# POPULATION MONITORING AND VIABILITY ANALYSIS FOR *HORKELIA CONGESTA* SSP. *CONGESTA* AT THE LONG TOM AREA OF CRITICAL ENVIRONMENTAL CONCERN

2004 Progress Report
December 2004

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A Cooperativ
e Challenge
Cost Share Project
funded jointly by

Bureau of Land Management
Eugene District

Institute for Applied Ecology
Corvallis, Oregon

## 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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## ACKNOWLEDGMENTS

The following individuals contributed their valuable time and expertise toward field work and/or data entry during some part of the last three years of this project: Carolyn Menke, Steve Gisler, Karin Rohland, Jen Cramer (IAE staff), and Karen Wells, Lauren Fety, Beth Lawrence, Angela Brandt, Melanie Barnes, Melissa Carr, and Emerin Hatfield (Native Plant Society of Oregon/IAE interns). In addition, many individuals from BLM, Oregon Department of Agriculture, and the Native Plant Society of Oregon helped with data collection and computer entry from 1993 to 1999. We are grateful for their help.

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## INTRODUCTION

### *Status*

*Horkelia congesta* ssp. *congesta*, shaggy horkelia (Figure 1), is a candidate for listing by the Oregon Department of Agriculture (ODA) as threatened or endangered, and it is considered threatened with extinction throughout its range by the Oregon Natural Heritage Program (ONHP, 2004). It is on the Bureau of Land Management (BLM) Special Status Species list. The subspecies *congesta* is endemic to Oregon.

### *Background*

Monitoring for *Horkelia* on land managed by BLM was initiated in 1993 at the Long Tom Area of Critical Environmental Concern (ACEC). Since that time, monitoring was conducted annually from 1993 through 1999 by BLM or ODA and from 2002 through 2004 by Institute for Applied Ecology (IAE) staff. The last summary report was prepared after the 2003 field season (Kaye and Brandt, 2003). *Horkelia congesta* ssp. *congesta* occurs in grassland and oak savanna remnants in the Willamette Valley and on grassy balds in the Umpqua Valley. Two populations occur on the Eugene District BLM, at the Long Tom ACEC and at Greenhill Road. At the Long Tom ACEC, three other sensitive species are also present and monitoring for them is underway: *Lomatium bradshawii* (listed as endangered by the U.S. Fish and Wildlife Service), *Montia howellii*, and *Microcala quadrangularis*. Information on monitoring for *Horkelia* at the Greenhill Road site is presented elsewhere (Kaye, 1997).

### *Reproduction and population biology*

*Horkelia congesta* ssp. *congesta* is an herbaceous perennial that reproduces by seed. Plants form rosettes of basal leaves and eventually produce one or more flowering stems. Occasionally, the root caudex splits beneath the soil surface, thus producing rosettes that appear separate but are connected underground. This is probably a rare event, however, and close inspection of the rosettes often reveals the old leaf bases of pre-existing transitional rosettes. No studies have documented the breeding system of the species, but our field observations indicate that insects (solitary bees and syrphid flies) are responsible for cross-pollination.

### *Objectives*

The objective of this report is to summarize population monitoring data for *Horkelia congesta* ssp. *congesta* at the Long Tom ACEC and discuss population trends from 1993-2004. In addition, the data available to date make it possible to conduct a population viability analysis and compare population size predictions from computer simulations with those observed in 2004.

