
***Lomatium cookii* population monitoring in the Illinois Valley, Josephine County, Oregon**

2009 Progress report

**Robert T. Massatti, Thomas N. Kaye, and Andrea S. Thorpe
Institute for Applied Ecology**



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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 the Bureau of Land Management. IAE is a non-profit organization dedicated to natural resource conservation, 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.

Questions regarding this report or IAE should be directed to:

Thomas N. Kaye or Andrea Thorpe
Institute for Applied Ecology
PO Box 2855
Corvallis, Oregon 97339-2855
phone: 541-753-3099
fax: 541-753-3098
email: tom@appliedeco.org, andrea@appliedeco.org
web: www.appliedeco.org

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INTRODUCTION

Lomatium cookii (cover photo, Figure 1), Cook's desert-parsley, is listed as endangered by the State of Oregon and by the U.S. Fish and Wildlife Service (USFWS). It is closely related to *L. bradshawii* (Rose) Math. & Const., an endangered species found in the Willamette Valley of western Oregon. Several significant populations of *L. cookii* occur on land managed by the Bureau of Land Management (BLM) Medford District. This progress report documents monitoring methods and results on the BLM Medford District through 2009 and is the product of a cooperative effort between the BLM and the Institute for Applied Ecology.

Review of past monitoring

The largest federally-owned population of *L. cookii* was discovered in 1992 at French Flat on the BLM Medford District. Areas around this population were placer-mined for many years. During the 1993 field season, staff from the BLM Medford District established long-term monitoring plots and transects in the three largest subpopulations of *L. cookii* in this area (Tong 1993). Additional plots and documentation of the monitoring protocol were added in 1994 (Kaye and Kirkland 1995). A long-term monitoring transect located southeast of these subpopulations was established by BLM Medford District botanists in 1990 (Knight 1992) and was monitored through 1994 (Kaye and Kirkland 1995), but has not been relocated in recent years and is not discussed in this report. Annual monitoring plots were established on BLM land near Rough and Ready Creek in 1994 and at Indian Hill in 1997. Monitoring between 1994 and 1999 was conducted by the Oregon Department of Agriculture Plant Conservation Biology Program. Since 2000, populations have been monitored by the Institute for Applied Ecology.

Description

Lomatium cookii is a member of the Apiaceae (parsley family). The plants are usually less than 3 dm tall and inconspicuous except when in flower. Ternately divided leaves feature many narrow leaflets and creamy yellow flowers are produced in compound umbels on leafless stems (Figure 1). Fruits are flat and oblong. The species was originally described by Kagan in 1986 from specimens collected in the Medford area.



Figure 1. Line drawing of *Lomatium cookii* from Kagan (1986).

Geographic range

Lomatium cookii is endemic to southwestern Oregon. Two population centers are known, the Illinois Valley in Josephine County and the Agate Desert north of the Medford Plains in Jackson County (Kagan 1994). This report focuses on population monitoring on BLM land in the Illinois Valley at French Flat, Indian Hill, and Rough and Ready Creek (Figure 2). The Nature Conservancy currently monitors populations on their lands in Jackson County.

Habitat

The populations of *L. cookii* studied in the Illinois Valley are found in moist, grassy meadows dominated by *Danthonia californica* (Kaye and Blakeley-Smith 2002). Other associated species include *Deschampsia cespitosa*, *Festuca roemerii* ssp. *klamathense*, *Stipa lemmonii*, *Camassia quamash*, *Ranunculus occidentalis*, *Hesperochiron occidentalis*, *Downingia yina*, *Horkelia daucifolia*, *Isoetes nuttallii*, *Calochortus nudus*, and *Viola hallii*. One patch of *L. cookii* individuals at the Rough and Ready Botanical Wayside was observed growing up through a dense ground-cover of *Rhus diversiloba*. Trees and shrubs, such as *Pinus ponderosa*, *Pinus jeffreyi*, *Arctostaphylos* spp., and *Ceanothus cuneatus* border these grassy meadows.

Reproductive biology

Flowering stems begin to emerge from a rosette of leaves in late February and flowers usually bloom around mid-March and continue into May. As with some other *Lomatium* species, the earliest umbels are predominately staminate, while later umbels have both staminate and hermaphroditic flowers. Plants that produce only one umbel produce very few, if any, fruits (Kaye and Kirkland 1994). Several pollinators have been observed visiting *L. cookii* including a small bee in the Andrenae family (Brock 1987) and a small black moth (Kagan 1986). During 1994 and 1995, we observed large numbers of bumblebees (*Bombus* spp.) regularly visiting the flowers at French Flat in the Illinois Valley.

Concerns

Lomatium cookii habitat in the Illinois Valley is threatened by rural development and abuse by recreational users in the area. Both the French Flat and Rough and Ready Creek sites continue to be severely damaged by OHRV use, where we observed fresh vehicle tracks in 2002 - 2007. At both sites damage was severe in the *L. cookii* population, even disturbing population monitoring plot markers. A trash pile, complete with old appliances and deep tire ruts, was found at the Rough and Ready Creek population in 2003. Tire ruts were found again at site in 2007.

Mining activities are also a concern. Placer gold mining has restricted the population at French Flat and permanently altered much of the natural hydrologic patterns through the meadows. Hydrology at the Rough and Ready Creek population is affected by a nearby irrigation ditch and by roads that pass through and divide the population. Some of the French Flat subpopulations monitored and discussed in this report are located on BLM managed lands adjacent to the Hillside Placer No. 1 and No. 3 Mines owned and operated by a local resident. A proposed mining plan filed in 1993 would involve destruction of a significant portion of this subpopulation.

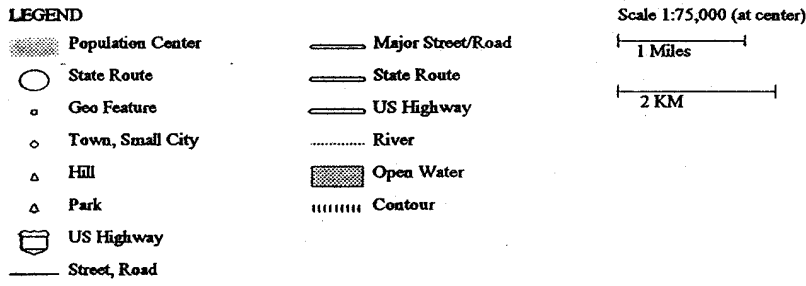
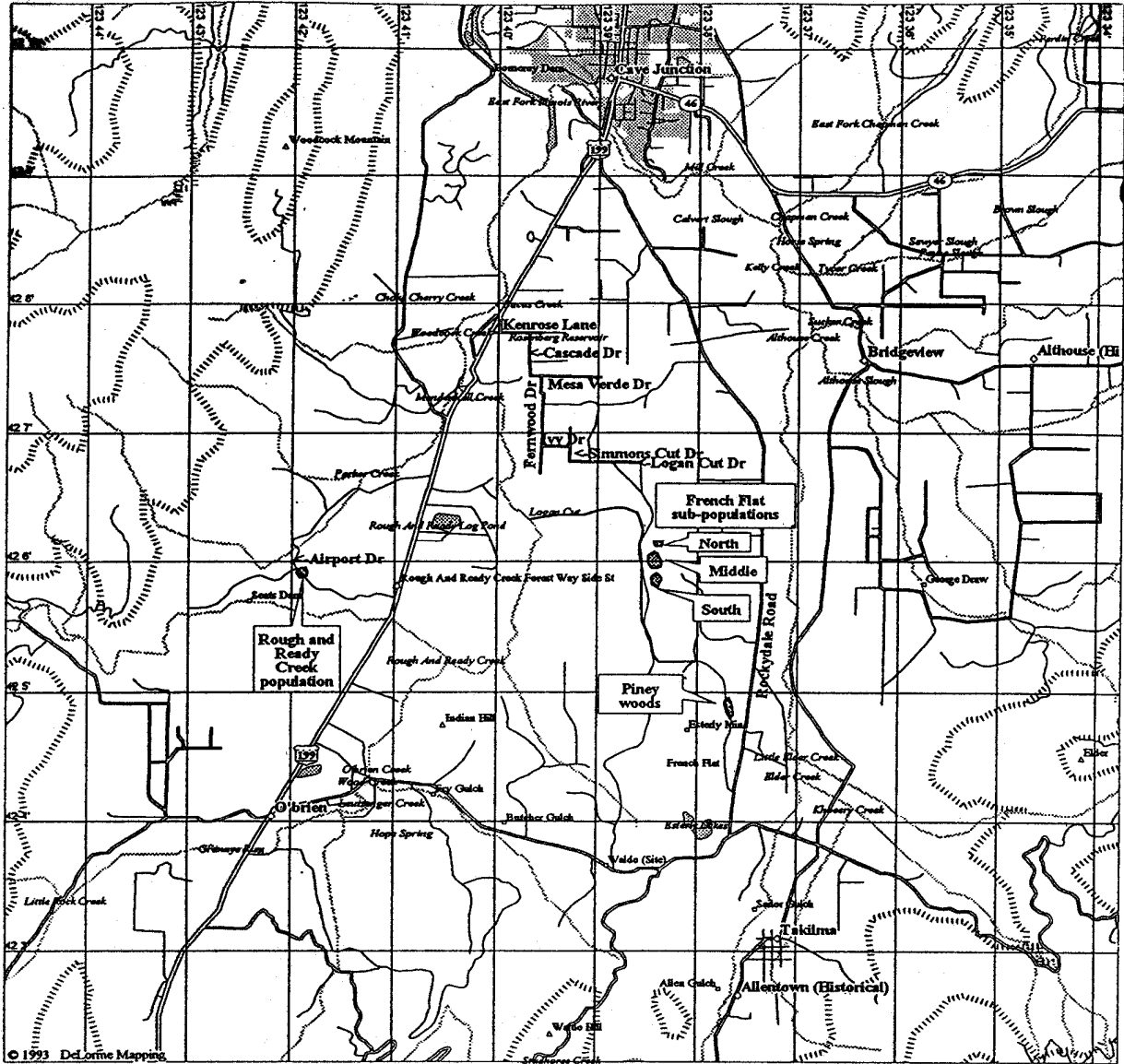


Figure 2. Locations of the *Lomatium cookii* study sites included in this report. Note: other *L. cookii* subpopulations occur in this general area but are not shown.

Objectives

The purpose of this cooperative project is to assist in recovery efforts for *L. cookii* through the following population monitoring tasks:

- Resample existing monitoring plots on BLM land near French Flat to monitor changes in population size or density.
- Resample existing monitoring plots at the Rough and Ready Creek Botanical Wayside to monitor changes in population size.
- Resample permanent monitoring plots at the Indian Hill population.
- Summarize monitoring data from 1993 through 2009.
- Summarize information from long-term demographic plots within the French Flat subpopulation to provide information on the mortality and survival of plants in six life-history stages, and develop a population viability model based on information from 1994-2009.

METHODS

Review of populations

Study populations included in this report are French Flat, Rough and Ready Creek, and Indian Hill. Monitoring has been conducted at four subpopulations, North, Middle, South, and Piney Woods (Figure 2), in or near French Flat since 1990. Currently, only the middle and south subpopulations (Figure 3) are monitored annually. Monitoring at Piney Woods was initiated in 1990 (Knight 1992). Monitoring at this site was conducted in 1994, but is not discussed here. Transects and monitoring at French Flat North was initiated by BLM staff in 1993 and was repeated in 1994 (Tong 1993). Transect and monitoring plots were also initiated by BLM staff at French Flat South and Middle in 1993 (Tong 1993). Sample plot numbers and sizes were modified in 1994 and the updated protocols are described below. These subpopulations continue to be monitored annually. Monitoring plots at Rough and Ready Creek were initiated in 1994. At Indian Hill, plots were established and sampled in 1997. The monitoring and sampling methods for each study site differ significantly, and are described separately. Units of measure (meters or feet) differ because different people initiated the monitoring plots at specific sites.

