# *LOMATIUM COOKII* POPULATION MONITORING IN THE ILLINOIS VALLEY, JOSEPHINE COUNTY, OREGON

2013

Report to the Bureau of Land Management, Medford District

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*Institute for Applied Ecology*

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## PREFACE

This report is the result of a cooperative project between the Institute for Applied Ecology (IAE) and the Bureau of Land Management. IAE provides services to public and private agencies and individuals through development and communication of information on ecosystems, species, and effective management strategies. Restoration of habitats, with a concentration on rare and invasive species, is a primary focus. IAE conducts its work through partnerships with a diverse group of agencies, organizations and the private sector. IAE aims to link its community with native habitats through education and outreach.

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**Cover photograph**: *Lomatium cookii* (Cook's Desert Parsley), and Illinois Valley habitat, Josephine County, Oregon.


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# EXECUTIVE SUMMARY

*Lomatium cookii* is endemic to southwestern Oregon, and is listed as endangered by the State of Oregon and by the U.S. Fish and Wildlife Service (USFWS). Populations discussed in this report are located in the Illinois Valley in Josephine County. Long-term monitoring has occurred at French Flat since 1990, at Rough and Ready since 1994 and at Indian Hill since 1997. Data from these efforts are used to track population dynamics at all sites and create a population viability analysis for French Flat.

French Flat South

- Total population size was estimated at 114,296 individuals in 2013, a 7% decrease since 2012. Average plant density was estimated at 13.0 plants $m^{-2}$. The proportion of reproductive plants in the overall population was 11%, a 35% decrease since 2012.
- The Population Viability Analysis (PVA) indicated a 98.9% probability this population will decrease 50% in the next 20 years. A catastrophic loss (99% population decrease) over the same period is not likely to occur (< 0.1%).

French Flat Middle

- The total population numbered 81,067 in 2013, a 118% increase since 2012. Density was estimated at 17.3 plants $m^{-2}$, which was less than the average 23.5 $m^{-2}$. Reproductive plants composed just over 10% of the overall population, a 60% decrease since 2012.
- The PVA indicated an 82.0% probability this population will decrease 50% in the next 20 years. A catastrophic loss (99%) over the same period is not likely to occur (< 0.1%).

Rough and Ready

- This population decreased 9% to 1,973 plants in 2013. Reproductive adults comprised 34% of the population, a 39% decrease from last year. Barricading with boulders has successfully blocked vehicles from dumping trash in the small meadow and accessing side roads.

Indian Hill

- This population increased 13% to 10,543 in 2013. Reproductive adults comprised 24% of the population, a 35% increase since 2012.

Overall, populations of *Lomatium cookii* in Josephine County have shown increased recruitment of seedlings and population sizes have remained relatively stable. This is likely due in part to active management of these populations by the Medford BLM, including preventing use by off road vehicles. However, population viability analyses indicate there is still risk of serious population declines. Proposed mining activities may have further detrimental impacts on these populations at French Flat. We recommend continued monitoring of these populations to assess population trends, trespass by ORVs, and provide data to assess future impacts to populations from climate change, mining, or other threats.

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# *LOMATIUM COOKII* POPULATION MONITORING IN THE ILLINOIS VALLEY, JOSEPHINE COUNTY, OREGON

REPORT TO THE BUREAU OF LAND MANAGEMENT, MEDFORD DISTRICT

## INTRODUCTION

### Project Overview

*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 2013 and is the product of a cooperative effort between the BLM and the Institute for Applied Ecology.

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

### Review of past monitoring

The largest population of L. cookii on federal land 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 Native Plant Conservation 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 flattened and oblong. The species was originally described by Kagan in 1986 from specimens collected in the Medford area.

## 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 roemeri* 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*, *P. 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

Mining activities continue to threaten *L. cookii*. 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. Recently, mining plans have been filed with BLM that will alter habitat immediately adjacent to *L. cookii* at French Flat ACEC.

*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 ORV 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.

## 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 2013.
- 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 1994-2013.

