.2. There was a small tendency for the Sheep Corral Gulch population to have higher seed production (Table 2). Weevils in the Family Curculionidae damaged 0-38% of the mature fruits (Lesica and Elliott 1987), and damaged fruits had 64-86% fewer seeds (Table 2).

Predation of whole inflorescences was typical at both sites. Although a small proportion of this predation may be due to vertebrate herbivores such as rabbits, deer or livestock, my observations indicate that most inflorescence predation is due to ants (Subfamily Formicinae) and moth larvae (Melacosoma spp., Family Lasiocampidae). Predation of inflorescences ranged from 8-49% of the total number present before abortion (Fig. 6, Table 3). Weevils reduced seed production of matured fruits by 0-33% (Table 3). Total reductions in fecundity due to both types of predation was 16-65%, and mean reduction was 42%.

The proportion of aborted inflorescences ranged from 15% to 92% at the two sites (Fig. 6). In years with greater production of inflorescences, a higher proportion of the inflorescences were fecund (Table 4). As the total number of inflorescences and the

Figure 4. Rate of mortality in two Astragalus scaphoides populations in 1988-91.

Figure 5. Rate of recruitment in two Astragalus scaphoides populations in 1988-91.

Figure 6. Number of fecund, predated and aborted Astragalus scaphoides inflorescences at two study sites in 1986-92.

Table 1. Effect of site and year on fecundity of Astragalus scaphoides measured as fruits per reproductive plant by ANOVA. Dependent variables were log-transformed for analysis. Only 1986, 1989, 1990 and 1991 were used in the analysis.

	Fruits/Reproductive Plant				
	1986	1988	1989	1990	1991
Sheep Corral	12.7 $\pm$ 2.3	--	7.2 $\pm$ 2.1	2.0 $\pm$ 0.0	10.6 $\pm$ 1.3
Haynes Creek	9.3 $\pm$ 1.4	10.9 $\pm$ 1.9	4.0 $\pm$ 0.0	14.0 $\pm$ 5.9	14.4 $\pm$ 2.1

Source	df	MS	F	P
Site	1	1.07	1.18	0.280
Year	3	2.38	2.62	0.053
Error	132	0.91		

Table 2. Number of seeds per fruit ($\pm$ SE) and proportions of fruits predated for Astragalus scaphoides at two study sites. Sample sizes are given in parentheses.

	Seeds/Unpredated Fruit				
	1986	1988	1989	1990	1991
Sheep Corral	15.0 $\pm$ 0.9 (34)	--	16.2 $\pm$ 1.0 (31)	--	15.0 $\pm$ 1.1 (31)
Haynes Creek	14.4 $\pm$ 0.6 (48)	14.0 $\pm$ 1.0 (36)	9.4 $\pm$ 1.5 (21)	15.9 $\pm$ 1.2 (33)	12.2 $\pm$ 0.6 (44)
	Seeds/Predated Fruit				
	1986	1988	1989	1990	1991
Sheep Corral	3.6 $\pm$ 1.1 (16)	--	2.2 $\pm$ 0.8 (19)	--	-- (0)
Haynes Creek	4.0 $\pm$ 2.8 (2)	3.2 $\pm$ 1.3 (14)	3.3 $\pm$ 0.9 (6)	4.6 $\pm$ 1.1 (17)	3.8 $\pm$ 2.2 (6)
	Percent Predated Fruit				
	1986	1988	1989	1990	1991
Sheep Corral	32%	--	38%	--	0%
Haynes Creek	4%	28%	22%	34%	12%

Table 3. Reduction in seed crop due to predation of inflorescences and seeds and total reduction due to both types of predation together.

Sheep Corral Gulch			
	Inflorescence Predation	Seed Predation	Total Predation
1986	23%	24%	41%
1989	33%	33%	65%
1991	19%	0%	19%

Haynes Creek			
	Inflorescence Predation	Seed Predation	Total Predation
1986	46%	3%	48%
1988	49%	22%	60%
1989	38%	14%	47%
1990	15%	24%	35%
1991	8%	8%	16%

Table 4. Pearson correlation coefficients for relationships among proportions of aborted, predated and fecund inflorescences and total number of inflorescences. Probability values (* <0.05, ** <0.01) are not adjusted for multiple tests.