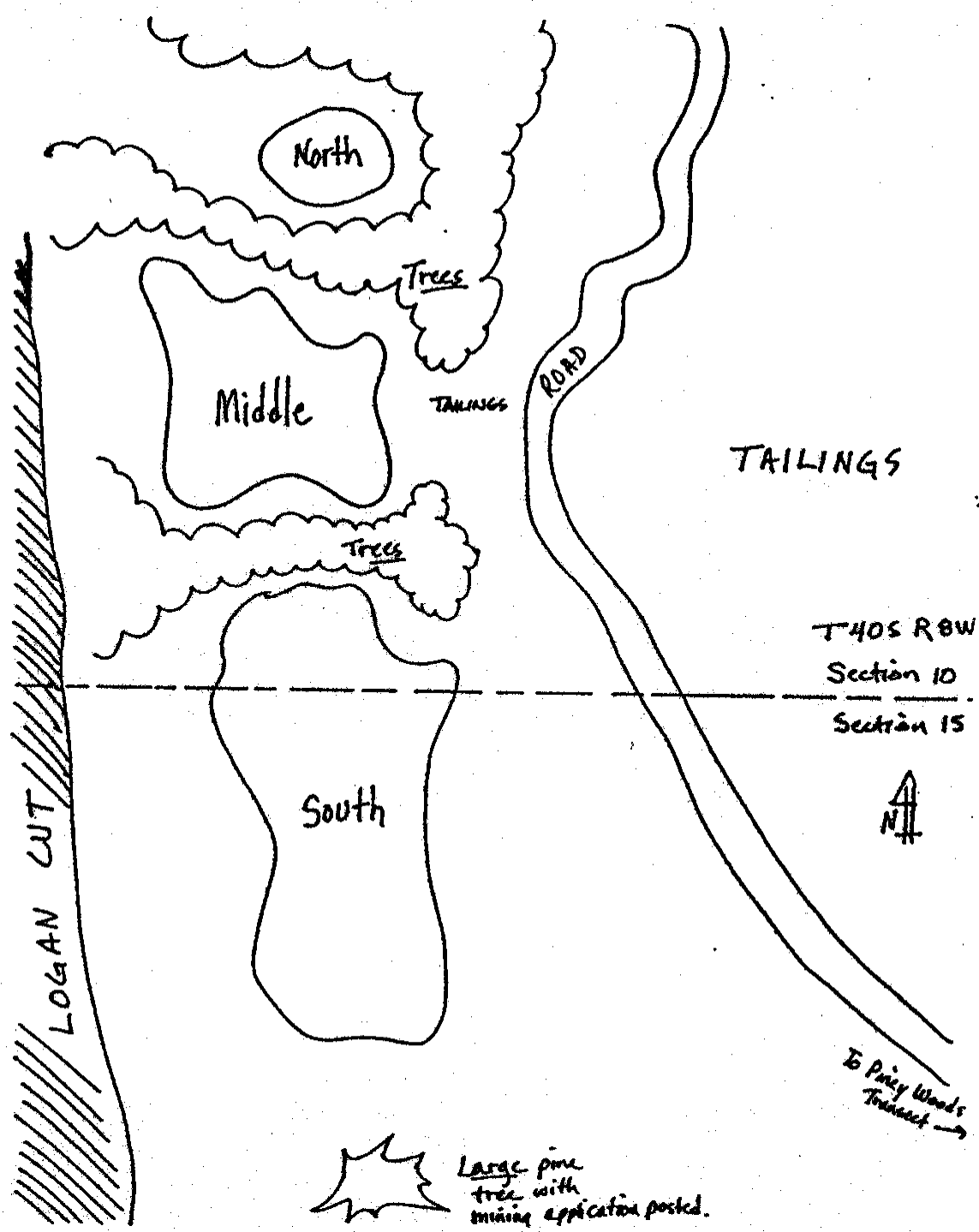


Figure 3. Sketch diagram of three French Flat subpopulations of *Lomatium cookii*. The Middle and South subpopulations include long-term monitoring subplots and transects, while the smaller North subpopulation is sampled with radially arranged transects only.

French Flat North

At the French Flat North subpopulation, seven radially arranged transects were centered on a flagged rebar post located roughly at the center of the patch of plants (Figure 4). The endpoints of each transect were marked with flagged rebar. A foot/meter tape was stretched from the center post to the endpoint rebar. The presence of *L. cookii* was recorded along each foot and within 6 inches of either side of the tape (Tong 1993). This population is not currently monitored.

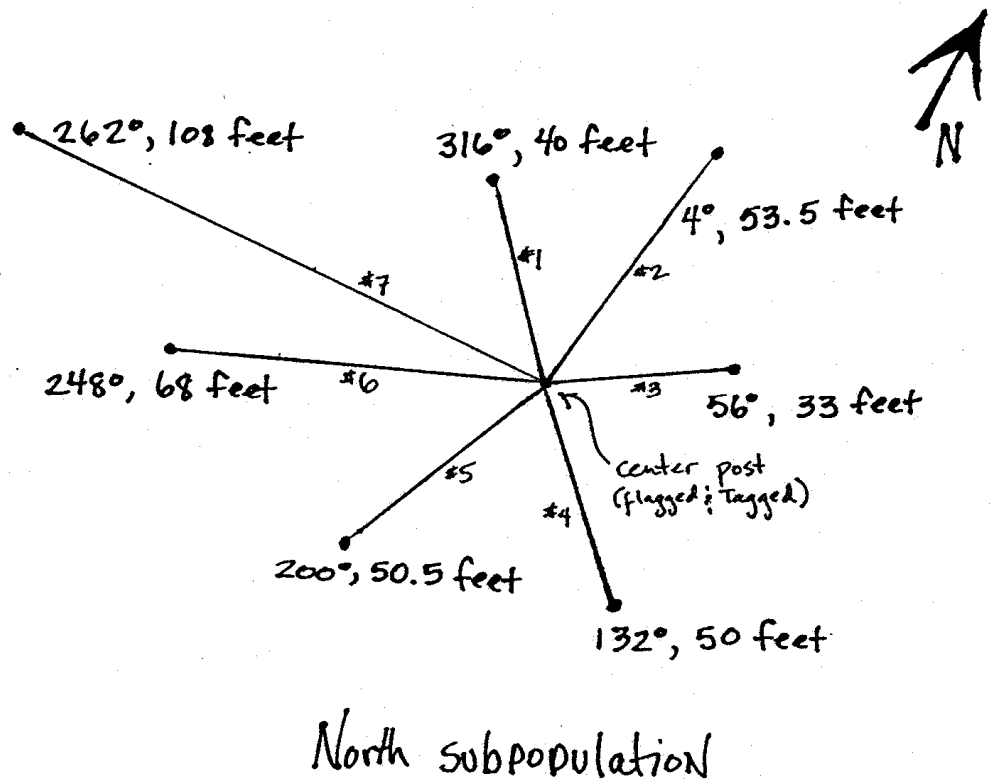


Figure 4. Sketch diagram of transects at the North subpopulation. Bearings and lengths (in feet) are indicated.

French Flat Middle and South subpopulations

Long-term monitoring plots were established at the Middle and South subpopulations in 1993. Density monitoring plots (1 foot x 10 feet and 1 foot x 20 feet) were located randomly within x, y coordinate grids positioned to cover the entire area of each subpopulation (Figures 5 & 6). The origins of the grid baselines were permanently marked with rebar. During the 1994 season, we recorded x, y coordinates for each of the plots at these subpopulations, measured locations and bearings of reference transects, added additional sampling plots, and adjusted the plot sizes [see discussions for each subpopulation below, and Kaye and Kirkland (1995)]. Two corners of each plot were permanently marked with rebar and metal pins were temporarily used for the other two corners of the rectangular plots during sampling.

Middle subpopulation

To locate the baseline grid in the Middle subpopulation, a tape representing the y-axis was stretched at a bearing of 35° east from the origin rebar (marked with a numbered copper tag and flagged) to a rebar post at 165 feet marked with a BLM "vegetation study" sign. Forty plots were established at random locations within the grid system. Demographic plots were established at sampling plots numbered 1, 3, 6, 7, 8, 10, 13, 16, 17, 18, 23, 25, 28, 29, 30, 31, 33, 37, 38, and 39.

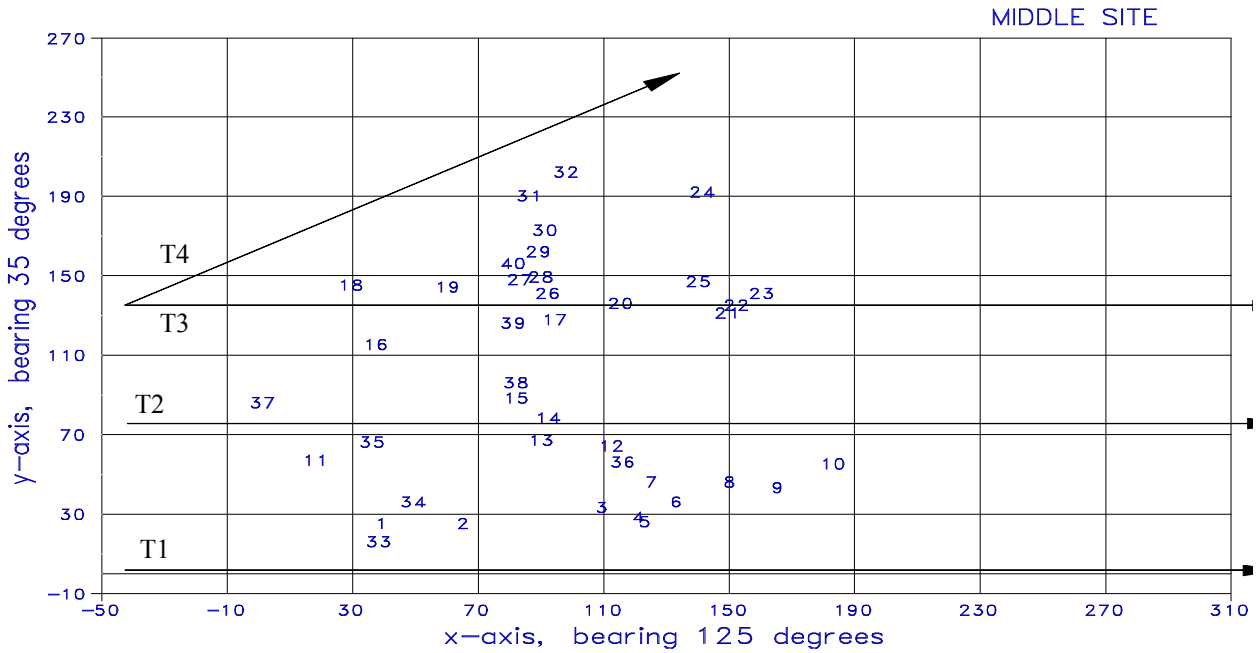


Figure 5. Layout of plots in the Middle subpopulation at French Flat. The plot numbers represent the relative location of the north corner of each plot. Lines with arrowheads are subpopulation boundary transects.

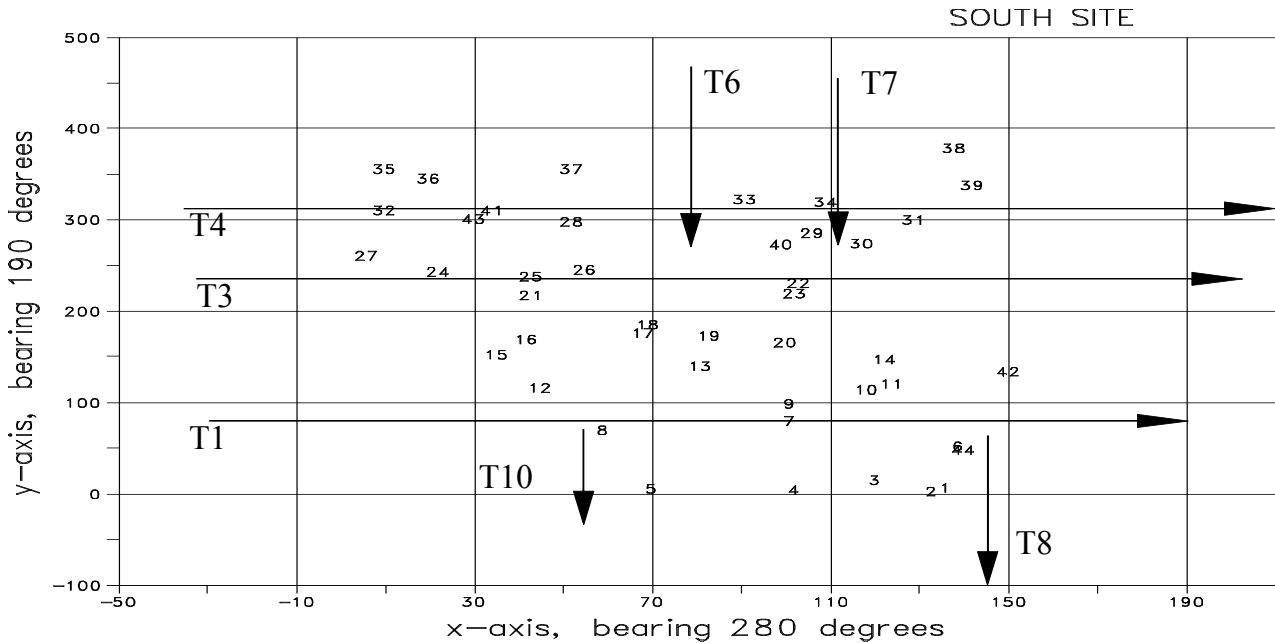


Figure 6. Layout of plots in the South subpopulation at French Flat. The plot numbers represent the relative location of the north corner of each plot. Lines with arrowheads are subpopulation boundary transects.

South subpopulation

Foot/meter tapes attached end-to-end representing the y-axis were stretched at a bearing of 190° east from the origin rebar to a rebar post approximately 400 feet away. A numbered copper tag was attached to the northeast corner rebar post of each plot for identification. Four new plots were established at random locations within the grid system, bringing the total number of sampling plots to 44. In addition, existing plots were enlarged by moving the northwest corner rebar of each plot ten feet west, making all plot dimensions 1 foot x 20 feet.

Demographic plots were established at twenty-two sampling plots numbered 1, 2, 3, 4, 7, 8, 13, 15, 16, 19, 21, 23, 24, 25, 26, 33, 35, 38, 39, 40, 42, and 43. Due to intense ORV disturbance in 2003, several rebar posts were missing, including one or both corner rebar posts for plots 5, 28, 34, 38, and 39. Plots were reconstructed using the appropriate compass bearings and coordinates, and the rebar pieces were replaced.

As at the North subpopulation, several transects cross the boundaries of the Middle and South subpopulations (Table 1). The presence of *L. cookii* along these transects was recorded in 1994 using the same method as described for the North subpopulation.

Density plots

We delineated plot boundaries with a meter tape and all plants within the plots were counted and assigned to a specific life-history category, as follows:

- S seedling
- V1/2 vegetative with 1 or 2 leaves
- V3 vegetative with 3 or more leaves
- R-1 reproductive with 1 umbel
- R-2 reproductive with 2 umbels
- R-3 reproductive with 3 or more umbels

Table 1. Orientation of population-boundary transects at the French Flat Middle and South subpopulations. Values under 'origin' represent x-y coordinates of tagged rebar posts.