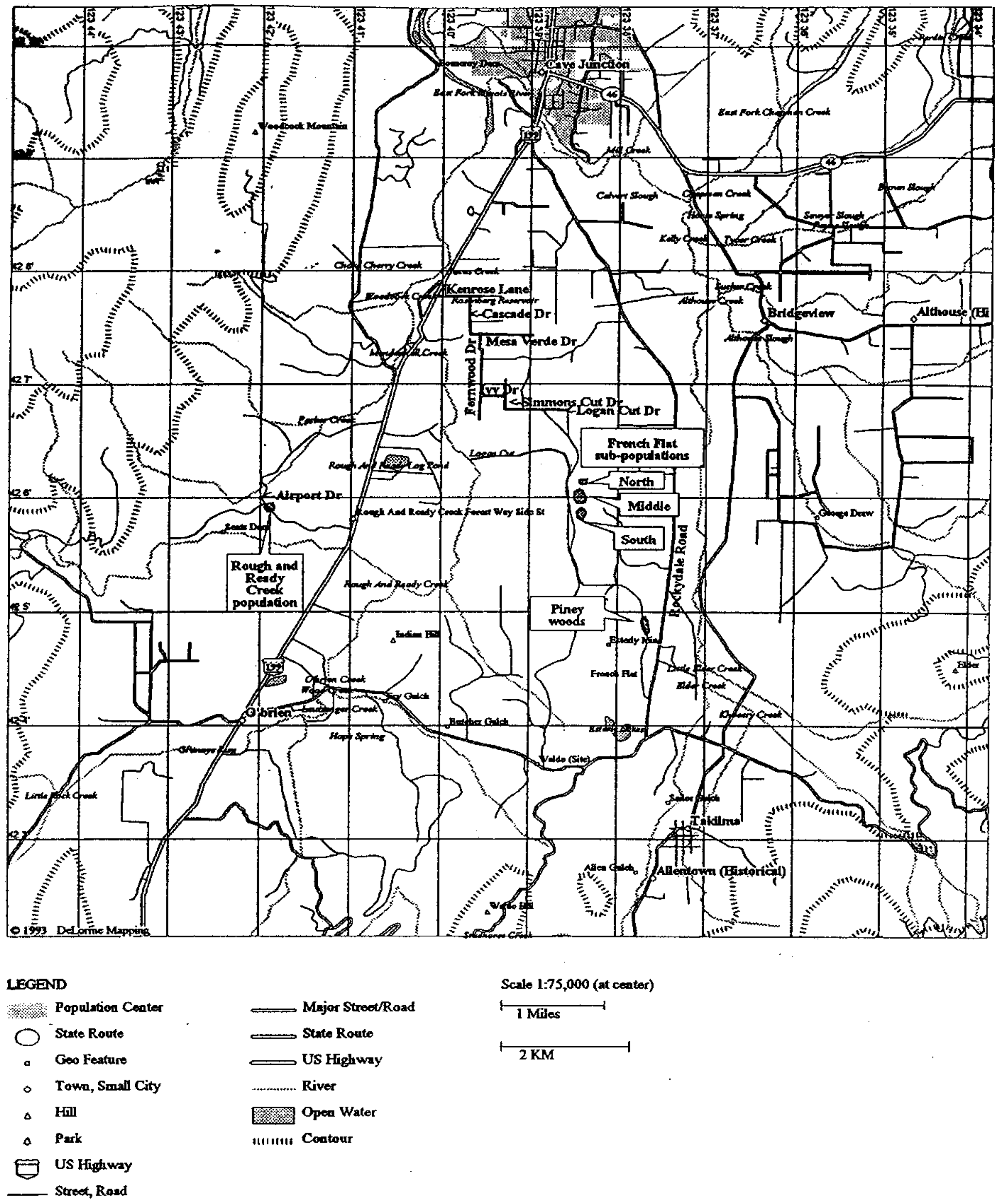


**Figure 2. Locations of the *Lomatium cookii* study sites included in this report. Note: other *L. cookii* subpopulations occur in this general area but are not shown.**

# 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 3), 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) and 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), but is not discussed here. 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.

## 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. 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. At some point between the 2011 and 2012 field season, all plot markers were removed from the French Flat South subpopulation. Only 3 of the 44 rebar remained in place and the plots could not be re-established. New plots were established in 2012 at South and in 2013 at Middle (see below for details).


**Figure 3. Map 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.**

**Middle subpopulation**

*1993-2012*

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.

*2013*

New density plots were established in 2013 to reflect the methods at French Flat South in 2012 (see below). The boundary of the population was mapped, and a 100m baseline transect was laid at a bearing of north 34° east to bisect the population. Thirty density plots were placed at random intervals perpendicular (either east or west) to the baseline transect (Table 1, Figure 4, and Figure 5). A tape was run for 40m and a 10cm strip on the south side of the tape was monitored for *L. cookii*. Plants in the density plots were assigned to the life-history categories detailed below.

