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Astragalus tyghensis: Actual vs. predicted population sizes

Final Report
2008

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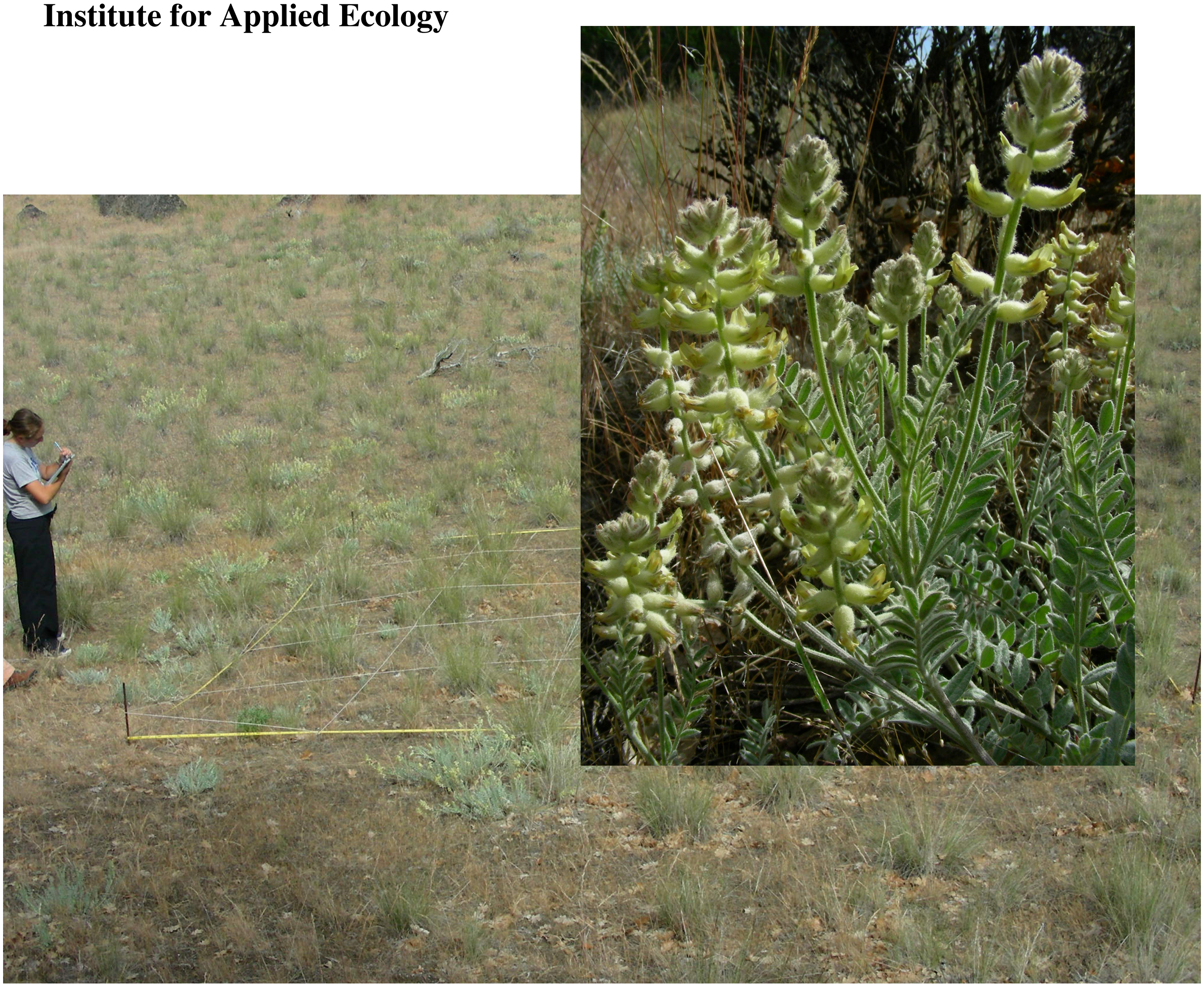

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PREFACE

This report is the result of a cooperative Challenge Cost Share project between the Institute for Applied Ecology (IAE) and a federal agency. IAE is a non-profit organization dedicated to natural resource con-servation, research, and education. Our aim is to provide a service to public and private agencies and individuals by developing and communicating information on ecosystems, species, and effective management strategies and by conducting research, monitoring, and experiments. IAE offers educational opportunities through 3-4 month internships. Our current activities are concentrated on rare and endangered plants and invasive species.

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Cover photograph: Tygh valley milkvetch (*Astragalus tyghensis*) and monitoring plot. Photos by T.N. Kaye.