Subpopulation	Transect	Origin (x, y; feet)	Bearing (degrees)	Length (feet)
Middle	1	-43, 0	120	297
“	2	-43, 72	124	345
“	3	-43, 134	120	345
“	4	-43, 134	86	199
South	1	-56, 90	280	235
“	2	unable to locate origin		
“	3	-43, 230	280	223
“	4	-43, 300	280	223
“	5	unknown (endpoint 14, 314)		
“	6	unknown	10	151.5
“	7	111,451.5	10	135.5
“	8	146, 70	10	157
“	9	101,72	10?	unknown
“	10	50, 74	10	57

Life-history categories were originally developed for *L. bradshawii* monitoring in the Willamette Valley (Kaye et al. 2001). The similarities of the life-history characteristics of these species cause the categories to be applicable to *L. cookii* as well. Reproductive plants were segregated by umbel number because studies of *L. bradshawii* have shown that one-umbel plants rarely produce seed, while two-umbel plants produce seed on the second umbel, and three umbel plants may produce many seeds (Kaye 1992, Kaye and Kirkland 1994).

Demographic plots and analysis

Demographic plots were established at the Middle and South subpopulations in 1994. Sampling was suspended from 2000 through 2007 at the Middle subpopulation because sufficient information on population dynamics could be obtained from long-term study of one subpopulation to understand the basic life-history of the species and prepare a transition matrix model. In 2008 and 2009 the Middle subpopulation was resampled and the updated information is presented below. Demographic monitoring at the South subpopulation has been consistent through the present year.

Plot sampling: At each subpopulation (Middle and South), 20 existing density plots were randomly selected as locations for 0.5 meter x 0.5 meter demographic plots (Figure 7). Within each demographic plot, all *L. cookii* plants were mapped, given unique numbers (beginning with #1), assigned to the life history categories discussed earlier, and the presence or absence of grazing was recorded. To sample, a 0.5 meter x 0.5 meter frame was placed over the left rebar post, with the post positioned in the lower left corner of the frame.

Calculation of survival rates and estimates of fertility: All first year vegetative plants with one or two leaves (and occasionally cotyledons) were considered seedlings; larger plants that appeared without previous observation were considered seedlings the previous year. We used spreadsheet and database computer software to calculate the proportion of each stage that entered another stage (or remained the same) between consecutive years, and the proportion of individuals in each stage in each year. To estimate the number of seedlings produced by an individual in each reproductive stage (i.e., the fecundity of each stage), we used data on seed production from *L. cookii* sampled in 1996, the number of plants in each reproductive stage in the density plots, and the number of seedlings observed the following year in the density plots. These survival rates and estimates of fertility for each stage were arranged in 'transition matrices' for each pair of years from 1994 through 1999 and 2008 through 2009 for the Middle subpopulation and from 1994 through 2009 for the South subpopulation. See Kaye and Pyke (2003), Kaye et al. (2001), Caswell and Kaye (2001), or Menges (1986) for complete discussions of transition matrix models for plant population dynamics and viability analyses.

Population Viability Analysis, deterministic and stochastic modeling: We evaluated population growth rate and viability with the transition matrices using data from the South subpopulation from 1994-2009, and for the Middle subpopulation from 1994-1999 and 2008-2009. For this analysis, we calculated both deterministic and stochastic measures of population growth [λ], and stochastic lambda (λ_s)] for each subpopulation. Lambda is the equilibrium population growth rate (and the dominant eigenvalue of the transition matrix), and can be used as a single measure of population viability to compare sites. Stochastic lambda (λ_s)

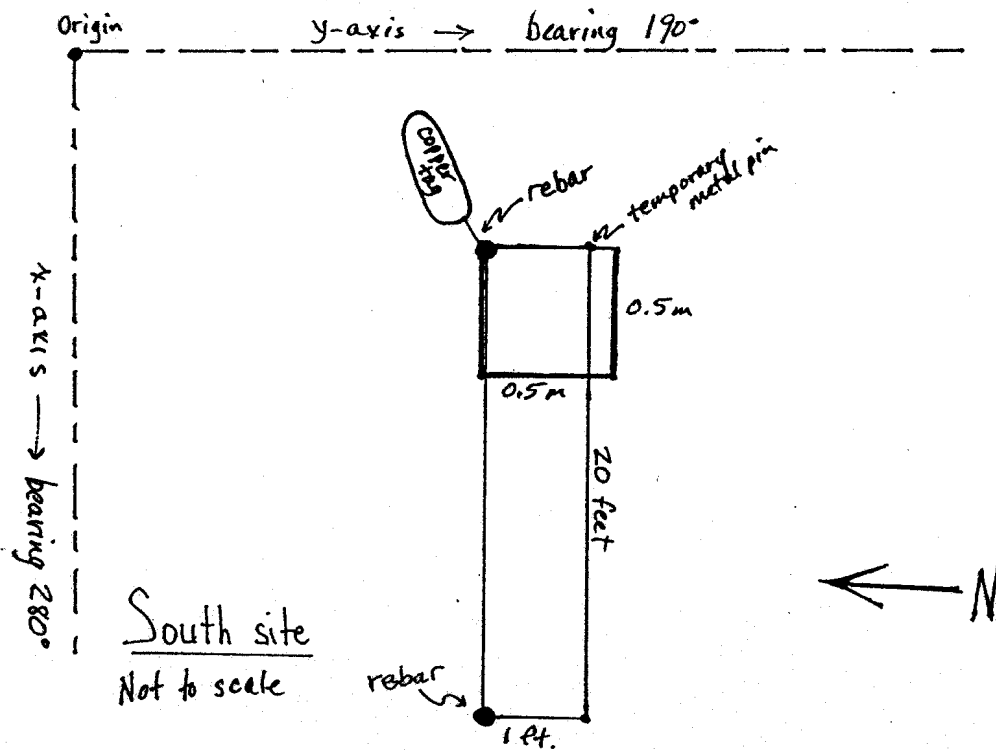
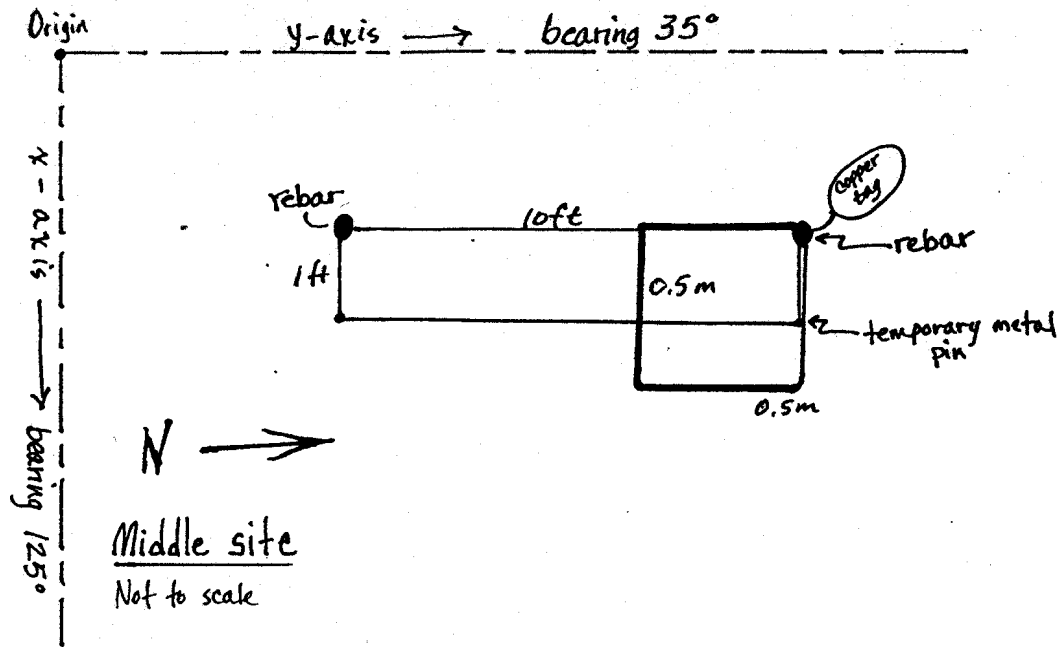


Figure 7. Sketch diagram of the orientation of the *Lomatium cookii* sampling and demographic subplots at the Middle (top) and South (bottom) subpopulations at French Flat.

does not assume equilibrium population dynamics and incorporates observed environmental variability. If either type of growth rate is less than 1.0, the population will be projected to decrease in size, and eventually become extinct (a non-viable population). If λ is greater than 1.0, the population will grow (a viable population), given that current conditions remain constant. For each site, we calculated λ for each year of observation (i.e., 1994-99 and 2008-2009 at Middle, and 1994-2009 at South). In addition, we used the average matrices from these available matrices to calculate an average population growth rate.

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 λ 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. In addition, we assumed that plants that first appeared in the V2 stage were seedlings in the previous year, and that plants did not exhibit dormancy; years in which plants were skipped were considered missing data. We tested these assumptions with data collected through 2003, and they were found to have little effect on population growth rate compared to alternative assumptions (e.g., that new V2 and V3 plants were seedlings in the previous year, and that dormancy can occur).

Analysis: We conducted a population viability analysis incorporating environmental stochasticity. Population viability was evaluated in two different ways, stochastic population growth rate and extinction probability. This involved projecting future population dynamics by randomly selecting survival and fecundity measures from past years. 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 1994. The matrices represent each year of the study, and the variation among them is considered to be environmental stochasticity. To calculate stochastic population growth rate, we used the program LAMS (Kaye 2001) with 100,000 iterations.

We also calculated extinction probabilities for each subpopulation as a second measure of population viability. This kind of modeling involved projecting future population dynamics by randomly selecting survival and fecundity measures from past years with the matrix selection method. More detailed descriptions of this method can be found elsewhere (e.g., Burgman et al. 1993, Kaye and Pyke 2002). These simulations ran for 20 years and consisted of 10,000 iterations. The starting population size for each simulation was 113,775 for the Middle subpopulation and 60,747 for the South subpopulation (the 2009 sizes), distributed among the six stages as follows: S=11%, V2=24%, V3=37%, R1=14%, R2=12%, and R3=2%. These proportions represent the average population structure. The simulations stopped at the quasi-extinction threshold of 50% decline or 99% decline; this provided a conservative estimate of extinction dynamics. We used the program SHUFFLE (Kaye, unpublished program) written for MATLAB to evaluate extinction probability with matrix selection methods.

In addition, we calculated elasticities of the mean matrix for both sites. 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). We used the commercially available computer software, MATLAB 6.1, to calculate elasticities.

Environmental factors affecting population dynamics: We also examined correlations of environmental variables and population growth rate at the South subpopulation. Stepwise multiple regression was used to build models with data from 1994 - 2003 and the models were validated with data obtained from the Middle subpopulation. Seasonal precipitation and herbivory by voles were the environmental variables examined. We obtained precipitation records from the Oregon Climate Service website for the Cave Junction weather station. Monthly precipitation amounts for each year of the study were combined into functionally seasonal precipitation measures as follows: fall (September through November), winter (December through February), spring (March through April), and summer (May through August). Vole herbivory, or grazing, was measured as frequency of damage to plants by voles as recorded on our field data sheets. This type of damage was encountered as eaten leaf stems or flower clusters.

Rough and Ready Creek

The population at Rough and Ready Creek was documented in 1993 (Kagan 1994). One patch of plants at this location is on BLM-managed land and was identified as a potential site for long-term monitoring.

In 1994, we established three transects for long-term monitoring of the two densest patches of *L. cookii* (plants in the remaining patches were simply counted and the patches were mapped; Figure 8). To sample these transects, a 1 meter x 1 meter quadrat frame (constructed from light-weight ¾ inch PVC pipe) was placed on the ground at each meter mark along a measuring-tape stretched between rebar posts (Figure 9). The individuals rooted within the frame were counted and assigned to the same stage categories used at French Flat.

Transects 1 and 2 are positioned within patch A (Figure 8). The origin for transect 1 was a rebar post set about 1 meter south of a flagged conifer and the endpoint was a rebar post set 15 meters away at a bearing of 130° east. The origin for transect 2 was a rebar post set 2 meters east of the origin-post for transect 1 and the endpoint was a rebar post set 15 meters away at a bearing of 130° east. Thus, transect 2 is adjacent and parallel to transect 1. [Note: In 1994, the origin for transect 2 was the same as used for the origin of transect 1; however, the plots along transect 2 began at the 3 meter mark to prevent overlap of plots 1, 2, and 3 along transect 1. The endpoint for transect 2 was a rebar post set 15 meters away at a bearing of 110° east from the origin post. This arrangement was altered in 1995 to reduce confusion.] Transect 3 (patch G) was located along the shoulder of the south side of the road across from transects 1 and 2. The origin rebar was located just above the shoulder of the road at a bearing of 150° east from the flagged conifer. This transect changed bearing at the 4.5 meter mark to accommodate the curve of the road. A second rebar post was set at 4.5 meters at a bearing of 120° east and the endpoint rebar was set at a bearing of 134° east and a distance of 7.8 meters from the second rebar post. Transect 3 parallels the shoulder of the road and passes through very dense patches of poison oak. In 2009 transect tapes were laid out along wheel ruts to define patches B, C, D, E and F.