Previous demography plots were located. Demography plots without plants for multiple years were abandoned and four new plots were established. Only two demography plots were not relocated in 2013.

**Table 1. Plot information for density and demography plots established in 2013 at French Flat Middle.**

| 2013 New Plot # | Side of Tape | Location on Baseline (m) | End Rebar at (m) | End Rebar Tag | 2013 Last Plant Found at (m) | Demog. Tag | Demog. Plot Location (NE Corner) | Demog. Plot Location (End) |
|---|---|---|---|---|---|---|---|---|
| 165 | W | 2.8 | 30 | 166 | 25.95 | 33 | 11.43 | 10.90 |
| 154 | W | 8.5 | 37 | 153 | 34 | 1 | 10.85 | 10.35 |
| 155 | E | 8.5 | 37 | 156 | 26.5 | 3 | - | - |
| 161 | E | 9.1 | 40 | 162 | 35.2 | 6 | 18.05 | 18.55 |
| 163 | E | 9.7 | 40 | 164 | 39.55 | 7,8 | 7: 15.5; 8: 23.25 | 7: 16; 8: 23.75 |
| 28 | W | 15 | 37 | 29 | 35.7 | - | - | - |
| 167 | E | 17.5 | 40 | 166 | 38.05 | 10/30? | 10: 34.35 | 10: 34.85 |
| 30 | E | 19 | 39.3 | 31 | 35.1 | - | - | - |
| 33 | W | 22 | 40 | 34 | 28.1 | - | - | - |
| 169 | W | 25 | 40 | 170 | 38.7 | 37? | 22.24 | 21.71 |
| 171 | E | 27.1 | 33.5 | 172 | 33 | 13 | 4.86 | 5.39 |
| 199 | W | 31 | 30 | 200 | 29.3 | - | - | - |
| 35 | E | 35 | 40 | 36 | 38.6 | - | - | - |
| 173 | E | 36.6 | 40 | 174 | 36.6 | - | - | - |
| 175 | W | 40.2 | 35 | 176 | 31.85 | 16 | - | - |
| 158 | W | 43.1 | 30 | 157 | 20.6 | 18 | 13.2 | 12.7 |
| 159 | E | 43.1 | 30 | 160 | 28.25 | 25, 28 | 28: 5.20 | 28: 5.79 |
| 177 | E | 46.6 | 35.5 | 178 | 33.9 | 29/30? | 29: 5.17 | 29: 5.69 |
| 179 | E | 55.1 | 15.4 | 180 | 13.7 | 31 | 4.75 | 5.25 |
| 181 | W | 56 | 20.4 | 182 | 19 | - | - | - |
| 183 | E | 60 | 11.3 | 184 | 11.05 | - | - | - |
| 185 | E | 62 | 10.8 | 186 | 9.7 | - | - | - |
| 187 | W | 67 | 9.9 | 188 | 6.7 | - | - | - |
| 189 | E | 72 | 15 | 190 | 14.9 | 168 | 6.5 | 7 |
| 37 | W | 74 | 16 | 38 | 6.9 | - | - | - |
| 191 | W | 82 | 15.5 | 192 | 11.4 | 169 | 2.5 | 2 |
| 193 | W | 86 | 10.5 | 194 | 3.5 | - | - | - |
| 195 | E | 89 | 21.4 | 196 | 19.5 | 170 | - | - |

| 2013 New Plot # | Side of Tape | Location on Baseline (m) | End Rebar at (m) | End Rebar Tag | 2013 Last Plant Found at (m) | Demog. Tag | Demog. Plot Location (NE Corner) | Demog. Plot Location (End) |
|---|---|---|---|---|---|---|---|---|
| 197 | W | 95 | 15 | 198 | 10.5 | - | - | - |
| 39 | W | 98 | 15 | 40 | 8.7 | - | - | - |

### South subpopulation

<u>*1993-2011*</u>

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.

<u>*2012-2013*</u>

In 2012, new monitoring and demography plots were established at this site because of vandalism to the plots in 2011. Sometime after population monitoring in 2011, most rebar posts that marked the long term monitoring plot locations were removed making it impossible to relocate the original plots. The boundary of the population in French Flat South was mapped using a handheld GPSmap 60CSx, and a 157m transect was laid at a bearing 180° due south to bisect the population. The head of the transect was marked with rebar capped with a yellow IAE cap and tagged with an aluminum disk embossed with #347. Additional rebar were placed at 50, 100 and 150m as well as at the end of the transect (157m) and tagged with #348-351 respectively (Table 2, Figure 4, and Figure 6). Thirty-three density plots were run perpendicular to the baseline transect to the East or West at randomly selected intervals. A tape was run for 40m and a 10cm strip on the South side of the tape was monitored for *L. cookii*. Plants in the density plots were assigned to the life-history categories detailed below.