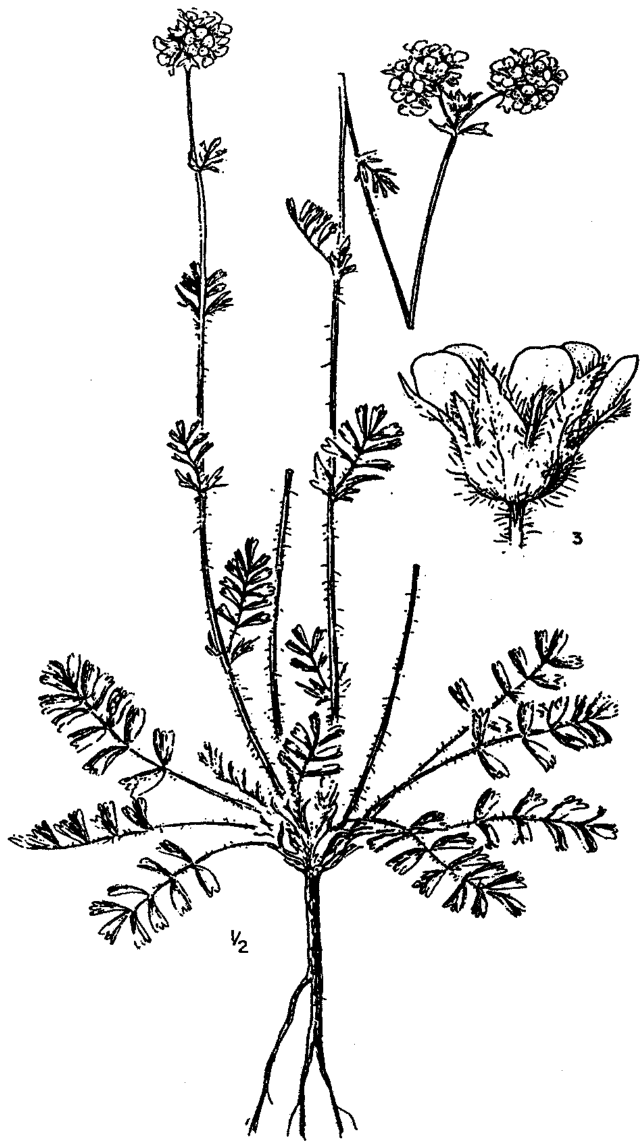



**Figure 1.** *Horkelia congesta* ssp. *congesta* (from Hitchcock et al., 1961).

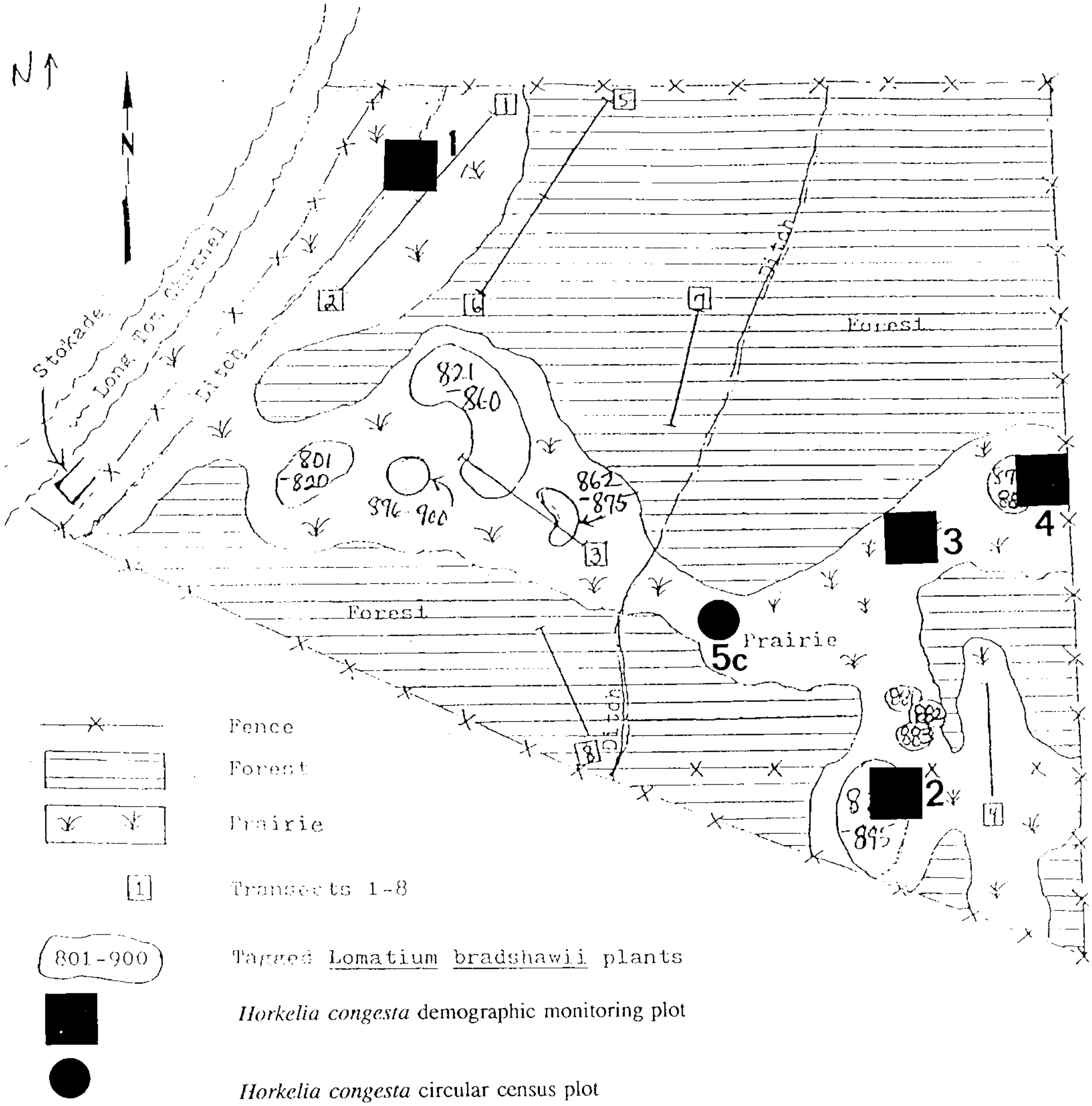



**Figure 2.** Sketch map indicating the location of the *Horkelia congesta* ssp. *congesta* monitoring plots #1-5c at the Long Tom ACEC. Other plot notations on this map refer to ongoing studies of *Lomatium bradshawii.*

## METHODS

### *Study site*

*Horkelia congesta* ssp. *congesta* occurs at the Long Tom ACEC of the Eugene District BLM, west of Eugene, Oregon. The habitat at this site is a wet-grassland matrix within a deciduous forest dominated by *Fraxinus latifolia* (Oregon ash) and *Quercus garryana* (Oregon white oak). At this site and other locations in the Willamette Valley, *Horkelia congesta* ssp. *congesta* occupies grasslands and forest edges. Prior to fire suppression, initiated when the Willamette Valley was settled in the 1800s, the site may have contained more prairie habitat than it does today, and thus may have supported a larger population of *Horkelia*. Portions of the ACEC have been burned to promote prairie species and to reduce the abundance of woody vegetation. The most recent burn was in September, 1998. In addition, *Fraxinus latifolia* trees have been manually removed. Figure 2 shows the locations of the study plots at the Long Tom ACEC.

### *Plot design*

To monitor population trends of *Horkelia congesta* ssp. *congesta* at Long Tom ACEC, five permanent plots were established and censussed between 6/28/93 and 7/1/93. The plots were arranged so that they contained nearly all of the *Horkelia congesta* ssp. *congesta* individuals at the site. A small number of scattered individuals could not be included in the plots, but they were counted to provide a complete census of the population. The size and shape of the monitoring plots differed from patch to patch of *Horkelia congesta* ssp. *congesta*, allowing us to 'custom fit' the plots to the distribution of the plants. Plots 1 through 4 were rectangular and ranged from 5 to 18 meters on a side, and were marked at their four corners with 3/8 inch rebar with yellow plastic caps. (Other rebar posts in this vicinity mark plots for different studies but in general, *Horkelia* plots are marked with 3/8" rebar and other plots are marked with ½" rebar.) Plots 1 through 4 were marked into a grid of 1 x 1 m squares by placing 7 inch nails into the soil to mark the corners of each square that contained *Horkelia*. Nails were used only to mark subplots containing *Horkelia* to keep costs down and reduce the amount of metal that might leach from the nails into the soil. Additional nails can be added to encompass plots in which new *Horkelia* plants are discovered in the future. Each 1 m x 1 m subplot was given a unique 'address' using an x-y coordinate system that numbered rows and columns in the plot. For example, the lower left hand subplot in each plot was defined as position 1-1; a subplot three columns to the right and two rows up would be at position 3-2 (see plot layout charts). Data recorded from these plots were used to track individual plants for demographic analyses.

A small patch of *Horkelia congesta* ssp. *congesta* was marked with a single rebar post, which was used as the center of a circular plot in which all plants were counted and recorded as either vegetative or reproductive (plot 5c). Data from this plot were used to track total numbers of plants (not suitable for demographic analyses).

Notes on the location and layout of each plot are provided below:

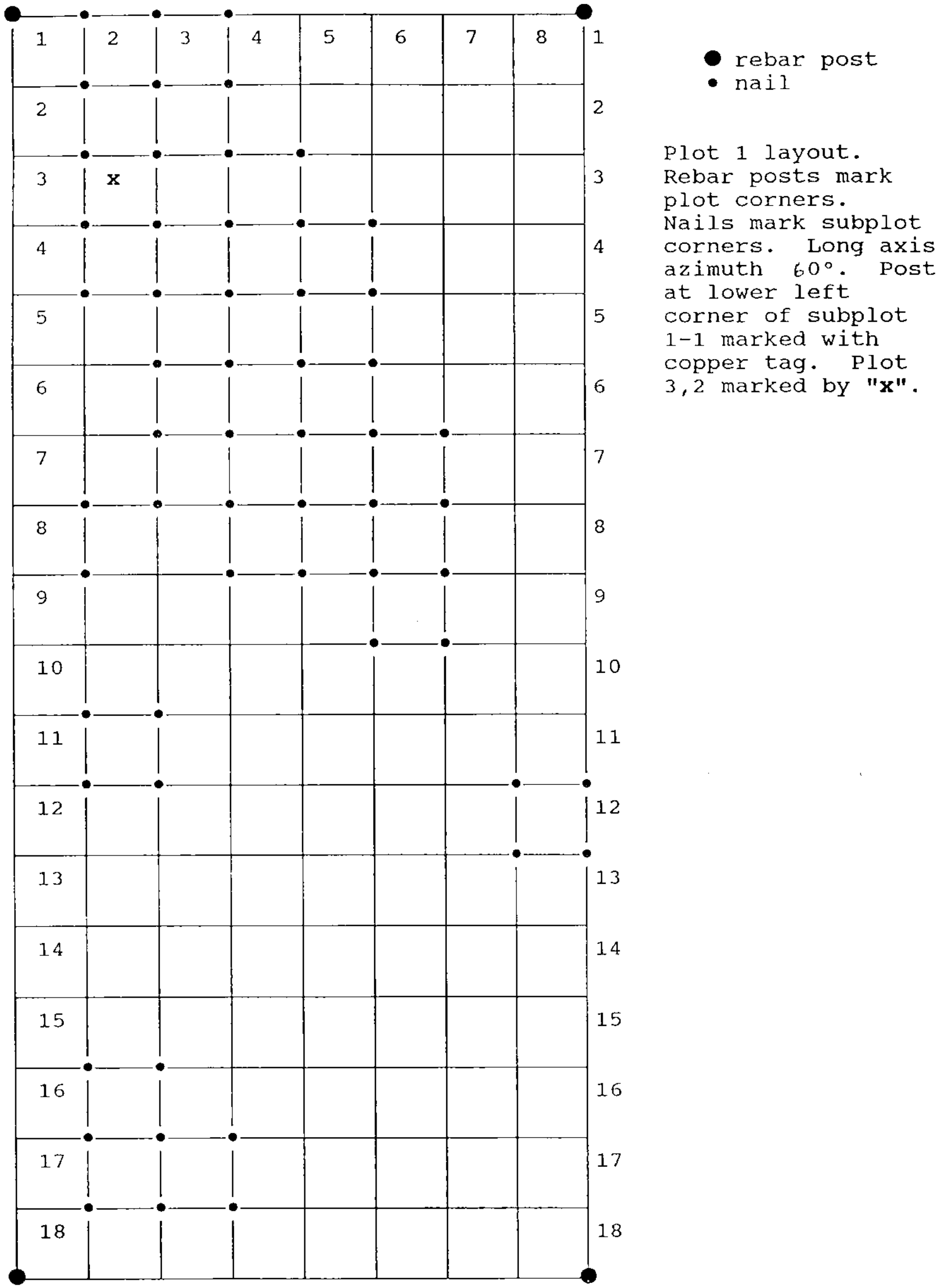
**Plot 1.** This plot contains the patch of *Horkelia congesta* ssp. *congesta* previously monitored by Nancy Wogen with two permanent transects. All of the plants encountered during her monitoring were included in this plot, as were several other plants not previously monitored. The plot is ca. 25 m east of the fence road that runs along the west edge of the ACEC. The northeast corner post of the plot is 4.0 m at 130° from a square metal tag 2 feet above the ground on an Oregon ash tree. A ditch runs north-south through the plot. The plot is 18 m x 8 m and encompasses all plants in the patch. The compass bearing of the long axis of the plot is 150°.

**Plot 2.** This plot is in the southeast portion of the ACEC, about 20 cm north of, and parallel to, the existing plot established to monitor *Microcala quadrangularis*. The southwest corner post of the plot is 2.2 m at 40° from a metal tag at the base of a cedar fence post. The plot is 8 m x 5 m, and the long axis is 287°. The plot contains all plants in the patch. There are two reproductive plants about 10 m northeast of the northeast corner of the plot.

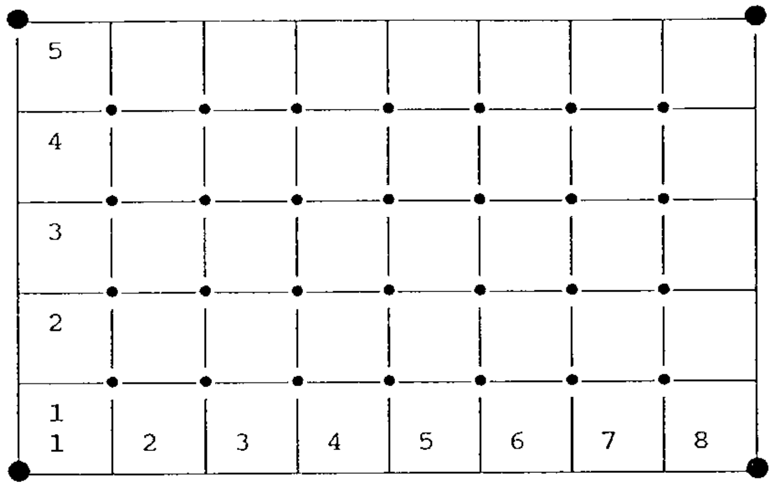
**Plot 3.** This plot is located about 20 m south of the north boundary fence of the ACEC. The plot is 8 m x 6 m, and the long axis is 30°. The plot contains all plants in the local patch, but a few plants are scattered around the drip-line of a large oak about 8 m south of the southeast corner post, and others are scattered between this plot and plot 4.

**Plot 4.** This plot is adjacent to the east fenceline-boundary of the ACEC (the fence actually forms the east edge of the plot). An orange BLM boundary post is 1 m north of the northeast corner post of the plot. A *Lomatium bradshawii* study-plant (tag no. 880) was along the west edge of the plot but may now be difficult to relocate. The plot is 10 m x 10 m, and the azimuth along the fence-line axis is 19°. A few plants on the other side of the fence from this plot and along the west edge are also tracked for demographic purposes.

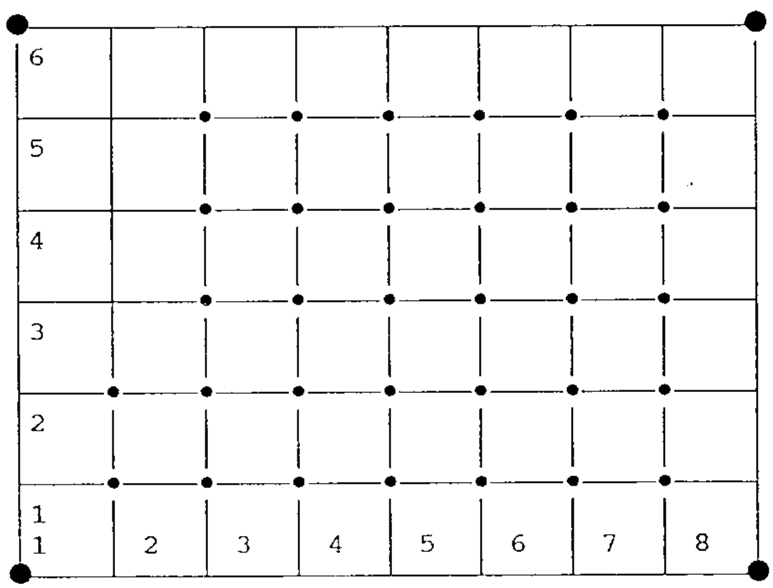
**Plot 5c.** This is a circular plot marked only by a center rebar post with a yellow plastic cap and a copper tag noted '5c.' It is located in the south-central part of the ACEC just east of a ditch that runs north-south through the center of the ACEC. All of the plants within 3 m of the post (which included all of the plants in that patch) were counted as either vegetative or reproductive. This plot was installed to capture a few plants that were too far from any other patch to be included in a larger plot.