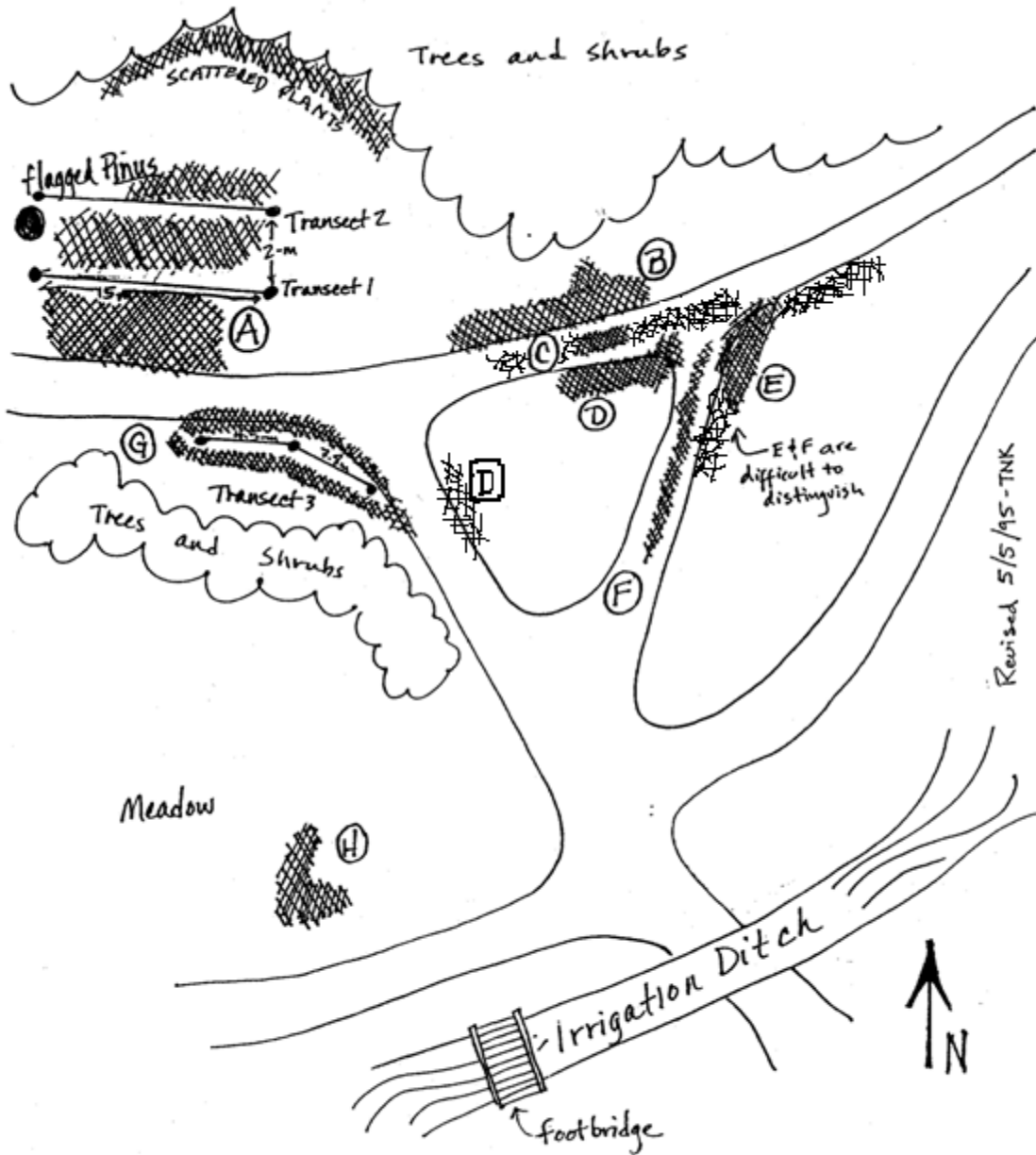


Figure 8. Sketch map of the *L. cookii* patches located at Rough and Ready Botanical Wayside. Cross-hatching indicates patches of plants. The long-term monitoring transects are also indicated in the drawing. Note that the patches are distinguished by the letters A-H.

Transects 1 and 2:

Transect line; plots oriented to either side of tape.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Transect 3:

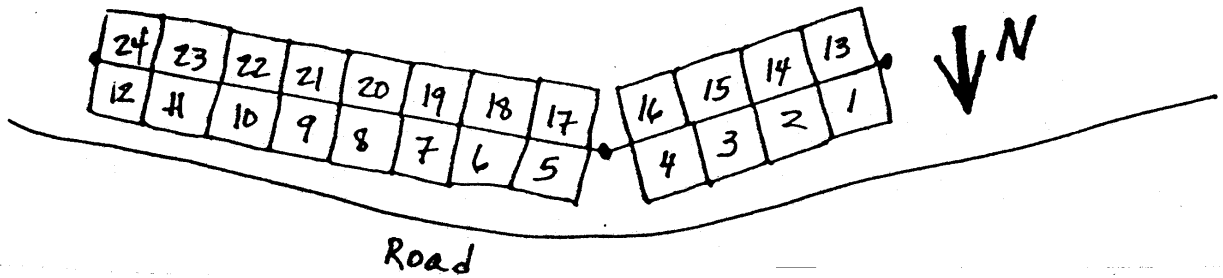


Figure 9. Orientation of the sampling plots around transects 1, 2 and 3 at the Rough and Ready Botanical Wayside population.

Indian Hill

The population of *L. cookii* at Indian Hill was first documented in 1996, and monitoring was initiated in 1997. The population occurs on BLM managed land, but access is through private land. The population occupies a long stringer of open vegetation surrounded by dense forest, and extends to near the banks of the West Fork Illinois River.

In 1997, we established a grid system over the population. The perimeter of the population was carefully outlined to determine the extent of the plants and available habitat. The grid system had a bearing of 30° along its long axis for the first 100 meters, then shifted westward to 5° for another 100 meters in order to conform to the shape of the habitat. Ten plots were sampled out of a total of 184 possible sample plot locations within the overall grid (Figure 10). All plots were 50 meters x 0.5 meters and were permanently marked at each end with rebar posts marked with flagging and copper tags with the plot number scratched onto the surface. To sample these plots, a 50 meter measuring tape was extended between rebar posts. The tape represented the west edge of the plot. Individual *L. cookii* plants that occurred within the plots (between the tape and 0.5 meter east) were counted and assigned to the same stage categories used at French Flat. Poison oak is patchy in this area, especially along the forest edges, so care should be exercised to minimize exposure. Also, *Lomatium utriculatum* and *Lomatium triternatum*, which may resemble *L. cookii*, occur in this area and were encountered in the sampling plots (Figure 11).

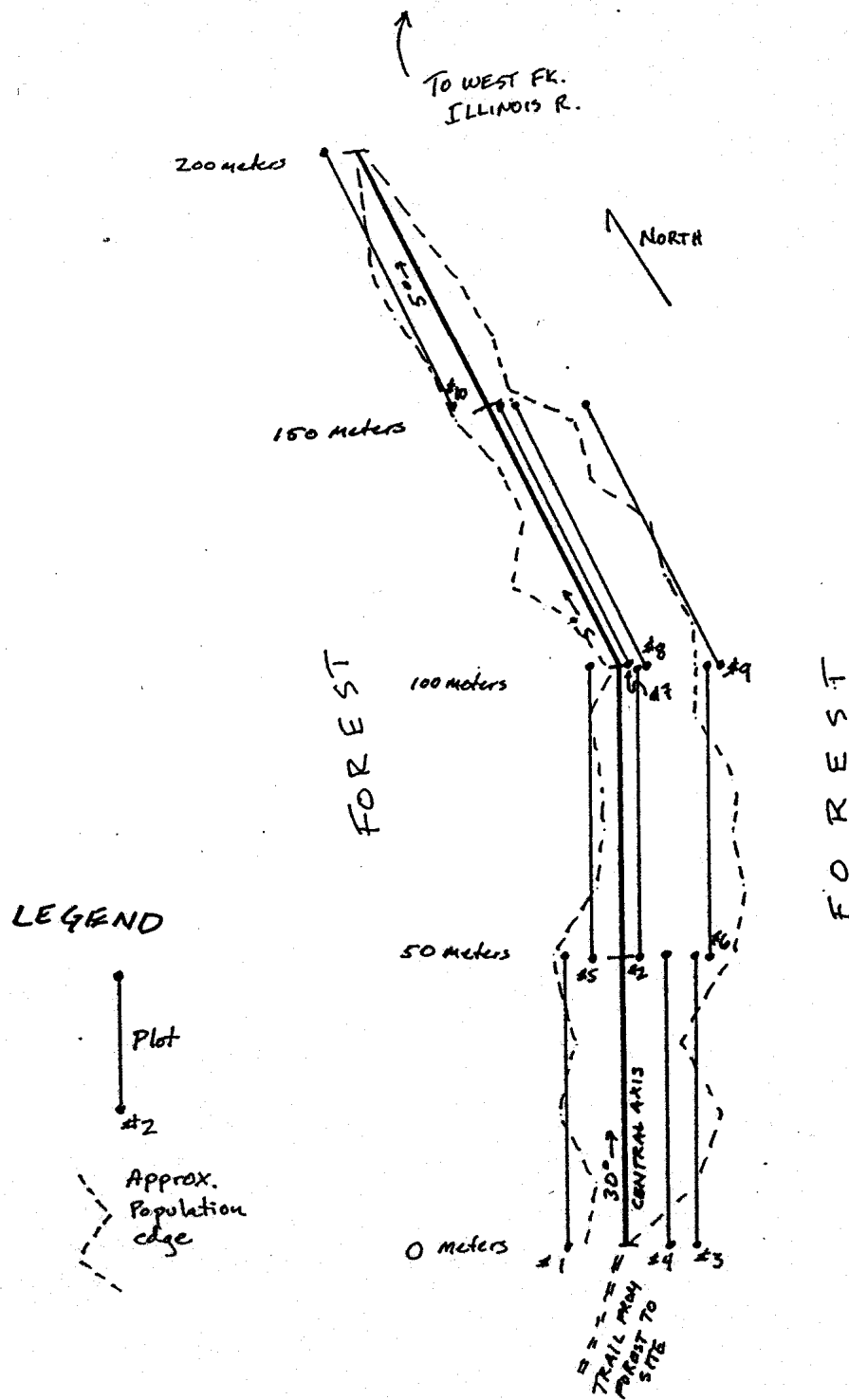


Figure 10. Plot layout of the *Lomatium cookii* population at Indian Hill. Sample plots are 50 meters x 0.5 meters, marked at either end by a rebar post (with a copper tag and flagging). The plots are monitored on the east side of the tape.



Figure 11. *Lomatium triternatum* (left), *L. cookii* (center), and *L. utriculatum* (right). These species can co-occur in sampling plots.

RESULTS

French Flat

Population size and density

In general, population size at the South subpopulation increased steadily from 25,538 (90% C.I.: 17,398 – 33,677) in 1993 to a peak of 124,890 (90% C.I.: 100,680 - 149,100) in 1998 (Figure 12, Table 2). This increase was due to several years of high seedling recruitment. From 1999 - 2007, with the exception of 2005, total population size declined to 37,531 (90% C.I.: 30,600 - 44,462). The population size has increased since 2007 by approximately 60% to 60,748 (90% C.I.: 47,545 – 73,951). The proportion of reproductive plants in the population declined from 1995 to 1997, reflecting the increased recruitment of seedlings that led to the total population increases observed in that time period (Figure 12 & 13). In general, the proportion of reproductive plants relative to the total population has increased, though in 2009 the proportion dropped 8% to 29%, again reflecting increased recruitment in recent years. In 2009, the density at the South subpopulation was 16 ± 2.2 (± 1 S.E.) plants/m², approximately $\frac{2}{3}$ of the long-term average. Density in this subpopulation has ranged from a low of 7 plants/m² in 1993 to a high of 33 plants/m² in 1997 and 1998 (Table 2).

The Middle subpopulation has been mirroring the trends of the South subpopulation (Figure 12). Population size grew from 88,688 (90% C.I.: 68,062 - 109,313) in 1993 to a high of 231,600 (90% C.I.: 191,710 - 271,490) in 2003. The population has since declined until 2009, when it increased 9.4% to 113,775 (90% C.I.: 90,453 - 137,097). The proportion of reproductive plants fell in 2009 to 31% after reaching a high of 41% in 2008 (Figure 13). In 2009, the density at the middle subpopulation was 20.5 ± 2.6 (± 1 S.E.) plants/m², $\frac{3}{4}$ of the long-term average. Density in this subpopulation has ranged from a low of 14.2 plants/m² in 1994 to a high of 41.7 plants/m² in 1998 (Table 2).