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Background

Figure 1. *Astragalus tyghensis*

Astragalus tyghensis (Figure 1) is considered a Species of Concern (formerly a candidate [category 2] for threatened or endangered species listing) by the USFWS. It is listed as Threatened by the state of Oregon and Threatened or Endangered Throughout Range (List 1) by the Oregon Natural Heritage Program (ORNHIC, 2004). It is on the Bureau of Land Management Special Status Species List. A 1990 study (Kaye et al., 1990) documented the abundance of the species on public and private lands in Oregon. Despite the improvement in our knowledge of the species' distribution, it remains rare and restricted to a relatively small area of Wasco County, Oregon. Analysis of aerial photographs shows that the habitat of the species has declined markedly since the area was settled and land was converted to range and cultivation (Kaye et al., 1990). The studies described here help assess the predictive power of population models for this species, as well as the health and long-term trends of individual populations.

Long-term monitoring for *Astragalus tyghensis* (Tygh Valley milkvetch) was conducted annually between 1991 and 2000 (Carlson and Kaye, 2001). This work lead to descriptions of the species' life-history, its long-term trends at five sites, and the development of computer models of population behavior based on demographic processes. These models were used to project population sizes through time and assess population viability. Until 2006, no follow up monitoring of the species was conducted. In this report, we detail the results of monitoring *Astragalus tyghensis* (Tygh Valley milkvetch) on Bureau of Land Management (BLM) and state land in 2006 – 2008 and compare these data to predictions from the population models created using the data from 1991–2000.

Reproductive biology

Astragalus tyghensis is perennial, blooms from May to early July, and reproduces from seed. It is unlikely that individuals reproduce vegetatively as this is uncommon within the genus, and excavated root systems rarely connected aboveground plants (Kaye et al., 1990; Kaye and Brady, 1991). Seed production in this species requires insect pollinators. Bagged inflorescences produce one-tenth the seeds/fruit of open-pollinated inflorescences. Pollination is accomplished by a diversity of solitary bees, primarily *Megachile* spp. and *Osmia* spp. (Kaye et al., 1990; Kaye and Brady, 1991). Insect visitors of *A. tyghensis* flowers are moderately abundant and diverse, possibly buffering the species from natural swings in the population size of any one pollinator group. However, in the event that the local use of pesticides damages native insect populations, many or all of the observed pollinators could be affected, resulting in a one year (or more) decrease in *A. tyghensis* seed production. In 1991, seed predation in *A. tyghensis* populations ranged between 2.3 percent and 18.6 percent on average. This is well below predation rates observed in other species of *Astragalus* in North America (Green and Palmblad, 1975; Youtie and Miller, 1986; Kaye 1990), which are often above 70 percent. Therefore, although predispersal seed predation occurs in *A. tyghensis*, it is relatively low and does not appear to be a significant threat to seed production. The fruits of *A. tyghensis* are passively dispersed near the parent plant. The primary dispersule is the fruit itself, because the fruits are indehiscent (most *Astragalus* species dehisce along the suture). Fruits contain 0-2 seeds each, with seed number apparently limited by the size of the fruit; the fruits are bilocular, and each chamber has the space to mature only one seed. Each fruit contains eight ovules, however, and theoretically has the potential to produce eight seeds. Apparently, a fixed rate of abortion limits seed production to no more than two per fruit, a situation similar to *Cryptantha flava*, which commonly aborts three of four nutlets, thus making the calyx with single nutlet the primary dispersal unit (Casper and Wiens, 1981). The selective advantages of this system may be to improve dispersal distance by reducing the total mass of the dispersule, provide opportunity for selection at the zygote level, and reduce sibling competition resulting from the germination of several seeds from a single dispersule at one location (Casper and Wiens, 1981). Seeds of *A. tyghensis* have at least 80 percent viability (Kaye, unpublished data), and germinate after dormancy is broken by scarification. The timing of seed germination is still unknown, but appears to be in winter or early spring.

Objectives

The goals of this cooperative project were to:

1. Re-sample permanent monitoring plots at five sites (four BLM and one State of Oregon) to determine current population status.
2. Compare current population size and structure to projections of computer models developed using population data collected form 1990–2000.

METHODS

Population monitoring

In 1991, we established 15 permanent monitoring plots at five sites to obtain baseline data on populations of *A. tyghensis* for future determination of population trends. We refer to these populations by the site numbers assigned to them in a 1990 report (Kaye et al., 1990). Monitored populations are at sites 4, 10, 13, 25, and 41 (Table 1). See previous progress reports for complete information on these sites including topographic maps and sketch maps detailing plot locations (e.g., Kaye and Brady, 1991).