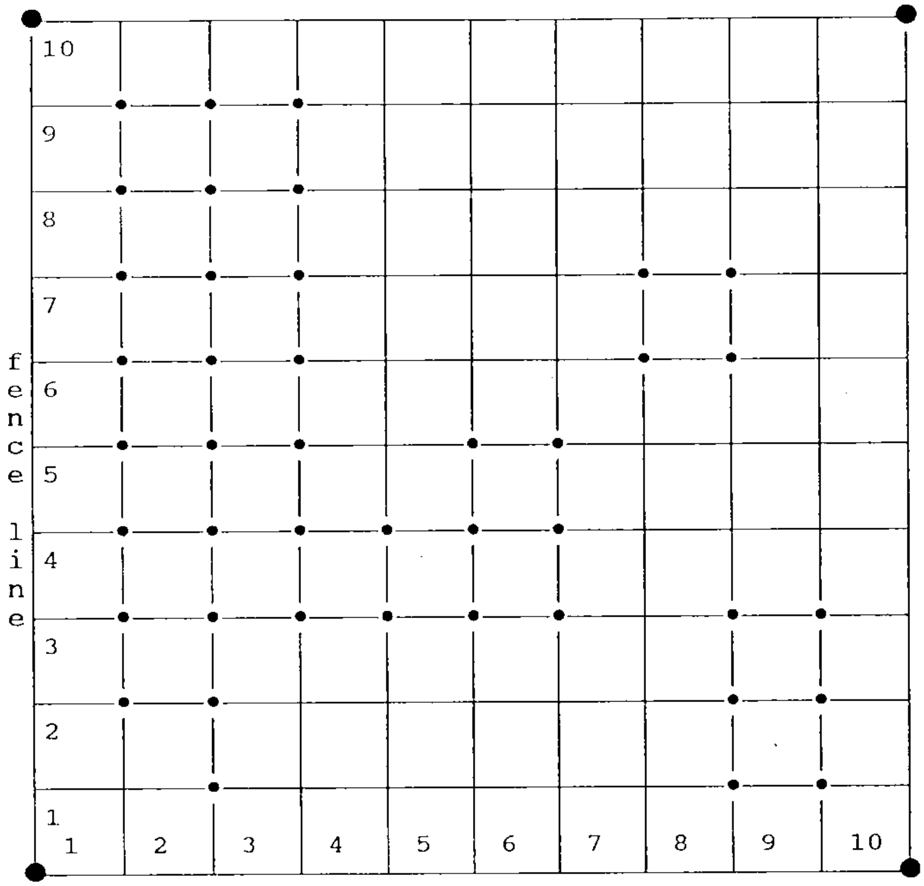

Plot 1 layout. Rebar posts mark plot corners. Nails mark subplot corners. Long axis azimuth 60°. Post at lower left corner of subplot 1-1 marked with copper tag. Plot 3,2 marked by "**x**".




Plot 2 layout. Rebar posts mark plot corners (●); nails mark subplot corners (•). Long axis azimuth 287°. Lower left corner post (subplot 1-1) marked with copper tag.




Plot 3 layout. Rebar posts mark plot corners (●); nails mark subplot corners (•). Long axis azimuth 30°. Lower left corner post (subplot 1-1) marked with copper tag.




Plot 4 layout. Rebar posts mark plot corners (●); nails mark subplot corners (•). Fence-line axis azimuth 19°. Lower left corner post (subplot 1-1) marked with copper tag.

### *Plant measurements and mapping*

In plots 1 through 4, all plants were mapped and measured to provide baseline demographic data for documenting future population trends. Plants were mapped by placing a square meter frame over each 1 m x 1 m subplot, and measuring the location of each plant in the subplot with a metric ruler. The location of each plant was then marked on a scale map of the subplot, and each mapped plant was numbered. Once mapped, each plant was measured to determine rosette width (cm), plant height (cm), and number of grazed and ungrazed flowering stems. The height of reproductive plants was measured as the distance from the base of the plant to the tip of the inflorescence. On vegetative plants, height was measured as the length of the longest leaf. If a plant consisted of more than one rosette, the diameter, height, and number of flowering stems were measured for both the largest rosette and the whole cluster, and measurements for the whole cluster were used in the analysis.

### *What is an individual?*

It was occasionally difficult to determine if a cluster of *Horkelia congesta* ssp. *congesta* rosettes represented one or more individuals because the main root stalk of some plants branches below the soil surface, thus producing two or more rosettes adjacent to one another. Prior to mapping plants at the Long Tom ACEC, we visited a site with several *Horkelia congesta* ssp. *congesta* plants that may be destroyed by road work in the near future. We selected a patch of plants at random from within this population and mapped all rosettes within one square meter, using the same method planned for Long Tom ACEC. We then excavated all rosettes within the square meter and checked for below ground root connections. Of the twenty-nine mapped rosettes, four were connected to each other by a large woody caudex that branched about 10 cm below the soil surface (Figure 3). These rosettes were fairly close to each other, about 7-10 cm apart at ground level, but other more closely spaced rosettes were clearly not connected below ground. Therefore, we determined that the distance between two rosettes was not a satisfactory indicator of below ground root or stem connections. Instead, evidence of prior years' rosettes (leaf bases, and/or raised, dead root-crowns) between two adjacent rosettes was favored as an indicator of below ground connection. Rosettes were considered independent plants in the absence of this evidence.

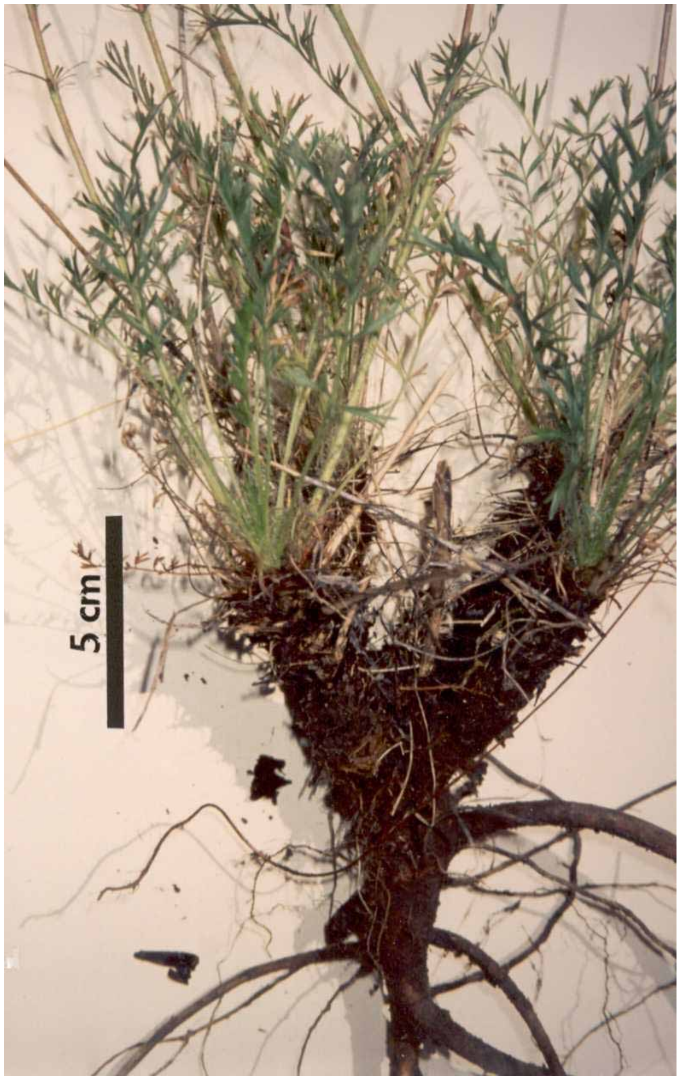



**Figure 3.** Excavated root system of a *Horkelia congesta* ssp. *congesta* plant. This plant superficially appeared to be four separate rosettes at ground-level. Excavation showed that all four were connected 8-cm below-ground by a single branched caudex. The best evidence that rosettes are connected is the presence of old-dead rosettes between them. Without this evidence, rosettes should be considered separate individuals.