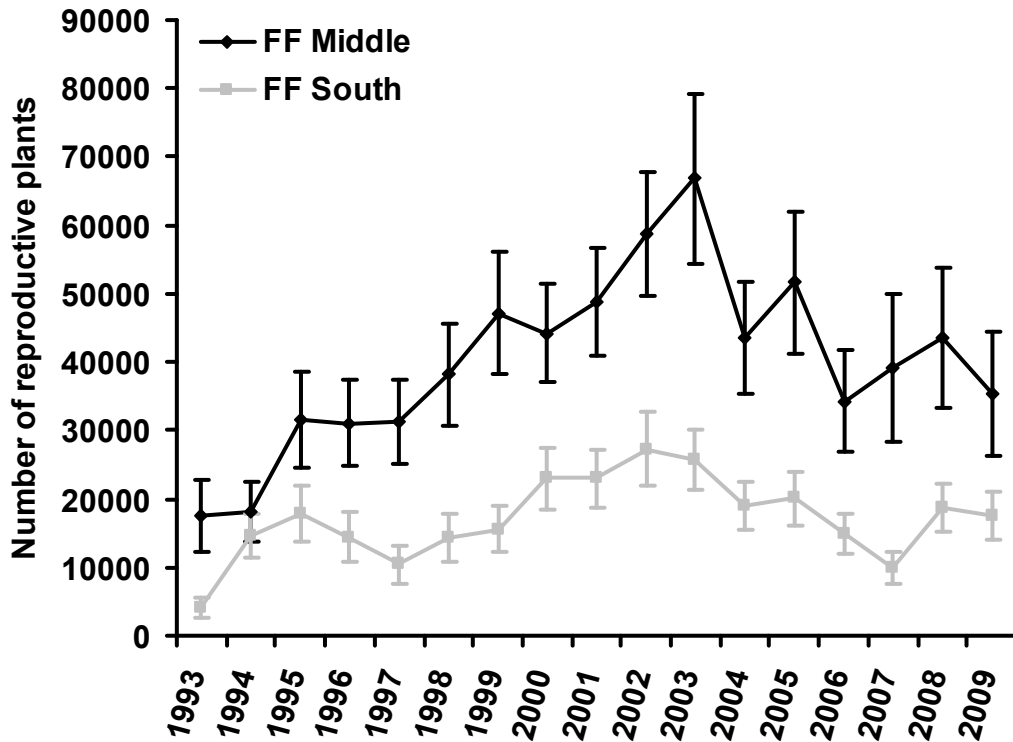


Figure 12. The total number of *Lomatium cookii* at Middle and South French Flat. Error bars represent a 90% confidence interval.

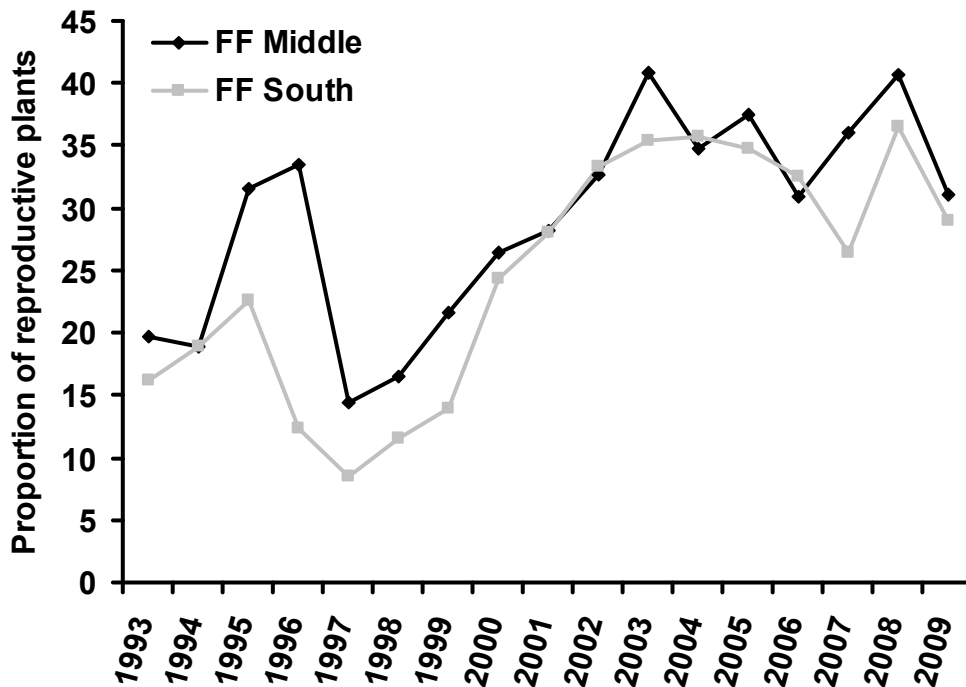


Figure 13. The number of reproductive *Lomatium cookii* relative to the total subpopulation at Middle and South French Flat.

Table 2. Summary of *Lomatium cookii* population data for the Middle and South French Flat subpopulations, 1993-2009. Population size and density estimates include all life-history stages from seedlings to large reproductive plants.

Year	Population Size (90% CI)	Density (plant m ⁻²) ± 1 SE	
French Flat Middle			
1993	88,688 (68,062 – 109,314)	16.0 ±	2.3
1994	95,250 (71,556 – 118,944)	14.2 ±	2.6
1995	100,575 (77,611 – 123,539)	18.1 ±	2.5
1996	92,850 (75,120 – 110,580)	16.7 ±	2.0
1997	217,050 (178,785 – 255,315)	39.1 ±	4.2
1998	231,600 (191,710 – 271,490)	41.7 ±	4.4
1999	217,200 (179,683 – 254,717)	39.1 ±	4.1
2000	167,250 (138,630 – 195,870)	30.1 ±	3.2
2001	173,100 (143,123 – 20,3077)	31.2 ±	3.3
2002	180,000 (150,522 – 209,478)	32.4 ±	3.3
2003	163,575 (132,505 – 194,645)	29.5 ±	3.4
2004	125,175 (99,990 – 150,360)	22.6 ±	2.8
2005	137,550 (110,795 – 164,305)	24.8 ±	3.0
2006	111,000 (85,810 – 136,190)	20.0 ±	2.8
2007	108,825 (83,640 – 134,010)	19.6 ±	2.8
2008	107,325 (87,378 – 127,272)	19.3 ±	2.2
2009	113,775 (90,453 – 137,097)	20.5 ±	2.6
French Flat South			
1993	25,538 (17,398 – 33,677)	6.8 ±	1.3
1994	77,081 (56,365 – 97,797)	20.6 ±	3.4
1995	79,192 (61,580 – 96,804)	21.2 ±	2.9
1996	115,714 (92,114 – 139,314)	31.0 ±	3.9
1997	123,697 (96,985 – 150,409)	33.1 ±	4.4
1998	124,890 (100,680 – 149,100)	33.4 ±	4.0
1999	111,786 (87,872 – 135,664)	29.9 ±	3.9
2000	94,517 (76,737 – 112,572)	25.3 ±	3.0
2001	81,807 (65,258 – 98,356)	21.9 ±	2.7
2002	81,624 (64,970 – 98,278)	21.8 ±	2.7
2003	72,402 (57,286 – 87,518)	19.4 ±	2.5
2004	52,948 (44,380 – 61,515)	14.2 ±	1.4
2005	57,719 (46,697 – 68,741)	15.4 ±	1.8
2006	45,928 (37,388 – 54,467)	12.3 ±	1.4
2007	37,531 (30,600 – 44,462)	10.0 ±	1.1
2008	50,975 (42,527 – 59,423)	13.6 ±	1.4
2009	60,748 (47,545 – 73,951)	16.3 ±	2.2

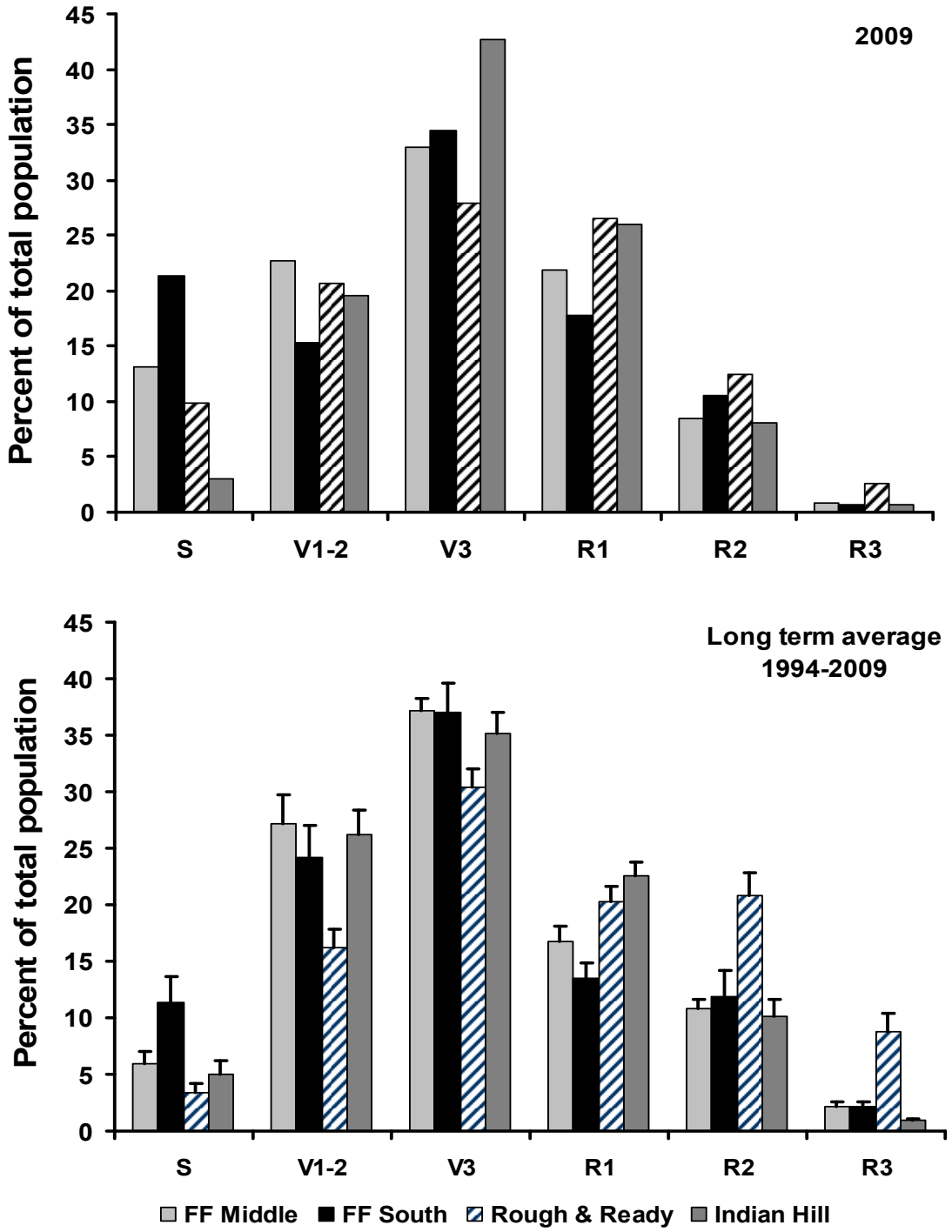


Figure 14. *Lomatium cookii* population structure in 2009 (top) and averaged over the course of the study (bottom) for the Middle French Flat subpopulation (1994 - 2009), South French Flat subpopulation (1994 - 2009), Rough and Ready Creek (1995 - 2009), and Indian Hill (1997 - 2009). Bars indicate the mean percentage of plants in each stage. See text for explanation of life-history stages. Error bars in the lower graph represent +1 SE.

Population structure

In 2009, the Middle and South subpopulations at French Flat were dominated by vegetative (V1-3) and small reproductive (R1) individuals (Figure 14). Previously, only the vegetative classes were dominant.

Demography and Population Viability Analysis

A total of 799 plants were mapped and categorized at the Middle subpopulation from 1994 through 1999 and 2008 through 2009 and 777 at the South subpopulation from 1994 through 2009. Data from these 0.5 meter x 0.5 meter demographic plots were analyzed to construct transition matrices for Middle and South subpopulations (Table 3).

Deterministic growth rates at Middle and South have fluctuated since monitoring began, indicating that the French Flat *L. cookii* populations vary in population dynamics over time (Table 4). Growth rates were at or above 1.0 at Middle from 1994 through 1998 but fell to 0.892 in 1998 – 1999. In 2008 – 2009, growth rate was also low at 0.843. Growth rates at South have experienced a downward trend since 1995 - 1996, when the population grew at its highest recorded rate of 1.416. In general, growth rates at South have remained below 0.9 since then. The lowest population growth rate, 0.598, was observed in 2007 - 2008, reflecting the extremely low number of seedlings observed in 2008.

In stochastic simulations incorporating environmental variability, South was projected to decline at an overall rate of 0.871. This reflects the overall poor annual growth rates at this site since monitoring began in 1994. At Middle, stochastic growth rate was much higher, 1.046, but this value represents observations from 1994-1999 and 2008-09 only. The risk of sharp decline (50% drop) in 20 years was 99% at South and less than 1% at Middle. At the South subpopulation, the risk of 99% decline in 20 years was 3.2% but 0 at Middle.

Thus, both deterministic and stochastic growth rates project that the South subpopulation will decline rapidly and substantially in the next two decades. These results are speculative, however, and additional years of data may show different trends if conditions at these locations change. The population growth rates and probabilities of decline reported here are best interpreted as comparisons of the performance of these two subpopulations rather than accurate predictions of future trends.

The elasticity analysis shows that small changes in the probability of V3 plants remaining in the V3 stage (0.101 at South and 0.114 at Middle) would have the single greatest effect on the population growth rate in both subpopulations (Table 5). The probability of R3 plants remaining at the R3 stage had the second greatest effect in both areas (0.076 and 0.109). Overall, V3 plants had the highest cumulative elasticity (0.213 and 0.245). The second highest elasticity was for the R2 stage (0.192) at South and R3 plants (0.216) at Middle. The seedling and R1 stages had the lowest cumulative elasticities (Table 5).

Annual mortality was generally lower in the Middle subpopulation than the South (Table 4). These mortality rates in the face of variable (sometimes positive) population growth over the same period indicate that the populations experience substantial dynamics, with individuals frequently changing size or dying with a variable influx of new plants. Complete information has not been tabulated on the life span of *L. cookii* individuals, but the information collected from the demographic plots can be used to determine or estimate how long individual plants live, if the plots

are sampled annually for several years. Of 53 seedlings mapped at South in 1994, 2 were still present in 2004 and 1 of them was reproductive. On average, less than half (42.9%) of seedlings survive for two years. Only 3 observed seedlings became reproductive after one year in the South subpopulation during this entire study. We found that 1.3% of seedlings became reproductive in 2 years, 4.1% in 3 years, and 5.1% in 4 years.