Table 1. Populations of *Astragalus tyghensis* monitored since 1991. Site numbers and population size estimates are the same as those assigned in 1990.

Site#	Location	TRS	Approximate size (#plants)	Ownership	# plots
4	White R. Road, Graveyard Butte Crossing (S side)	*this information removed from public versions of this report*	~600	BLM	2
10	White R. Road, Graveyard Butte Crossing (N side)		1000-1300	BLM	4
13	0.75 mi SW of Graveyard Butte Crossing, rimrock		100-1000	BLM	3
25	1.0 air mi. S of Tygh Valley		2000	BLM	3
41	Tygh Valley State Wayside		189	State Parks	3

Plot design and sampling procedure

All permanent plots were 5 x 5 m square, marked in each corner with a 1 m piece of iron rebar protruding at least 30 cm from the soil. The upper left corner-rebar of each plot (facing upslope) was labeled with an aluminum tag noting plot number.

To sample, each side of the plot was marked temporarily at 1 m intervals with nails, and string was tossed back and forth over the plot (looped each time around a nail) to create a grid of 1 x 1 m subplots within the 5 x 5 m macroplot (Figure 2). The location of each *Astragalus tyghensis* individual in every subplot was mapped and numbered on map sheets designed especially for this project. A dot and a corresponding plant number were placed on the map sheets to mark the position of each plant. In some cases, it was difficult to determine whether tufts of plants were clusters of individuals, a single plant that had branched below the soil surface, or a combination of these. In these cases, the loose soil was gently excavated and probed with fingers to check for root connections. On a separate data sheet, we noted diameter (cm), length of longest stem (cm), number of inflorescences, and evidence of grazing (yes or no) of each mapped and numbered plant[1].

1 The original field data are on file at Oregon Department of Agricutlure.

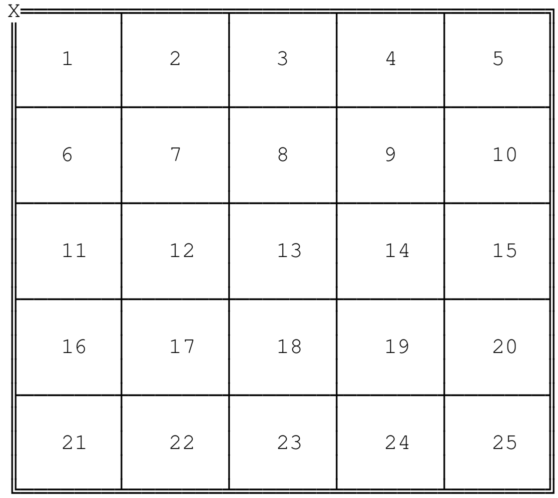

Figure 2. Layout of a 5 x 5 m macroplot containing twenty-five 1 x 1 m subplots. The upper left hand corner-rebar (facing uphill) of each macroplot was marked with an aluminum tag (X) noting plot number. Subplots were numbered 1-25 in five rows of five.

The matrix model of population dynamics

Population model -- Populations from each study site were modeled with a transition matrix approach. This type of model is based on the reproduction and survival of individuals. For the purposes of the model, the individuals in a population are divided into categories (stages) based on age (for seedlings only) and size. Then, the number of seedlings produced per plant in each category is determined, and the probability that an individual will survive in the same stage or make the transition from its current category to another must be calculated. The "transition probabilities" are merely the proportion of individuals in each stage that "make the transition" to another stage (e.g., become smaller or larger) from one year to the next. Figure 3 is a life-cycle graph for *A. tyghensis* with five life-history stages: seedling (I), longest stem <10 cm (II), 10-20 cm (III), 20-30 cm (IV), and >30 cm (V). These stages were defined subjectively after displaying the size data graphically in several different ways. The arrows indicate the possible transitions (or fecundities) that plants in each category can make as one year passes. Note that seedlings can become stage II or III plants, but not IV or V, apparently because they are not able to grow that large in a single year.

Below is an example of a stage-classified transition matrix based on the life-history graph, and a population vector, which contains the number of plants in each category. The matrix contains five categories (I through V). Plants in each category can make the transition from their current condition to the same or another class the following year.