***Population dynamics and viability analysis:***

**Population model**

The population dynamics of *Horkelia congesta* ssp. *congesta* at Long Tom ACEC were modeled with a transition matrix approach. This type of model is based on the reproduction and survival of individuals that are divided into categories based on age, size, or life-history stage. The number of seedlings produced per plant in each category is then 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 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 4 is a life-cycle graph for *Horkelia congesta* ssp. *congesta* with six possible stages based on both life history and plant size: seedling (I); vegetative plants with rosette diameter 12 cm or less (II), vegetative plants with rosette diameter 13 cm or greater (III), reproductive plants with one flowering stem (IV), reproductive plants with two stems (V), and reproductive plants with three or more stems (VI). These stages were defined subjectively after displaying the size data graphically. The arrows indicate the possible transitions (or fecundities) that plants in each category can make as one year passes. Note that seedlings can make the transition to both vegetative and reproductive stages.

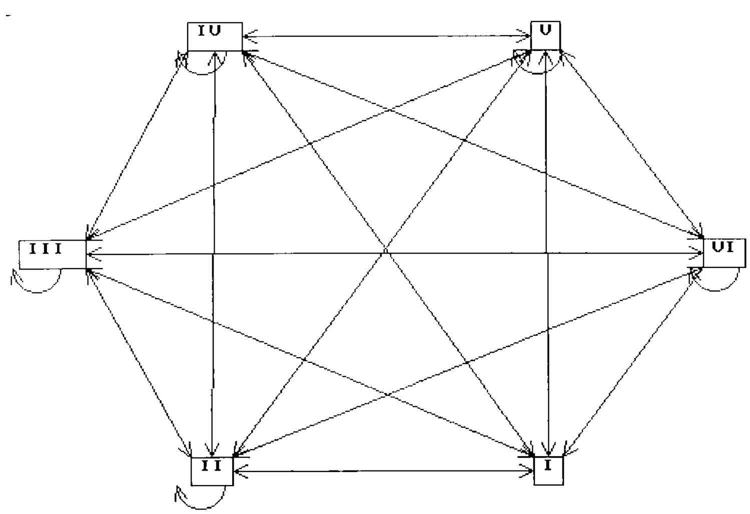



**Figure 4**. Life cycle graph for *Horkelia congesta* ssp. *congesta*. Arrows connecting two stages indicate transition probabilities. The time step for transition between stages is one year.

Below is a stage-classified transition matrix for *Horkelia congesta* ssp. *congesta* based on the life-history graph (Figure 4), and a population vector, which contains the number of plants in each category. The matrix contains six categories (I through VI). Plants in each category can make the transition from their current condition to the same or another class the following year.

*Transition matrix:*

*Population vector:*

$$\mathbf{A} = \begin{array}{ccccccc} & \mathrm{I} & \mathrm{II} & \mathrm{III} & \mathrm{IV} & \mathrm{V} & \mathrm{VI} \\ \mathrm{I} & \text{--} & \text{--} & \text{--} & F_{IV\text{-}I} & F_{V\text{-}I} & F_{VI\text{-}I} \\ \mathrm{II} & G_{I\text{-}II} & P_{II\text{-}II} & G_{III\text{-}II} & G_{IV\text{-}II} & G_{V\text{-}II} & G_{VI\text{-}II} \\ \mathrm{III} & G_{I\text{-}III} & G_{II\text{-}III} & P_{III\text{-}III} & G_{IV\text{-}III} & G_{V\text{-}III} & G_{VI\text{-}III} \\ \mathrm{IV} & G_{I\text{-}IV} & G_{II\text{-}IV} & G_{III\text{-}IV} & P_{IV\text{-}IV} & G_{V\text{-}IV} & G_{VI\text{-}IV} \\ \mathrm{V} & G_{I\text{-}V} & G_{II\text{-}V} & G_{III\text{-}V} & G_{IV\text{-}V} & P_{V\text{-}V} & G_{V\text{-}IV} \\ \mathrm{VI} & G_{I\text{-}VI} & G_{II\text{-}VI} & G_{III\text{-}VI} & G_{IV\text{-}VI} & G_{V\text{-}VI} & P_{VI\text{-}VI} \end{array} \qquad \mathbf{n} = \begin{array}{c} n_{I} \\ n_{II} \\ n_{III} \\ n_{IV} \\ n_{V} \\ n_{VI} \end{array}$$

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 V produce $F_{V\text{-}I}$ seedlings per year, they have a probability $P_{V\text{-}V}$ of remaining in category V, and probabilities $G_{V\text{-}VI}$ and $G_{V\text{-}IV}$ of making the transition to category VI or IV, 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, the process to determine plant age may require its destruction, a method that is clearly inappropriate for rare plants. Instead, most models of plant populations place individuals into size or stage classes, or in a combination of the two, as was done here. The number of individuals in each category $n_i$ 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.

**Assumptions of the model**
Our use of the transition matrix model assumes that fertility and transition rates are independent of plant density. This is an acceptable assumption for many species with population densities below a density-dependent threshold (density vague populations). We have assumed that this species does not maintain a persistent seed bank (or, if it does, then inputs and outputs are equal in each year). In addition, the model assumes that population growth is a first-order Markov process, where the probability that a plant will change in size next year is independent of its size in the previous year. And finally, for deterministic modeling, transition rates are assumed to remain constant in time. All of these assumptions need to be kept in mind when interpreting the results of the following demographic analyses. At this time, we can also incorporate environmental stochasticity so that constant conditions do not have to be assumed (see below).

**Population Viability Analysis**
<u>Deterministic measures of viability</u> – We used MATLAB 6.0 to assist in the construction and analysis of our model. This commercially available computer software makes implementation of the matrix population model a fairly easy task but requires writing of customized computer code. For the *Horkelia congesta* ssp. *congesta* population, we calculated equilibrium population growth rate, lambda, which is a deterministic measure of population growth. If lambda is less than 1.0, the population will decrease in size, and if lambda is greater than 1.0, the population will grow, given that current conditions remain constant (i.e., no environmental variability). We calculated lambda for each pair of years for which matrices were available (i.e., 1993-94, 1994-95, and so on), as well as for the average matrices calculated by taking the mean value of all available matrices. We also calculated elasticities of the matrix. Elasticities are the sensitivity of lambda to small changes in the transition probabilities. Elasticities provide valuable information about the extent to which population growth depends on survival, growth, and reproduction at different stages in the life-cycle (Caswell, 1989). The identity of seedlings in 1993 was uncertain because they could have been confused with small plants. Therefore, we used the mean seedling transitions from all subsequent years to model seedling dynamics in 1993. This procedure for 1993 seedlings introduces a small amount of error into our model, but since the seedling stage has a low elasticity (see Results), our model should not be greatly affected.