Environmental factors affecting Lomatium cookii at French Flat

Herbivory by voles during the previous year and fall precipitation were identified by stepwise multiple regression as the best explanatory variables of population growth rate of the South subpopulation (Figure 15). A total of 75% of the annual variation in population growth rate was explained by frequency of herbivory ($P = 0.004$) and fall precipitation (September through November, $P = 0.015$). Both variables had a negative effect on population growth rate. When this model was applied to the population growth rate of the Middle subpopulation, it explained 77% of the annual variation, but the variables were not significant at the 0.05 level (herbivory: $P = 0.093$, fall precipitation: $P = 0.061$). Both variables had a negative effect on population growth rate at the Middle subpopulation as well.

In an effort to understand how herbivory and precipitation were influencing population growth rate, the variables were correlated with seedling production per reproductive plant (R2 and R3 plants combined) present the previous year. Vole herbivory may damage plants by removing photosynthetic tissue (leaves and stems) as well as reduce or eliminate seed production if flower stalks are consumed. At the South subpopulation, herbivory in the previous year and fall precipitation were the only variables significant at the 0.1 level, explaining 65% of the annual variation in seedling production (Figure 16). Herbivory frequency ($P = 0.008$) and fall precipitation ($P = 0.057$) were both negatively correlated with seedling production. This model was also applied to the Middle subpopulation, where grazing ($P = 0.105$) and fall precipitation ($P = 0.040$) were found to explain 43% of the annual variation. Both were negatively correlated with seedling production.

From the elasticity analysis, changes in the probability of seedling production from both R2 and R3 plants is expected to have some effect on population growth rate (0.111 at South and 0.121 at Middle, Table 5) but this number is lower than the effect expected from changes in the V3 to V3 (0.101 and 0.114). Thus, some of the variability in population growth rate explained by the regression model is likely due to changes in probabilities of transitioning between other growth stages that correlate with changes in grazing frequency and fall precipitation. For example, an R3 or V3 plant that is heavily grazed in one year may be more likely to return the following year at a smaller stage than to remain at its current stage. Because of the high sensitivity of the population growth rate to changes in these transition probabilities, this could have a substantial effect on population growth rate.

Table 3. Average transition matrices used in the stochastic analyses for *L. cookii* at French Flat. The top row of each matrix represents the number of seedlings produced per reproductive plant (fecundity). Lower rows represent the probability of an individual in a given stage changing to another stage the following year. Stage-specific mortality is provided in the bottom row. The elements in the matrices are averaged from the transition data collected in 1994 through 2009 for the South subpopulation and 1994 through 1999 and 2008 through 2009 for the Middle subpopulation.

South, average matrix (1994-2009), lambda = 0.896						
	S	V2	V3	R1	R2	R3
S	0.000	0.000	0.000	0.000	0.572	3.561
V2	0.403	0.254	0.106	0.036	0.035	0.028
V3	0.259	0.329	0.418	0.199	0.079	0.000
R1	0.029	0.036	0.118	0.223	0.226	0.188
R2	0.026	0.014	0.062	0.218	0.268	0.106
R3	0.004	0.000	0.010	0.032	0.103	0.452
Mortality	0.254	0.309	0.245	0.245	0.280	0.204
Middle, average matrix (1994-1999 & 2008-2009), lambda = 1.063						
	S	V2	V3	R1	R2	R3
S	0.000	0.000	0.000	0.000	0.905	2.672
V2	0.525	0.397	0.099	0.028	0.020	0.000
V3	0.223	0.317	0.505	0.146	0.062	0.009
R1	0.033	0.022	0.168	0.424	0.260	0.221
R2	0.017	0.010	0.066	0.230	0.331	0.246
R3	0.007	0.007	0.016	0.069	0.176	0.434
Mortality	0.174	0.199	0.106	0.082	0.131	0.090

Table 4. Population growth and mortality rates at the French Flat Middle and South sub-populations from 1994 - 2009. [Note: Demographic data was not collected at the Middle subpopulation from 2000 through 2007.]

year	Lambda		Mortality (%)	
	Middle	South	Middle	South
1994-1995	1.116	1.145	15	38
1995-1996	1.411	1.464	19	15
1996-1997	1.01	0.781	12	32
1997-1998	1.129	0.873	10	26
1998-1999	0.892	0.611	13	33
1999-2000	N/A	1.008	N/A	23
2000-2001	N/A	0.751	N/A	26
2001-2002	N/A	1.104	N/A	24
2002-2003	N/A	0.655	N/A	40
2003-2004	N/A	0.82	N/A	27
2004-2005	N/A	0.808	N/A	-
2005-2006	N/A	0.941	N/A	-
2006-2007	N/A	1.012	N/A	-
2007-2008	N/A	0.768	N/A	-
2008-2009	0.843	0.82	-	-

Table 5. Elasticity matrices of the South and Middle *Lomatium cookii* subpopulations derived from the average transition matrices. Elasticities represent the relative sensitivity of the population growth rate (λ) 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 λ to changes in transition probabilities in that stage. The top two individual elasticities are shown in bold.

South subpopulation

	S	V2	V3	R1	R2	R3
S	0	0	0	0	0.0417	0.0697
V2	0.0535	0.0408	0.0121	0.0019	0.0009	0
V3	0.0373	0.0534	0.1012	0.0163	0.0046	0.0004
R1	0.0088	0.0059	0.0538	0.0754	0.0305	0.0147
R2	0.007	0.0041	0.0325	0.0632	0.0596	0.0251
R3	0.0049	0.005	0.0135	0.0323	0.0543	0.0759
sum	<i>0.1115</i>	<i>0.1092</i>	<i>0.2131</i>	<i>0.1891</i>	<i>0.1916</i>	<i>0.1858</i>

Middle subpopulation

	S	V2	V3	R1	R2	R3
S	0	0	0	0	0.0334	0.088
V2	0.0483	0.0285	0.0189	0.0024	0.0018	0.0006
V3	0.0475	0.0565	0.1141	0.0201	0.0062	0
R1	0.008	0.0093	0.0485	0.0339	0.0269	0.0095
R2	0.0122	0.0062	0.0433	0.0563	0.0543	0.0091
R3	0.0053	0	0.0197	0.0233	0.0588	0.1091
sum	<i>0.1213</i>	<i>0.1005</i>	<i>0.2445</i>	<i>0.136</i>	<i>0.1814</i>	<i>0.2163</i>

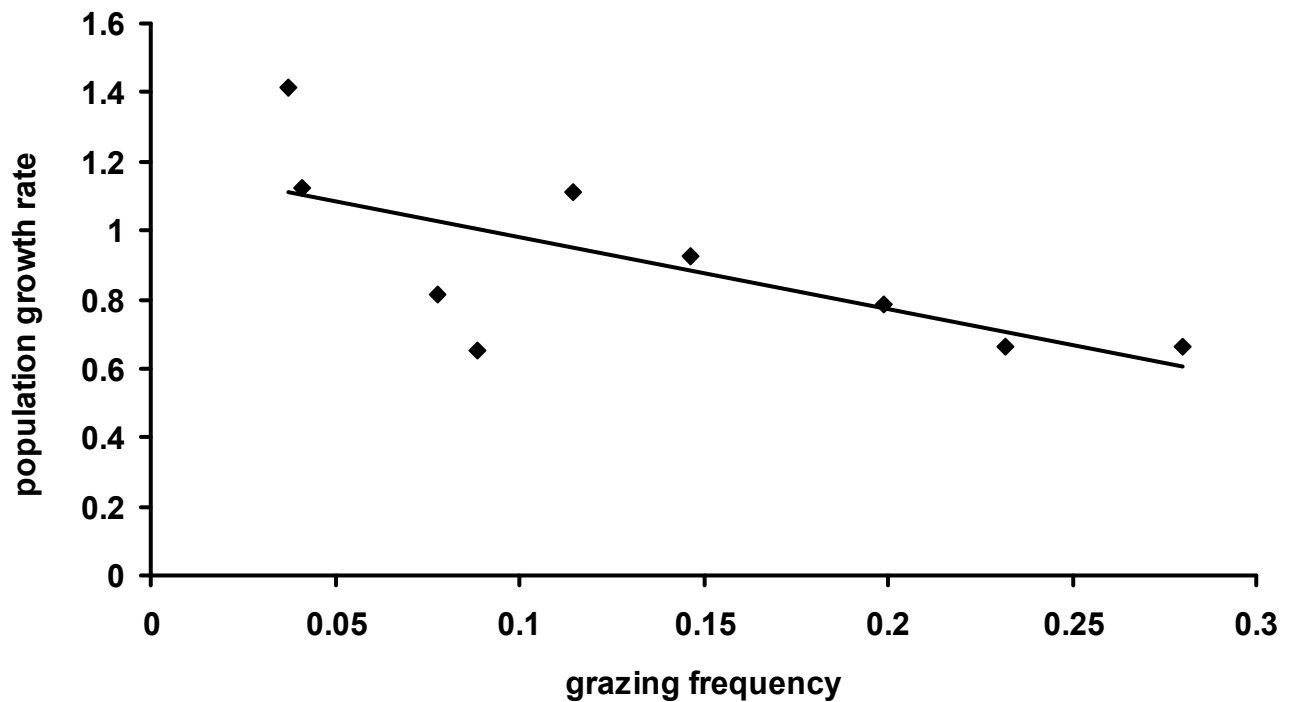
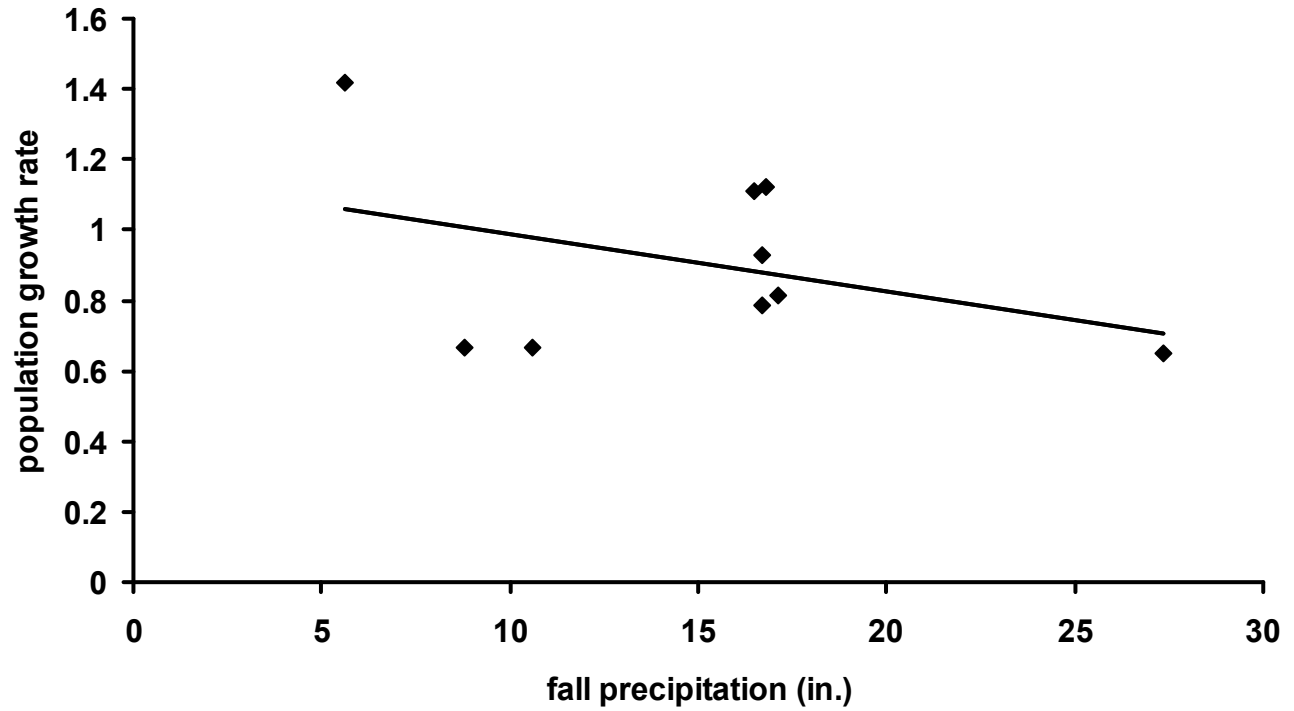


Figure 15. Relationship between population growth rate at the South subpopulation and grazing frequency of plants in the previous year (top, $R^2 = 0.6664$, $P = 0.0004$) and fall precipitation in the previous year (bottom, $R^2 = 0.3509$, $P = 0.015$).