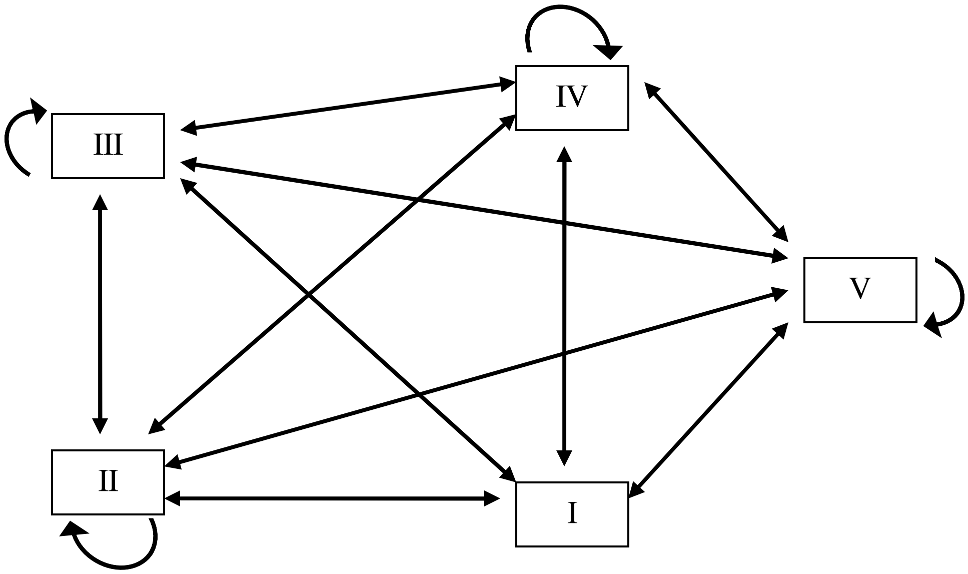

Figure 3. Life-cycle graph of *Astragalus tyghensis*. **I** indicates seedlings and **II-V** are size categories. Each arrow represents a possible transition (or reproduction) pathway from one year to the next. Curved arrows allow for plants to remain in the same stage.

Transition matrix (A):	I	II	III	IV	V	*Population vector (n):*
I	--	F_{II-I}	F_{III-I}	F_{IV-I}	F_{V-I}	n_I
II	G_{I-II}	P_{II-II}	G_{III-II}	G_{IV-II}	G_{V-II}	n_{II}
III	G_{I-III}	G_{II-III}	$P_{III-III}$	G_{IV-III}	G_{V-III}	n_{III}
IV	--	G_{II-IV}	G_{III-IV}	P_{IV-IV}	G_{V-IV}	n_{IV}
V	--	G_{II-V}	G_{III-V}	G_{IV-V}	P_{V-V}	n_V

In this transition matrix (A), the number of seedlings produced per year per individual (fertility) in each category is represented by **F** in the top row. The probability that a plant in a particular category will persist in the same category the following year is indicated by **P**; these probabilities are found along the diagonal of the matrix. Finally, plants have a probability **G** of growing into a new category the following year. For example, plants in category III produce F_{III-I} seedlings per year, they have a probability $P_{III-III}$ of remaining in category III, and probabilities G_{III-II}, G_{III-IV}, and G_{III-V} of making the transition to category II, IV, or V, respectively. Notice that plants can regress from a larger category to a smaller one, and that small plants can grow to larger plants more than one size class above them. This type of matrix is a Lefkovitch matrix (Lefkovitch, 1965), which is a generalization of an age-based (or Leslie) matrix (Leslie, 1945). For plants, the age of an individual is often difficult to determine or not very meaningful. For example, many herbaceous perennials do not form annual growth rings the way trees do, and even if they did, age does not necessarily relate to a plant's size or ability to reproduce. Moreover, techniques for aging plants may require the destruction of the plants, a process that is clearly inappropriate for rare plants. Instead, most models of plant populations place individuals into size or stage classes, or a combination of the two, as was done here.

The number of individuals in each category $\mathbf{n_i}$ is found in the population vector (n). The transition matrix is post-multiplied by this population vector to project the total population in time. Each time the model is iterated in this way, a single time step (one year) is completed.

Analysis -- For each of the five populations included in our study, we constructed a series of transition matrices, one for each pair of years that observations were made (e.g., 1991-92, 1992-93, etc.). We included environmental variability in our model through the matrix selection method. Matrix selection was accomplished by selecting a whole matrix at each time step, selected at random and with equal probability from the matrices available since demographic monitoring began in 1991. The matrices represent each year of growth between 1991 and 2000, and the variation among them is considered to be environmental stochasticity. All simulations ran for 17 years and consisted of 10,000 iterations. The starting population size for each was arbitrarily set at the observed values in 1991 (number of plants in all plots combined for each site), and the proportion of plants in each stage was determined using the average 1991-2000 population structure. Projections through time started in 1991 and ended in 2008, and estimates were made within ± 1 standard deviation (STD). Population projections were implemented with the program SHUFFLE (Kaye, unpublished program) using the software MATLAB. We compared actual and projected population sizes in 2006 and 2007 by displaying population trends graphically.