<u>Stochastic measures of viability</u> – In 2004 we conducted a population viability analysis incorporating environmental stochasticity. Viability was measured in two ways, stochastic population growth rate and extinction probability. Each involved projecting future population dynamics by randomly selecting survival and fecundity measures from past years to simulate environmental variability. For stochastic population growth rate (also called stochastic lambda), we used two methods. In the first, we used the element selection method, which involves calculating a mean and variance for each transition probability and then randomly selecting a value from a distribution with the given mean and variance during each time step of the simulation. For this approach, we used a beta-distribution for each transition element, a gamma-distribution for fertilities, and a rescaling method to correct for overall survivals greater than 100% without introducing bias (see Kaye and Pyke [2002] for details of these methods). Correlation among transition rates was also included following methods in Kaye (2001). We

used the MATLAB program STOCMVBETA2 (Kaye 2001) to implement this model. The second method, matrix selection, was accomplished by selecting a whole matrix at each time step, selected at random from the eight matrices available since monitoring began in 1993. This method is similar to one used and described by Menges (1992); we used the program LAMS (Kaye 2001) to implement this type of simulation. For each method, simulations projected population size for 10,000 time steps to estimate stochastic lambda.

To estimate extinction probability, we used the matrix selection method and projected population size for 100 years and this was repeated 1000 times. At each year of the simulations, a new matrix was selected at random from the series of eight available matrices (in a manner similar to that used in the program LAMS). In this way, population size was projected forward for 100 time steps (years), and this was conducted for 1000 replicates. We used the MATLAB program SHUFFLE (Kaye 2001) with a starting population size of 442 (the 1993 observed size) and the mean historic stage structure as determined from our observed data. The frequency with which population size fell below 90% of its original size in each 100 year simulation was our measure of extinction risk. Defining extinction as falling below a certain threshold, in our case 90% of original size, is known as quasi-extinction (Burgman et al., 1993), and it provides a conservative estimate of extinction dynamics. Projected population sizes from the program SHUFFLE were used to display the forecasted population size in Figure 6.

## RESULTS

### *Long Tom ACEC population summary*

Observed population trends of *Horkelia congesta* at Long Tom ACEC were consistently positive from 1993 through 1996, then declined slightly from 1997 to 2002, when the population reached its lowest recorded size since monitoring began (Table 1 and Figure 5). The population made an upturn in the subsequent two years, increasing to 1997-98 levels in 2004. During the most recent population increase, the number of individuals climbed from 327 in 2002 (plus an additional 19 plants in plot 5c and scattered around the population area) to 392 individuals in 2003 (plus an additional 13 plants in plot 5c and scattered) to 515 individuals in 2004 (plus 14 plants in plot 5c and scattered). Since monitoring commenced in 1993, total population size within the four largest sampling plots has remained between 414 and 560 individuals. These numbers represent a census of all observed plants in the population. The population is composed of five more or less distinct patches or clusters of plants, and a few separated and isolated individuals, and this spatial pattern has remained fairly constant since 1993.

Plant sizes have also remained relatively stable throughout the monitoring period. From 1993 through 2004, average rosette diameter stayed between 11.6 cm and 16.7 cm, height ranged from about 20 to 32 cm, and the average number of flowering stems remained between 0.7 and 1.56 per plant (Table 1). All of the largest average plant sizes were recorded in 2002. The reason for this larger average plant size in 2002 is unknown, but may be linked to favorable climatic conditions (such as seasonal temperature and precipitation) that year, or mortality of smaller (and possibly younger) plants, leaving larger (older?) plants to dominate the population. Average plant size decreased in 2003, with rosette diameter of 13.8 cm, height of 22.3 cm, and 1.01 flowering stems. In 2004, average plant size remained similar to 2003. Average rosette diameter was 12.16 cm, height was 21.16 cm, and flowering stems was 1.36 per plant. Decreases in plant size compared to 2002 may be a result of greater seedling recruitment in 2003 and 2004 or transition of previously reproductive plants to a vegetative growth stage (especially in 2003). Herbivory of flowering plants, which resulted in the removal of one to all reproductive stems, was presumably caused by deer as evidenced by the angled break in the stem that these animals characteristically leave. This herbivory has varied substantially from a high of 83% of all reproductive stems in 1995 to a low of 13% in 1997 (Table 1).

**Table 1.** Summary of observed population size (number in parentheses includes estimate of unrecorded seedlings and dormant plants), plant size, and herbivory data for *Horkelia congesta* ssp. *congesta* at Long Tom ACEC. Data for plant size attributes (rosette diameter, height, and number of reproductive stems) are means followed by standard errors (SE) in parentheses. Data are for plants within demographic sample plots (no data recorded for plants outside plots 1-4 [fewer than 30 individuals]).

| Year | No. Plants | Diameter (cm) | Height (cm) | No. Reproductive stems per plant | No. Grazed stems per reproductive plant | Percentage reproductive stems grazed |
|---|---|---|---|---|---|---|
| **1993** | 420 (442) | 11.90 (0.22) | 19.64 (0.71) | 0.86 (0.07) | 0.96 (0.07) | 50% |
| **1994** | 458 (494) | 13.60 (0.23) | 30.33 (0.80) | 1.44 (0.09) | 1.33 (0.10) | 57% |
| **1995** | 526 (566) | 12.48 (0.27) | 20.39 (0.69) | 0.78 (0.06) | 1.68 (0.08) | 83% |
| **1996** | 561 (596) | 12.88 (0.30) | 22.01 (0.82) | 0.78 (0.07) | 1.14 (0.09) | 53% |
| **1997** | 528 (569) | 13.41 (0.30) | 25.05 (0.92) | 0.95 (0.08) | 0.30 (0.03) | 13% |
| **1998** | 511 (533) | 12.13 (0.27) | 22.16 (0.82) | 0.64 (0.05) | 0.26 (0.04) | 41% |
| **1999** | 414 (459) | 11.41 (0.30) | 24.73 (0.90) | 1.26 (0.11) | 0.25 (0.05) | 20% |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2002** | 327 (369) | 16.72 (0.46) | 31.73 (1.03) | 1.56 (0.12) | 0.59 (0.08) | 22% |
| **2003** | 392 (432) | 13.81 (0.36) | 22.32 (0.86) | 1.01 (0.10) | 1.21 (0.13) | 49% |
| **2004** | 515 | 12.16 (0.38) | 21.16 (0.90) | 1.36 (0.11) | 1.69 (0.13) | 55% |

***Population structure***

The structure of the Long Tom ACEC *Horkelia congesta* population in most years has been fairly stable (Figure 5). Seedlings have generally been infrequent (an average of 12% of the population), with the greatest recruitment seen in 2004. Small vegetative plants (stage II) were usually the most abundant stage (an average of 27% of the population), with large vegetative plants being second most abundant (an average of 19%). A shift to a greater proportion of large vegetative plants was observed in 2003, however. Larger stage classes ranged in abundance from year to year, but were especially abundant in 1994, 1999, 2002, and 2004. Stage IV plants comprised an average of 15% of the population for years in which data were taken; stage V, 13%; and stage VI, 13%.