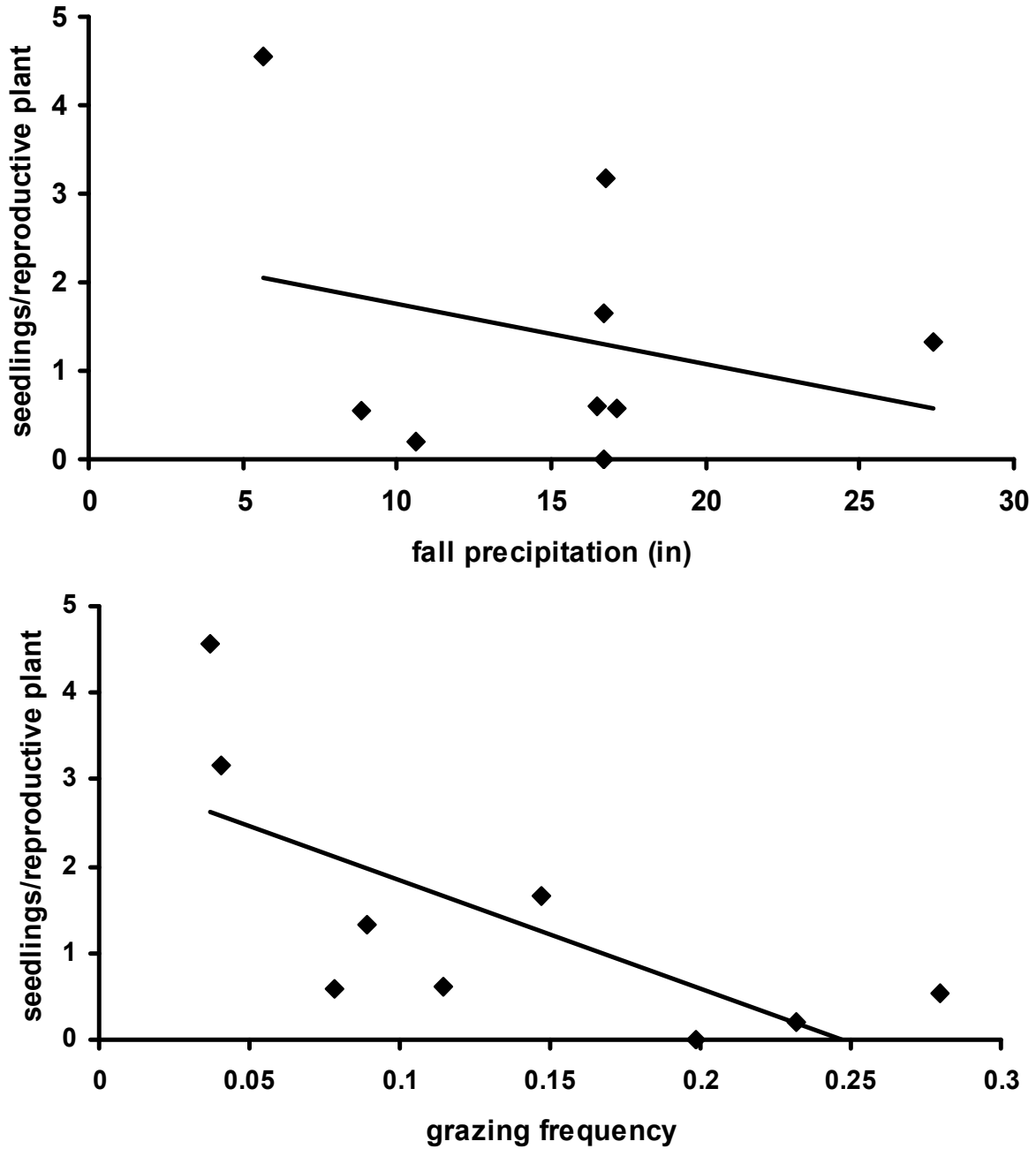


Figure 16. Relationship between seedling production per reproductive plant present the previous year at the South subpopulation and grazing frequency of the previous year (top, $R^2 = 0.6591$, $P = 0.008$) and fall precipitation of the previous year (bottom, $R^2 = 0.2426$, $P = 0.057$).

Rough and Ready Creek

Due to its relatively small size, we are able to census the entire *L. cookii* population at Rough and Ready Creek. In 2009, we counted 2,776 *L. cookii* plants in eight patches on BLM land at the Rough and Ready Creek site (Table 6, Figures 17 & 18). This was three times the number of plants counted in 2007 and the highest number recorded since monitoring began in 1994. The population increase observed in 1999 was due to an increase in *L. cookii* plants in all patches except G and H (Table 6, Figure 18). The declines observed in 2000 - 2001 were largely due to losses of plants in patches B - E, while the decline in 2002 was primarily due to large losses in patches A and G. While ORV damage near the roadside in patch A likely affected some *L. cookii* plants in 2004, the loss was mitigated by an increase in plants in other patches in 2005 and 2006, especially in patches E and F. In 2008, increases were seen in all patches except G, and in 2009 increases were seen in all patches except C and E. Increases and decreases in patch sizes for B through E might reflect actual fluctuations, but they could also result from differential placements of the survey tapes demarcating population boundaries in different years.

The proportion of reproductive plants in the population in 2009 (41.5%) was close to the long-term average of 48% (Figure 17). Large vegetative plants (V3) and small reproductive plants (R1) were the most abundant stages at Rough and Ready Creek in 2009.

Table 6. Number of *Lomatium cookii* individuals in each patch at Rough and Ready Creek. Patches A and G contain permanently-marked monitoring transects. The total number of plants in all patches combined represents a census of the population. Totals include plants in all stages from seedlings to large reproductive plants.

Year	Number of Plants								Total
	Patch								
	A	B	C	D	E	F	G	H	
1994	144	6	3	15	13	10	80	7	278
1995	177	79	22	85	127	53	135	14	692
1996	259	82	44	82	30	42	119	14	670
1997	167	56	104	315	91	131	119	12	990
1998	141	82	93	180	128	48	106	7	785
1999	223	237	201	308	393	197	81	14	1,654
2000	228	167	105	171	102	296	61	11	1,141
2001	292	113	102	189	245	119	64	24	1,148
2002	88	153	104	135	274	217	16	18	1,005
2003	298	93	217	64	34	382	73	25	1,186
2004	251	114	123	46	271	174	74	25	1,078
2005	248	146	124	56	148	369	72	25	1,188
2006	98	271	235	69	424	540	50	28	1,715
2007	127	141	67	132	217	197	23	20	924
2008	397	250	477	157	433	325	79	9	2,127
2009	567	363	430	424	347	526	102	17	2,776

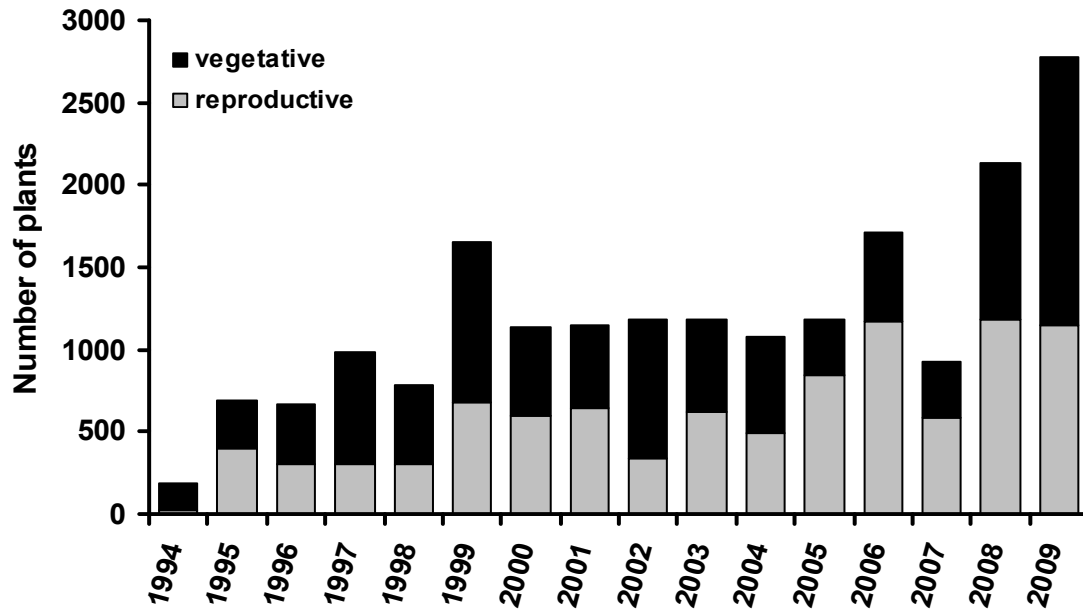


Figure 17. Population trends for reproductive plants and the total number of plants (reproductive and vegetative) at Rough and Ready Creek, 1994 - 2009. There were only 26 reproductive plants recorded in 1994.

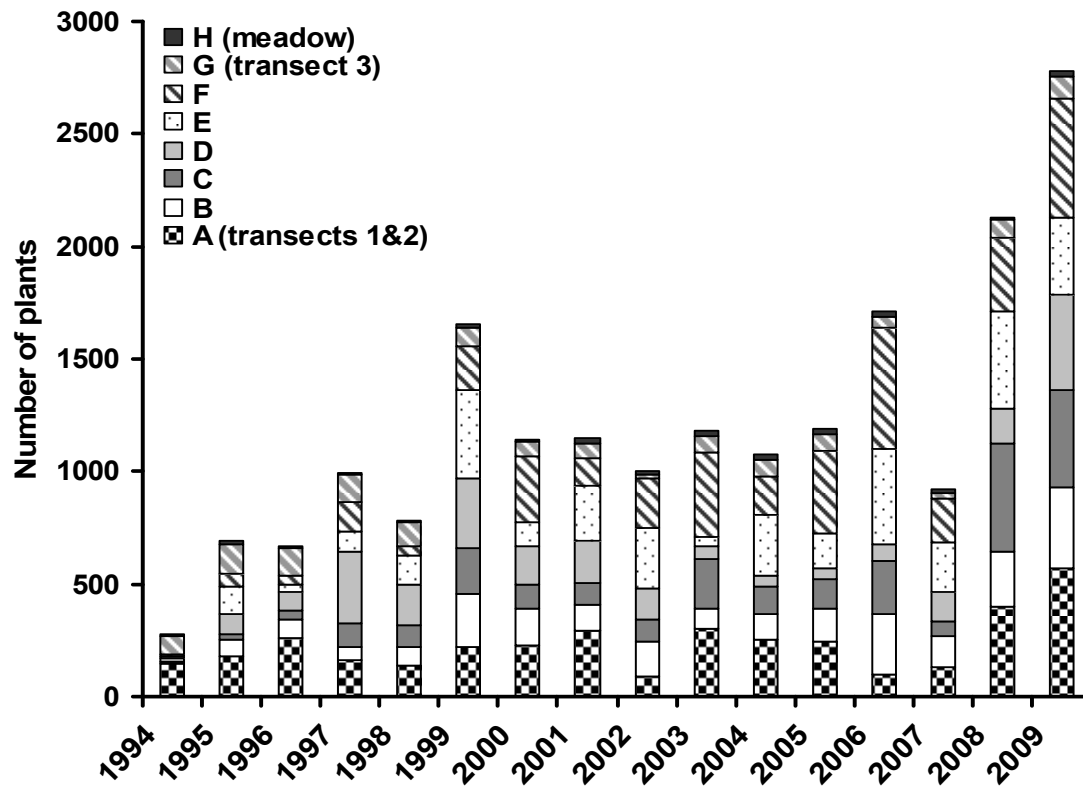


Figure 18. Population fluctuations in *Lomatium cookii* patches A - H at Rough and Ready Creek, 1994 – 2009.

Indian Hill

The total population size of *L. cookii* at Indian Hill has remained relatively stable since monitoring was initiated in 1997 (Figure 19). From 2008 to 2009, the population increased by approximately 350 plants, to 9,973. On average, reproductive plants have comprised 34% of the population (minimum, 16% in 1997; maximum, 46% in 2003). In 2009, reproductive plants composed 35% of the total population. The 1997 - 1998 and 1999 - 2000 declines in total population size are the result of attrition of vegetative plants, while the increase in density from 2002 - 2005 can be attributed to a higher proportion of reproductive plants. The mean density of reproductive plants in the population increased steadily from 0.4 plants/m² in 1997 to 0.81 plants/m² in 2004, 2005, and 2006. In 2009, there were approximately 0.76 reproductive plants/m².

The majority of plants at Indian Hills are vegetative. The V1-V2 and V3 stages comprised 20% and 43% of the population, respectively. The R1 stage also made a substantial contribution (26%) to the population in 2009. Many of the V3 and R1 plants are likely a result of the prolific seedling recruitment event in 2005. The number of seedlings at the site has varied substantially. No seedlings were recorded at this site in 1999 or 2000. The highest proportion of seedlings in the population was 8.5% in 2004. In 2009, seedlings accounted for 3% of the population, an increase from 0.8% in 2008. Compared to the other populations and the long-term population average, Indian Hill had few seedlings in 2009.