	Predated Inflors.	Fecund Inflors.	Total Inflors.
Aborted Inflors.	-0.49	-0.79*	-0.87**
Predated Inflors.		-0.15	0.21
Fecund Inflors.			0.84**

proportion of fecund inflorescences increased, the proportion of aborted inflorescences decreased (Table 4). There was a weak negative correlation between proportion of inflorescences that were aborted and those that were predated (Table 4). There was no correlation between proportion of predated inflorescences and proportion of fecund inflorescences or total inflorescences (Table 4).

Climate and Life History

Increased mortality of Astragalus scaphoides was associated with low fall and winter precipitation, low summer temperatures, high spring and summer precipitation, and high fall temperatures. High recruitment was associated with high fall temperatures, low spring temperatures and low summer precipitation. Proportion of reproductive plants was negatively correlated with spring and summer precipitation.

DISCUSSION

Astragalus scaphoides is a long-lived perennial with a cohort half-life of approximately six years. Mortality is relatively high during the first two years and is lower afterwards. Extrapolation of the survivorship curve suggests that approximately one-third of the plants at Sheep Corral Gulch live to be 14 years old. Life expectancy at Haynes Creek is somewhat lower.

Results of the study indicate that the two populations were stable or increasing in size during the past seven years. Mortality and recruitment were highly variable among years, and patterns of mortality and recruitment were only partly congruent between the two sites. These observations suggest that mortality and recruitment are dependent on yearly climatic fluctuations. Indeed, mortality was negatively correlated with fall and winter precipitation, and recruitment was associated with warm fall temperatures. These correlations are based on very small sample sizes and must be viewed as tentative. Data acquired in future years should help elucidate the relationships between climate and life history parameters.

Number of fruits per reproductive plant did not differ significantly between the two sites; however, the proportion of reproductive plants was higher and less sporadic at Haynes Creek than at Sheep Corral Gulch.

Reduction in reproductive effort due to inflorescence and seed predation was high, averaging 42% at both sites. Although reduced fecundity can have adverse effects on plant populations (Greig-Smith and Sagar 1981, Hester and Mendelsohn 1987, Cabin et al. 1991), population sizes were stable or increased during this study. Nonetheless, such high levels of predation could

adversely affect population persistence if they were coupled with other environmental challenges such as pollinator limitation or climatic stress.

The strong positive correlation between the proportion of fecund inflorescences and total inflorescences and the strong negative correlation between proportion of aborted inflorescences and total inflorescences suggests two possible hypotheses:

(1) Pollinator limitation. In years when fewer inflorescences are produced, pollinators are less attracted to A. scaphoides resulting in lower levels of pollination, a lower proportion of fecund inflorescences, and a higher proportion of aborted inflorescences (Heinrich 1975).

(2) Resource limitation. In years with suboptimal growing conditions (e.g., low soil moisture), fewer inflorescences are produced, and a higher proportion of these are aborted (Ehrlén 1992, Harper and Wallace 1987, Stephenson 1981).

The negative correlation between proportion of fecund inflorescences and aborted inflorescences is consistent with both hypotheses. These two hypotheses are not mutually exclusive (Vaughton 1991).

Under the pollinator limitation hypothesis, a reduction in total flowering inflorescences decreases pollination, thus increasing the proportion of aborted inflorescences. Predation reduces the number of flowering inflorescences; thus, the pollinator limitation hypothesis predicts a positive correlation between predation and abortion. If abortion is primarily the result of resource limitation, removal of inflorescences by predation should lower abortion levels. Consequently, the resource limitation hypothesis predicts a negative correlation between abortion and predation.

The observed negative correlation between proportion of aborted and predated inflorescences indicates that abortion is caused primarily by resource limitation. Furthermore, these results and the generally high annual levels of abortion suggest that Astragalus scaphoides plants frequently initiate more inflorescence than they have resources to mature. This behavior may be the result of selection imposed by predation. A plant that initiates more inflorescences than it can mature can lose preflowering inflorescences to predation without sacrificing reproductive output. If predation is low, the surplus inflorescences are aborted. Thus, inflorescence predation can be at least partly compensated for lower levels of abortion.

Population persistence is determined by an interplay of mortality, reproduction and recruitment. Monitoring Astragalus scaphoides has shown that these critical demographic parameters

are affected by climate and predation. It appears that A. scaphoides is able to persist with current levels of predation and under the present climatic regime.

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