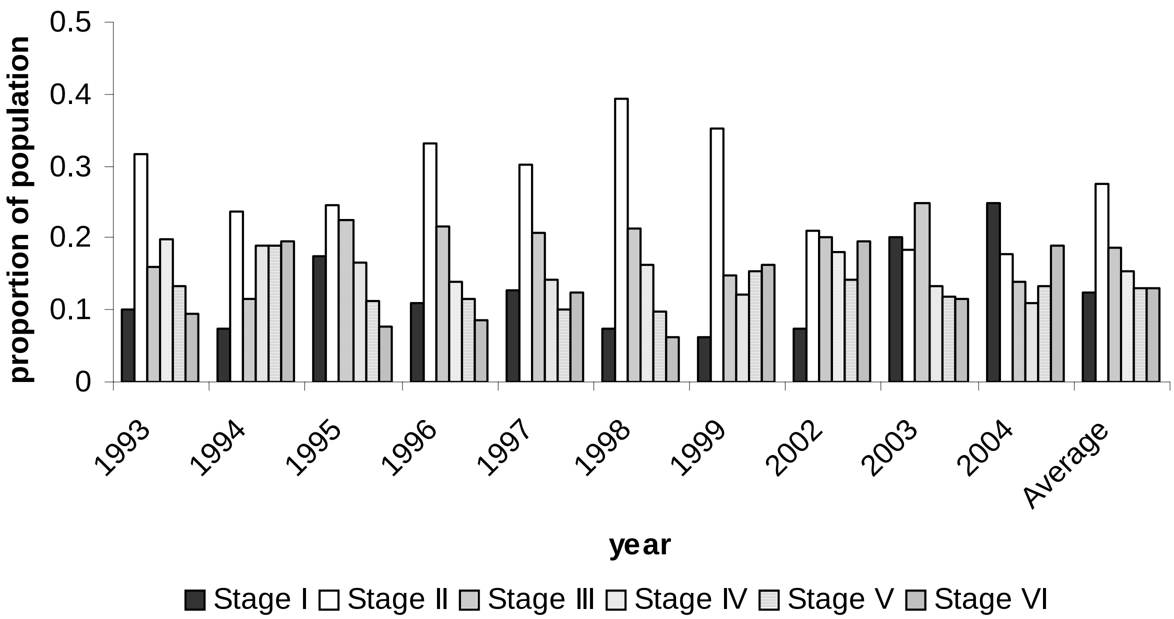



**Figure 5.** Distribution of stages of *Horkelia congesta* at the Long Tom ACEC from 1993-2004 and the average proportion of each stage for all years over which data was taken (data not taken in 2000 or 2001). Includes estimates of unrecorded seedlings and dormant plants. I=seedling, II=less than 13 cm, III=13 cm or greater, IV=1 reproductive stem, V=2 stems, VI=3 or more stems.

***Population dynamics***

The average transition matrix for *Horkelia congesta* ssp. *congesta* yielded a population growth rate, or lambda, equal to 1.035 (Table 2), suggesting that the long-term population dynamics of this species at the Long tom ACEC are stable, increasing at the average rate of 3.5% per year. Values in the top row of the matrix represent the number of seedlings produced per individual, while values in the lower rows are probabilities of plants moving from one stage to another. For example, the probability of a seedling becoming a small vegetative plant is 0.576, while the probability of a seedling dying is 0.222. Stage VI individuals have a high probability of remaining in that category (0.562). Mortality is higher for seedlings (22.2%) than the other stages (4.1%-14.1%). The average annual growth rate of 1.035 indicates that the population, on average, increased from 1993 to 2004, and that the population may be minimally viable under a deterministic environment.

***Viability analysis***

The stochastic population growth rate of the *Horkelia congesta* ssp. *congesta* population at Long Tom ACEC was 1.032 for the beta-distributed element selection method of stochastic simulation and 1.029 using the matrix selection method. Stochastic projection through the year 2013 predicts that the *Horkelia congesta* ssp. *congesta* population will continue to increase at a very gradual rate (Figure 6). The probability of quasi-extinction (90% population decline) within a 100 year time frame was estimated at 0.0%.

***Elasticities***

The elasticity analysis shows that small changes in the probability of stage VI plants remaining at stage VI (0.1315) would have the single greatest effect on the population growth rate, with stage II plants remaining at stage II being the second most important transition (0.0980; Table 3). The lowest elasticity was for stage I plants growing to stage VI (0.0000), followed by stage I plants growing to stage V (0.0011). Overall, stage VI plants had the highest cumulative elasticity (0.2421) and stage II plants the second highest (0.2046). The seedling stage (I) had the lowest cumulative elasticity (0.0818).

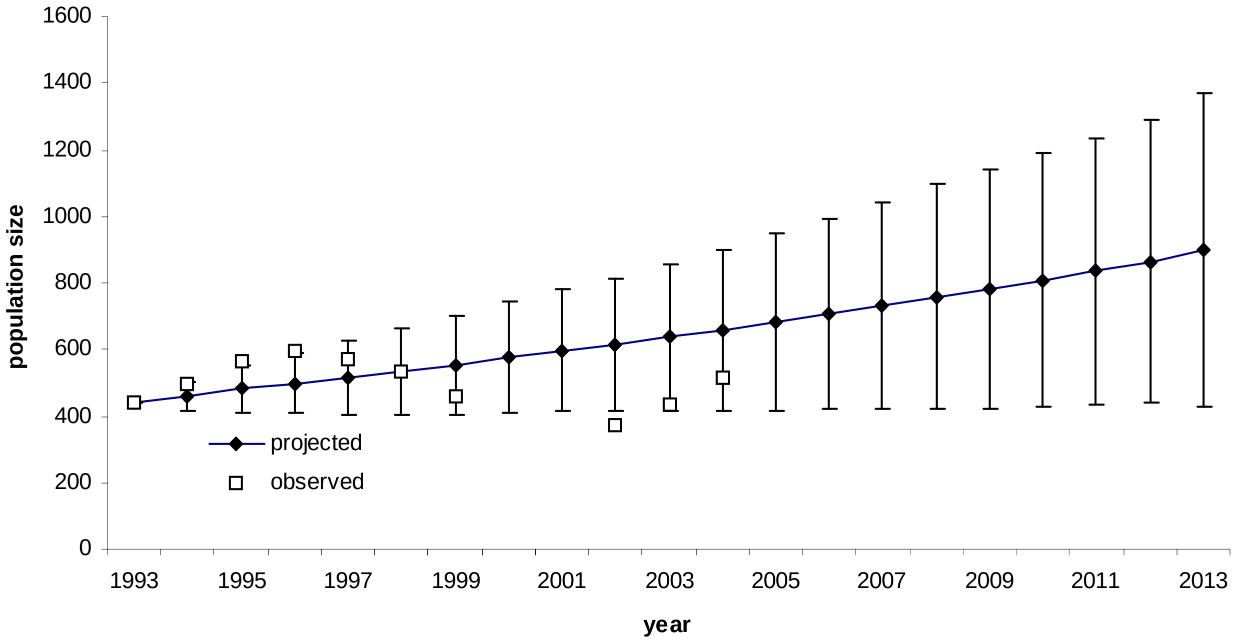



**Figure 6.** Observed population size of *Horkelia congesta* at the Long Tom ACEC from 1993 though 2004 and projected population size through 2013 from a stochastic model simulation (vertical bars represent one standard deviation). Observed population size includes estimate of unrecorded seedlings and dormant plants; no data are available for 2000-2001.