Table 7. Summary of population density and size (mean \pm 90% confidence limit) for the Indian Hill population.

year	density (per m ²)		population size	
	reproductive	total	reproductive	total
1997	0.4 \pm 0.17	2.56 \pm 1.07	1,840 \pm 764	11,776 \pm 4,801
1998	0.46 \pm 3.4	1.41 \pm 0.84	2,134 \pm 1,541	6,477 \pm 3,737
1999	0.39 \pm 0.25	1.54 \pm 0.80	1,803 \pm 1,117	7,084 \pm 3,580
2000	0.46 \pm 0.3	1.24 \pm 0.73	2,098 \pm 1,400	5,704 \pm 3,266
2001	0.58 \pm 0.48	1.54 \pm 1.05	2,686 \pm 2,144	7,084 \pm 4,685
2002	0.60 \pm 0.44	1.42 \pm 0.88	2,778 \pm 1,980	6,477 \pm 3,931
2003	0.73 \pm 0.50	1.58 \pm 1.23	3,349 \pm 2,232	7,250 \pm 5,485
2004	0.82 \pm 0.632	1.91 \pm 1.36	3,772 \pm 2,834	8,795 \pm 6,074
2005	0.81 \pm 0.53	2.8 \pm 2.2	3,735 \pm 2,364	12,898 \pm 9,936
2006	0.80 \pm 0.5	2.1 \pm 1.47	3,680 \pm 2,225	9,862 \pm 6,568
2007	0.48 \pm 0.37	1.89 \pm 1.87	2,226 \pm 1,647	8,685 \pm 8,319
2008	0.60 \pm 0.45	2.04 \pm 1.71	2,870 \pm 1,986	9,623 \pm 7,546
2009	0.76 \pm 0.51	2.17 \pm 1.62	3,478 \pm 2,277	9,973 \pm 7,229

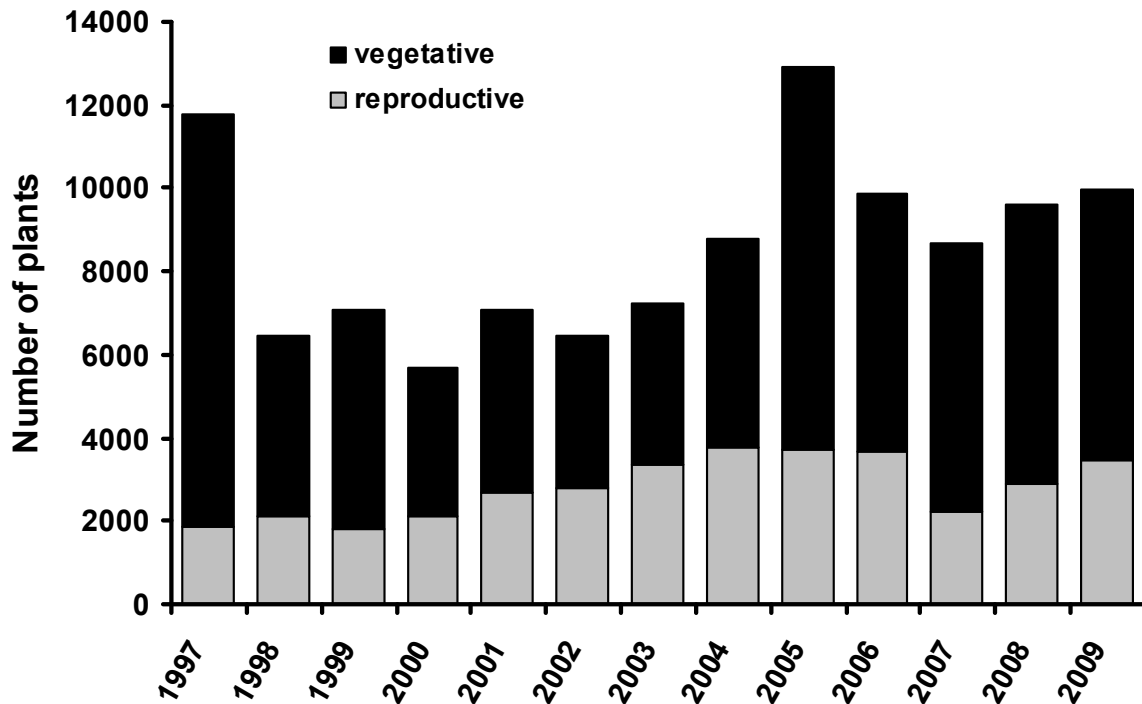


Figure 19. The number of vegetative and reproductive plants at Indian Hill, 1997- 2009.

Herbivory on *Lomatium cookii*

Herbivory by voles is relatively frequent on *L. cookii*, but the frequency of damage to the plants has varied substantially among sites and years. Typically, damage to the plants ranges from consumption of leaf tips and inflorescences, to removal of nearly all aboveground plant material. Consumption of the flower clusters results in little damage to the individual plant, but eliminates seed production and, therefore, recruitment of seedlings in the following year. The long-term impact of herbivory on *L. cookii* plants is unknown, but appears to play an important role in population growth and seedling dynamics. Environmental parameters (e.g., rainfall, average maximum daily temperature, and average minimum daily temperature) may influence vole populations similarly across the region and in turn affect the number of individuals of *L. cookii* that are grazed.

In general, herbivory has increased at French Flat South, French Flat Middle, and Indian Hill from the time monitoring was initiated to 2007. In 2008, grazing was relatively low at all sites. In 2009, the frequency of grazing continued to fall at French Flat South and Indian Hill, but it increased at French Flat Middle and Rough and Ready (Figure 20). In our observations since 1993, the highest recorded herbivory was 50% detected at Indian Hill in 2003, while the lowest was 1% at French Flat Middle in 1994.

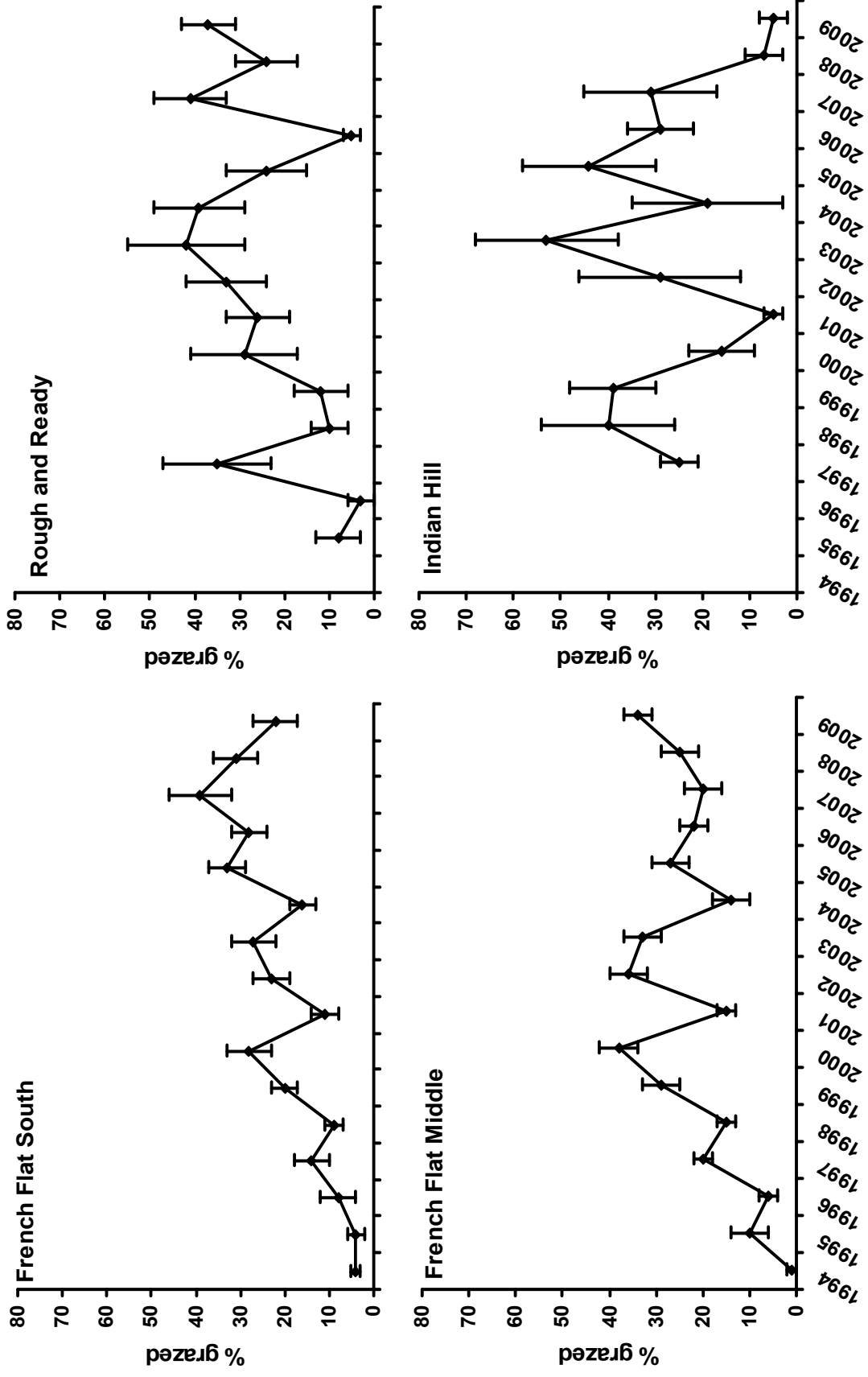


Figure 20. Frequency of herbivory on *Lomatium cookii* at four populations, 1994 - 2009. Error bars represent a 90% confidence interval.

DISCUSSION

Current population status

In 2009, the number of *L. cookii* increased at every site.

French Flat

Current population estimates at this site are approximately 113,775 plants at the Middle subpopulation and 60,748 at the South subpopulation. The Population Viability Analysis suggests that the South subpopulation may be at risk of long term decline if current conditions persist. ORV use remains frequent and damaging (Figure 21). In addition, analysis of environmental variables suggests that both herbivory by voles and heavy fall precipitation may have negative effects on the population dynamics of this species and cause population declines.

The Middle subpopulation hosted an estimated 231,600 individuals in 1998 when the population was at its highest, up from 88,688 when monitoring began in 1993 and twice the current estimate. Although there has been some variability, the population has generally been declining since 2000. The South subpopulation also peaked in 1998, with a total of 124,890 individuals. Since then, it has generally declined as well.

Results from population viability analyses based on information from 1994 - 1999 and 2008 - 2009 for Middle and 1994 - 2009 for South indicated that these subpopulations differed in their growth rates. The subpopulation at Middle was projected to grow, while the one at South was likely to decline. Stochastic simulations based on observed environmental variability indicated that the risk of extinction or catastrophic decline was very low at the Middle subpopulation if past environmental and biological conditions persist. At South, however, the population appears to be at a high risk of 50% decline over a 20-yr period.

Rough and Ready Creek

We counted 2,776 plants at Rough and Ready Creek, about three times the number from 2007, and more than we have observed since monitoring began in 1994. This population is traversed by dirt roads and the habitat is quite different from the French Flat area. Instead of broad flat areas of relatively homogeneous grassland, the Rough and Ready Creek population occurs in grassy patches and roadways on gentle to moderate slopes among shrubs and trees (*Pinus jeffreyi*). This patchy, less extensive habitat pattern is probably responsible for the large difference in population size between these two areas. The dirt roads that dissect the Rough and Ready Creek subpopulation may also have reduced the number of plants that occurred here in 1994; however, most of the additional plants at this site in 1995 - 2006 were observed on the roadbeds, and were probably trampled and damaged in 1994. A large trash pile found on the western edge of Patch A in 2003 and fresh ORV tracks in 2004, 2005, and 2007 are indicative of active road use and off-road habitat impact.



Figure 21. ORV damage in the *Lomatium cookii* population at French Flat.

Indian Hill

The Indian Hill population, which is intermediate in size between the Rough and Ready and French Flat populations, declined in total numbers from 1997 (when monitoring began) to 1998, then remained relatively stable from 1998 to 2004. Overall, the population has increased slightly from 2005 – 2009. Estimates of total plant density and reproductive plant density followed similar changes. The proportion of seedlings in the population has been increasing since a low point in 2007. It is unclear why seedling recruitment was so low in 2007 and 2008; population size has been relatively stable in recent years, and the site does not appear to receive heavy ORV use.

Management recommendations

French Flat

We recommend that population monitoring at the French Flat subpopulations be conducted once per year for all plots. If insufficient time is available for these activities, sampling of the density plots should be conducted at least once every three years for data collection and plot maintenance. Sampling of the subpopulation boundary transects can occur at five-year intervals (or when changes in population boundaries are suspected). Additional data from the demographic plots will allow improved population viability analyses, including enhancement of environmental stochasticity estimates and greater certainty in evaluations of the importance of environmental variables such as precipitation and vole herbivory.

Maintaining the motorized vehicle closure should be a priority for management of this site. Off Road Vehicles still use this area, despite official closure of the roads, making this important population extremely vulnerable to damage. Also, horse-back riders that use French Flat should be warned of the presence of rebar posts interspersed throughout the habitat.

Rough and Ready Creek

The road leading through the Rough and Ready population should be gated to protect the plants and this vulnerable population. The large trash pile found on the western edge of Patch A in 2003 and fresh ORV tracks in 2004 and 2005 indicate that the road is actively being used. If traffic were to increase even by a small amount, this population could be severely impacted.

Monitoring at Rough and Ready Creek should be repeated each year to detect changes in population size and density. However, if insufficient resources are available for this activity, sampling should be conducted at least once every three years. The roads that dissect this site pose a real threat to the viability of the population, and opportunities for road closures (at least from February through August) should be evaluated.

Indian Hill

The habitat at Indian Hill is restricted by forest that surrounds a long strip of meadow habitat. These meadows are being invaded by shrubs that may eventually have detrimental impacts on the *L. cookii* population through competition for light, water, and nutrients. Monitoring at Indian Hill should be repeated annually to detect changes in population size and density. If insufficient resources are available for annual monitoring, sampling should be conducted at least once every three years.

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APPENDIX A. GEAR LIST.

Field Gear

Last year's report
Last year's datasheets
Density plot datasheets
French Flat South and Middle demographic datasheets
Rite-in-the-rain paper
Jepson guide
Clipboards/pencils
Maps
3 100+ feet tapes, 2 smaller (50ft) tapes
3-4 candy canes
2 rulers
2 large binder clips
Bundle of pinflags

Quadrat frames: 1x1m for Rough and Ready, .5x.5m for French Flat
Extra rebar, hammer, and flagging to replace lost/bent
Compass
First Aid Kit/Tecnu
Water jug *2
Pruning tool
Health and Safety box

Note for planning:

Indian Hill – 10 transects took about 3-4 hours
Rough and Ready – Population census for T1 and T2. T3 is “loosely” sampled, in order to obtain census. This took about 4 hour hours.

Need vehicle with clearance