Assumptions of the model **--** Our use of the transition matrix model assumed that fertility and transition rates were independent of plant density. This is an acceptable assumption for many species with population densities below the density-dependent threshold (density-vague populations). However, density dependence eventually limits growth of populations with lambda greater than one. Demographic stochasticity was also ignored by our models, but it usually generates little variation in population dynamics relative to environmental stochasticity, except at very low population sizes (Menges 1992). Our model assumed that population growth is a first-order Markov process, in which the probability that a plant will make a transition is independent of its stage in the previous year. Finally, we assume that no persistent soil seed bank exists for this species, or, if it does, that seed input and output from the seed bank is the same within each year.

RESULTS AND DISCUSSION

Population monitoring: summary and trends

Population sizes at five sites in 2008 – When viewed graphically, sites 10, 25 and 41 appear to be relatively stable while sites 4 and 13 appear to be in decline (Figure 4). In 2006 - 2008, there were substantially fewer plants at sites 4 and 13 compared to any of the years 1991–2001 (Table 2). The size of the population at site 41 increased from 2007, but remains lower than the long-term average (Table 2). Population 10 increased by 41% from 2007 to 2008. Population 25, which had more than doubled in size from 2006 – 2007 declined in 2008 to near it's long-term average. As in previous years, much of the variability between sites and years appears to be driven by the abundance of seedlings (Table 3). The number of seedlings per population has historically been quite variable between both plots and years (Carlson and Kaye 2001). Years with high seedling numbers were generally followed by high numbers of non-seedling plants the next year. Conversely, low seedling-years were usually followed by declines in non-seedling plants.

There were differences among sites in reproductive plant diameter, length of longest stem, inflorescence number, and number of seeds per plant during each year of the study (Table 3). As in the previous two years, the largest plants (both diameter and length of longest stem) were found at site 13. The number of inflorescences per plant has declined since 2006, from an average of 12 in 2006, to 4 in 2007, and 1.6 in 2008.

The structure of *A. tyghenssis* populations was generally skewed toward smaller plants in all years and at all sites (Figure 5). We define structure as the relative number of individuals in each of the five stages identified for the matrix model. Populations were dominated by plants in the first three size classes (less than 20 cm). The abundance of seedlings at sites 10 and 25 suggests that recruitment of new individuals continues to be frequent. Initially, the population at site 41 showed rapid growth and a shift toward larger plants after it was protected from grazing. However, as mentioned before, this population now appears to be declining and shows poor recruitment of younger individuals.

Grazed vs. ungrazed plots at Site 10 **--** Evaluating the effects of grazing on *A. tyghensis* was not a primary objective of this project, but at site 10, two of the plots were situated so that grazing could be evaluated (without replication). Plot 3 was located on the non-grazed side of a fence, while plot 4 was placed directly across the fence on the grazed side. In previous years, there was little yearly variation in the number of plants in plot 4. However, in 2008, the number of plants in plot 4 more than tripled, from 23 to 83. The majority of these plants were small and not reproductive. In contrast, there was little change in the number of plants in plot 3 (24 in 2007, 20 in 2008), but these plants were fairly large and, on average, produced 9.5 inflorescences per plant (Table 4). These results were similar to those reported previously (Carlson and Kaye 2000; Kaye and Thorpe 2006, 2007), when plants in the grazed plot were smaller, produced fewer seeds, and had a lower population growth rate than those in the ungrazed plot.

Table 2. The total number of *A. tyghensis* plants in permanent monitoring plots from 1991–2000, 2006-2008.

Site	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Average '91-'00	2006	2007	2008
4	184	186	201	156	128	119	135	129	121	112	151	77	73	73
10	155	329	242	229	258	236	320	293	370	399	270	257	258	364
13	451	858	1132	681	1246	771	830	851	716	481	837	299	259	221
25	355	617	695	485	555	470	446	415	353	513	488	362	788	430
41	100	153	200	156	161	152	157	148	89	87	146	130	103	117

Table 3. Summary of population totals, density, and mean reproductive plant size variables obtained from monitoring plots at five study sites in 2008.