**Table 2**. Average transition matrix for the *Horkelia congesta* population at Long Tom ACEC, 1993-2004 (n=8; data not recorded in 2000 and 2001). The stage/size categories are defined as: I (seedling); II (vegetative plants with rosette <13 cm), III (vegetative plants with rosette ≥13 cm), IV (plants with 1 flowering stem), V (plants with 2 stems), and VI (plants with ≥3 stems). The top row indicates the number of seedlings produced per plant of the given stage. The lower rows are probabilities of moving from one stage to another. The bottom row lists the average annual mortality of each stage. The variances associated with each transition probability are presented in the lower half of the table.

**Average matrix, 1993-2004** — lambda=1.035; stochastic lambda=1.032[1], 1.029[2]

| | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| I | -- | -- | -- | 0.155 | 0.311 | 0.671 |
| II | 0.576 | 0.496 | 0.208 | 0.120 | 0.091 | 0.040 |
| III | 0.184 | 0.197 | 0.379 | 0.198 | 0.105 | 0.061 |
| IV | 0.012 | 0.100 | 0.159 | 0.278 | 0.205 | 0.088 |
| V | 0.006 | 0.043 | 0.106 | 0.195 | 0.291 | 0.208 |
| VI | 0.000 | 0.025 | 0.063 | 0.118 | 0.251 | 0.562 |
| Mortality | 0.222 | 0.141 | 0.085 | 0.092 | 0.057 | 0.041 |

**Variance matrix**

| | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| I | -- | -- | -- | 0.006 | 0.024 | 0.150 |
| II | 0.004 | 0.007 | 0.006 | 0.004 | 0.005 | 0.002 |
| III | 0.019 | 0.004 | 0.012 | 0.017 | 0.004 | 0.002 |
| IV | 0.001 | 0.002 | 0.005 | 0.002 | 0.006 | 0.004 |
| V | 0.000 | 0.001 | 0.005 | 0.005 | 0.002 | 0.007 |
| VI | 0.000 | 0.000 | 0.002 | 0.011 | 0.029 | 0.028 |

[1]Estimated from element selection method
[2]Estimated from matrix selection method

**Table 3**. Elasticity matrix for the *Horkelia congesta* population at Long Tom ACEC, 1993-2004 (data not taken in 2000 and 2001). The stage/size categories are defined in the caption for Table 2. Elasticities represent the relative sensitivity of the population growth rate (lambda) to small changes in the transition probabilities. The sum of all elasticities is 1.0, and the sum of each column is the total proportional sensitivity of lambda to changes in transition probabilities in that stage.

**Elasticities, 1993-2004 matrix**

| | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| I | -- | -- | -- | 0.0111 | 0.0202 | 0.0505 |
| II | 0.0566 | 0.0980 | 0.0282 | 0.0107 | 0.0074 | 0.0037 |
| III | 0.0223 | 0.0480 | 0.0632 | 0.0217 | 0.0105 | 0.0070 |
| IV | 0.0018 | 0.0301 | 0.0328 | 0.0376 | 0.0253 | 0.0125 |
| V | 0.0011 | 0.0161 | 0.0272 | 0.0328 | 0.0446 | 0.0369 |
| VI | 0.0000 | 0.0124 | 0.0213 | 0.0262 | 0.0508 | 0.1315 |
| sum | 0.0818 | 0.2046 | 0.1727 | 0.1401 | 0.1588 | 0.2421 |

### *Population growth rate vs. seasonal precipitation*

The observed and predicted population growth rates were correlated against seasonal precipitation (measured at the Eugene Airport) through 2003 to determine if growth rate was related to precipitation (Figure 7). No significant correlations were observed, however.

## DISCUSSION

### *Population trends at Long Tom ACEC*

The population of *Horkelia congesta* ssp. *congesta* at Long Tom ACEC grew from 442 plants in 1993 to 596 in 1996, declined to 369 in 2002 but increased again to 515 in 2004. The average annual population growth rate, lambda, can be interpreted as an integrated summary for the rates of birth, death, and survivorship. Lambda is most appropriately used as a short term measure of population health. Overall, the population of *Horkelia congesta* ssp. *congesta* at Long Tom ACEC was fairly stable from 1993 to 2004, with an average equilibrium population growth rate of 1.035 (nearly 1.0). The stochastic population growth rate was only slightly lower, at 1.029 and 1.032 for two methods of stochastic simulation. The population is projected to continue this very gradual increase and, based on simulations with observed levels of environmental variability, has no probability of extinction (0.0%) in the next 100 years. However, if conditions change at the site (e.g., non-native species invasion, tree encroachment, increased deer populations, etc.), these projections will not be valid.

The elasticity analysis indicates that small changes in the survivorship of reproductive adults, especially the largest class with three or more flowering stems, would have large effects on the population growth rate. Two potential threats to survivorship are grazing by deer and succession. Grazing by deer results in removal of inflorescences. However, individuals that were grazed in 1993 did not differ in survivorship from individuals that were not grazed in 1993; therefore, continued grazing of *Horkelia congesta* ssp. *congesta* by deer may not impact the population growth rate via lowered adult survivorship. However, since an average of nearly half (44%) of all reproductive stems have been grazed off over the years in which data were gathered, it seems likely that deer negatively affect fitness of *Horkelia congesta* ssp. *congesta* by reducing seed output, which may, in turn, limit population growth. On the other hand, seedling recruitment has a relatively small impact (elasticity=0.0818) on population growth rate, so the effects of deer are currently unknown.

Succession of woody plants in the habitat of *Horkelia congesta* may also be cause for concern. In the absence of fire, woody shrubs and trees may shade and out-compete many prairie plant species, resulting in a conversion of prairie/savannah habitat to woody thicket or riparian forest. In addition, invasion by weedy grasses and other herbaceous species can increase competition for *H. congesta* and create habitat conditions favorable to voles, which in turn may graze on native species. Although the current viability of the population appears to be strong, invasion of the prairie habitat by woody vegetation is continuing to occur at this site. Past management efforts have improved conditions at this site, but will need to be repeated to maintain low extinction probability and high stochastic growth rates of *Horkelia congesta* here. Prescribed burns in 1998 and subsequent manual tree removals have been conducted by BLM to improve habitat for *Lomatium bradshawii* and other species at this site. These activities appear to improve the overall habitat and may have benefitted *Horkelia congesta* as well. The population declined in 1999 following the 1998 burn, but this decline appeared to start in 1997 and may have little to do with the burn. In the last three years the population has increased substantially but remains lower than sizes recorded in 1995 through 1998.

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