Site	Total Plants	# (%) Seedlings	# Non-seedlings	diameter (cm)	longest stem (cm)	inflorescences (total)	inflo. (#)/plant
4	73	15 (21%)	58	10.9	9.6	88	1.2
10	364	123 (34%)	241	5.2	5.9	350	1.0
13	221	40 (18)	181	12.8	11.6	643	2.9
25	430	152 (35%)	278	9.0	7.7	674	1.6
41	117	18 (15%)	99	10.2	7.7	170	1.5
Total	**1205**	**348**	**857**			**1925**	
Average				**9.6**	**8.5**		**1.6**

Table 4. The number of plants and plant characteristics of paired plots 3 (exclosed/ungrazed) and 4 (not-exclosed/grazed) at site 10 in 2008.
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Plot	Total Plants	# Seedlings	# Non-seedlings	diameter (cm)	longest stem (cm)	Inflorescences/ plant
3 (exclosed)	20	0	20	19.3	15.0	9.5
4 (not-exclosed)	83	25	58	3.7	4.5	0.02

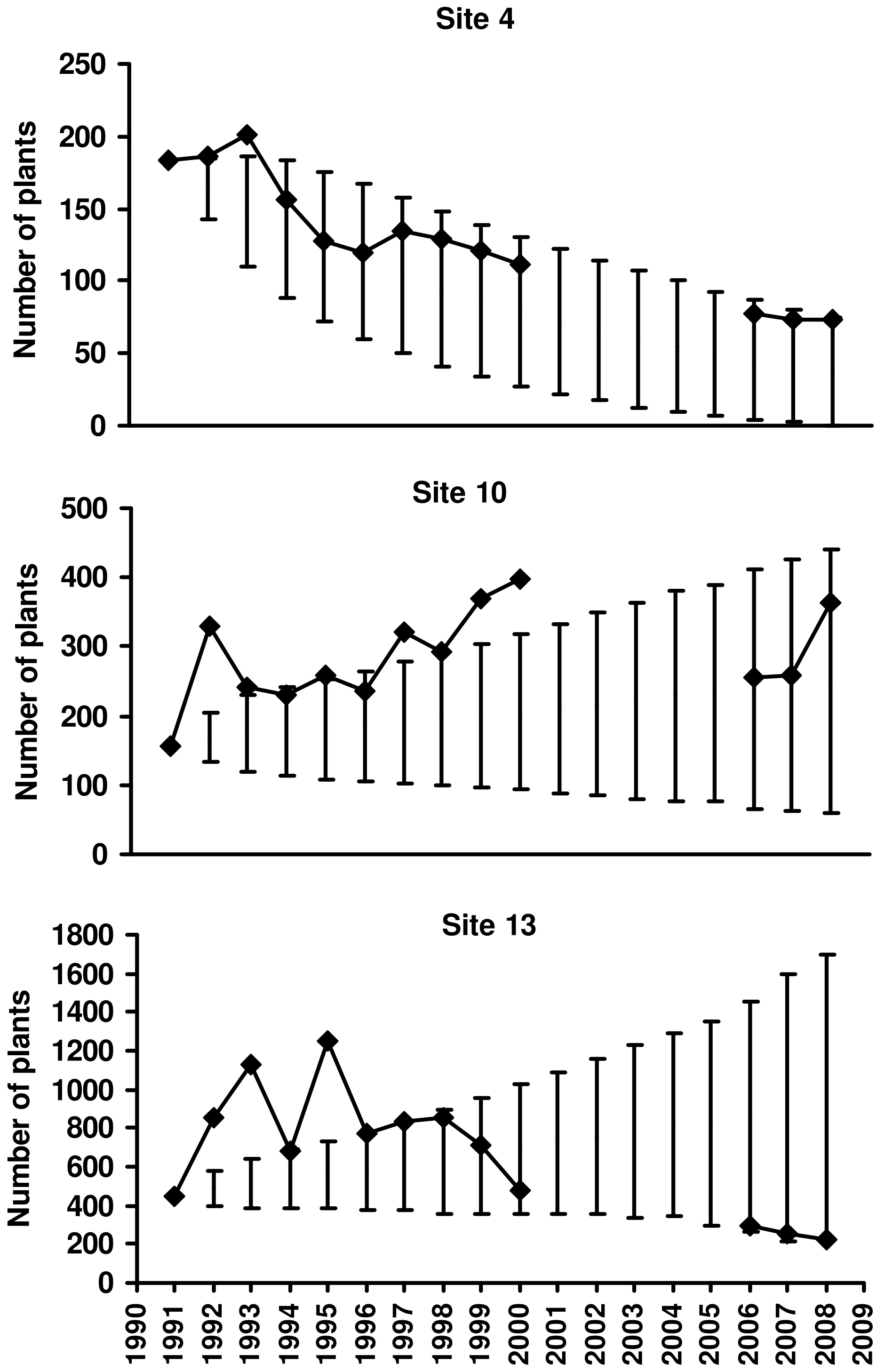

Figure 4. Observed population size (black diamonds) from 1990–2000, 2006-2008, and the projected population size (± 1 SD, bars) for *Astragalus tyghensis* in permanent monitoring plots located at five sites.

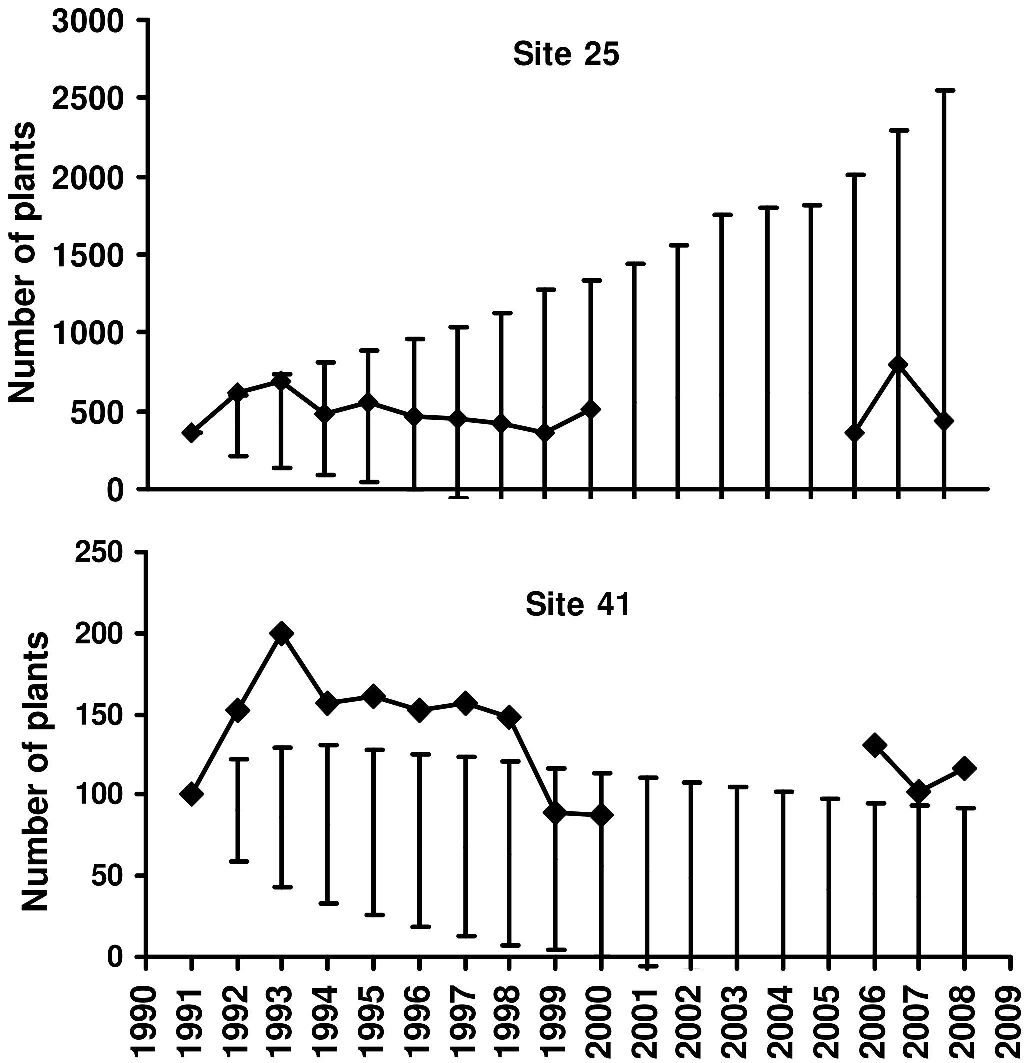

Figure 4, continued. Observed population size (black diamonds) from 1990–2000, 2006-2008, and the projected population size (± 1 S.D.) for *Astragalus tyghensis* in permanent monitoring plots located at five sites.

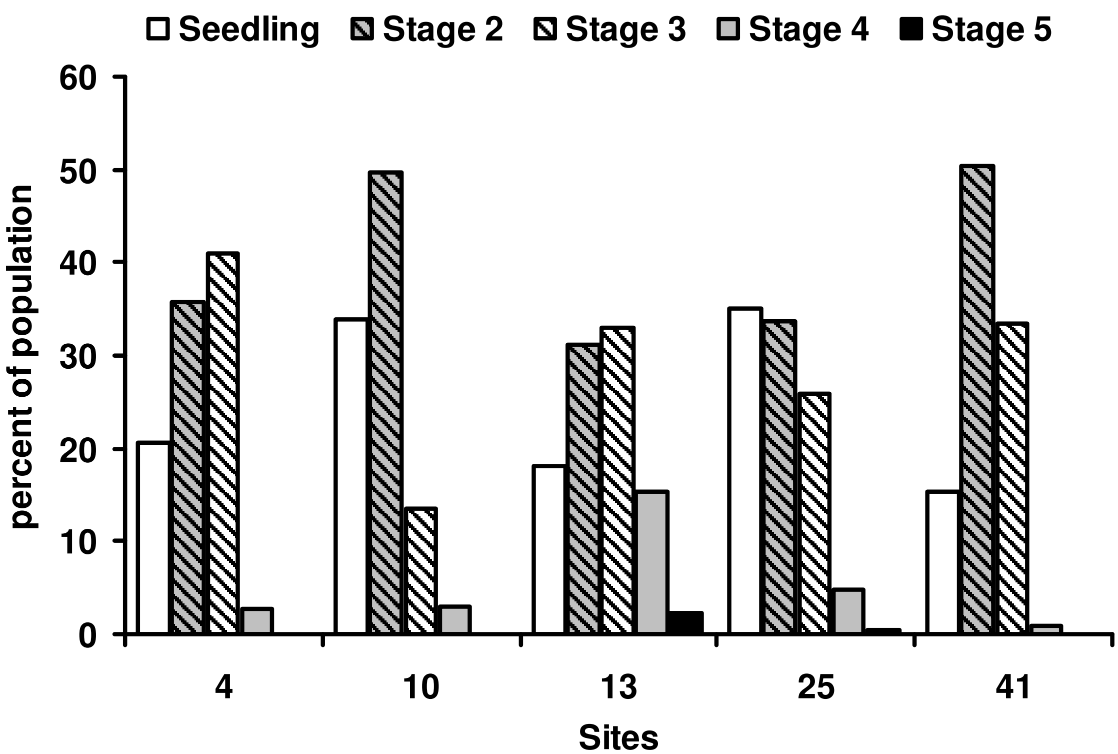

Figure 5. Population structure at all sites in 2008. Values are percentage of individuals in each stage (from left to right within each site: I=seedling, II=longest stem <10cm, III=10-20cm, IV=20-30cm, and V=>30cm).

Model projections compared to observed populations in 2008

The computer simulations accurately predicted the size of four of the five populations (Figure 4). Only at site 41 did the observed population size fall outside of the projected range. The model projected that in 2008, the population would be 35 ± 57 (1 S.D.) plants, but we counted 117 plants. The higher than predicted values may indicate a positive effect from protecting the population from intensive grazing.

Site 4 was the only population at high risk of 50% decline in a 50 year period as determined through stochastic simulations incorporating environmental variability (Carlson and Kaye 2001) (Table 5). This population had a 94% (95% confidence interval: 90-98%) chance of dropping by half in 50 years. Site 41 had a 44% chance of catastrophic decline, and the remaining populations had very low risks (≤12%).

Table 5. Probability of catastrophic decline and population growth rate (λ) for simulated populations from each study-site. Probability of decline is the chance of dropping to fewer than 50% of the original individuals in a 10-year period. Derived from 500 simulations using the average 1991-2000 matrices. C.I. indicates a 95% confidence interval. Reproduced from Carlson and Kaye (2001).

Site	Risk of catastrophic decline	Growth rate (λ)
4	94% (CI: 90-98%)	0.933
10	5% (CI: 1-9%)	1.056
13	12% (CI: 8-16%)	1.036
25	3% (CI: 0-78%)	1.137
41	44% (CI: 40-48%)	0.955

Recommendations

Based on our observations, we recommend the following actions,

- Protect *Astragalus tyghensis* population from grazing. Grazing reduces size, reproduction, and survival. However, if site 41 is representative, recovery from grazing may be relatively rapid.
- Control invasive weeds, particularly *Centaurea diffusa* (Figure 6)*, Bromus tectorum*, *Poa bulbosa*, and *Taeniatherum caput-medusae.* All of these species may inhibit germination and plant growth through competition. In addition, *C. diffusa* may negatively affect *A. tyghensis* by the production of toxic allelochemicals (Callaway and Aschehoug 2000, Vivanco et al. 2004).
- Monitor population size every five years in order to detect significant changes in population structure or size.

Figure 6. Site 41 (Tygh Valley State Wayside). On the far left is *Centaurea diffsua* and on the far right is *A. tyghensis*.

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