### 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

R1 reproductive with 1 umbel

R2 reproductive with 2 umbels

R3 reproductive with 3 or more umbels

Life-history categories were originally developed for *Lomatium 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).

**Table 2. Plot information for density and demography plots established in 2012 at French Flat South.**

| 2012 New Plot # | Side of Tape | Location on Baseline (m) | End Rebar at (m) | End Rebar Tag | 2012 Last Plant Found at (m) | Demog. Tag | Demog. Plot Location (NE Corner) | Demog. Plot Location (End) |
|---|---|---|---|---|---|---|---|---|
| 362 | E | 13 | 23 | 363 | 9.3 | - | - | - |
| 364 | W | 27 | 30 | 365 | 10.4 | - | - | - |
| 366 | W | 30 | 33 | 367 | 6.9 | - | - | - |
| 707 | W | 36 | 21 | 708 | 15.9 | 329 | 10.5 | 11 |
| 709 | W | 38 | 21 | *710* | 15.8 | 330 | 6.5 | *7* |
| 711 | W | 42 | 21 | 712 | 12.7 | 331 | 4 | 4.5 |
| *749* | E | 45 | 40 | *750* | 23.6 | 353 | 15.5 | 15 |
| *713* | E | 52 | 37 | 714 | 25.8 | 332 | 17.5 | 17 |
| 741 | E | *57* | 35 | *742* | 27.1 | 352 | 20.5 | 20 |
| 743 | E | 59 | 40 | 744 | 30.1 | 354 | 21.5 | 21 |
| 753 | E | 61 | 36 | 754 | 31.8 | 357 | 23 | 22.5 |
| *745* | W | 65 | 39 | 746 | 23.9 | 361 | 13.5 | 14 |
| *747* | E | 70 | 40 | 748 | 32.1 | 360 | 8.5 | 8 |

| 2012 New Plot # | Side of Tape | Location on Baseline (m) | End Rebar at (m) | End Rebar Tag | 2012 Last Plant Found at (m) | Demog . Tag | Demog. Plot Location (NE Corner) | Demog. Plot Location (End) |
|---|---|---|---|---|---|---|---|---|
| 751 | E | 72 | 40 | 752 | 22.8 | 355 | 5.5 | 5 |
| 725 | W | 79 | 40 | 726 | 11.8 | 338 | 3 | 3.5 |
| 715 | E | 81 | 40 | 716 | 30.4 | 333 | 11.5 | 11 |
| 717 | W | 94 | 40 | 718 | 28.7 | 334 | 13.5 | 14 |
| 719 | E | 95 | 40 | 720 | 30.9 | 335 | 19 | 18.5 |
| 721 | E | 97 | 40 | 722 | 30.6 | 336 | 15.5 | 15 |
| 723 | W | 99 | 32 | 724 | 31.0 | 337 | 16 | 16.5 |
| 727 | W | 107 | 28 | 728 | 24.6 | 339 | 13 | 13.5 |
| 701 | E | 109 | 40 | 702 | 27.2 | 326 | 24.5 | 24 |
| 703 | E | 111 | 40 | 704 | 28.3 | 327 | 23 | 22.5 |
| 705 | W | 116 | 32 | 706 | 23.0 | 328 | 19 | 19.5 |
| 729 | W | 119 | 33 | 730 | 22.8 | 340 | 24 | 24.5 |
| 755 | E | 125 | 40 | 756 | 27 | 356 | 16.5 | 16 |
| 731 | E | 126 | 40 | 732 | 19.1 | 341 | 5.5 | 5 |
| 733 | W | 128 | 35.5 | 734 | 29.2 | 342 | 20 | 20.5 |
| 735 | E | 129 | 40 | 736 | 23.6 | 343 | 9 | 8.5 |
| 737 | W | 136 | 40 | 738 | 31.5 | 344 | 15 | 15.5 |
| 757 | W | 142 | 33 | 758 | 32.8 | 358 | 5 | 5.5 |
| 759 | W | 144 | 34 | 760 | 32.6 | 359 | 9.5 | 10 |
| 739 | W | 154 | 40 | 740 | 32.8 | 345 | 18 | 18.5 |

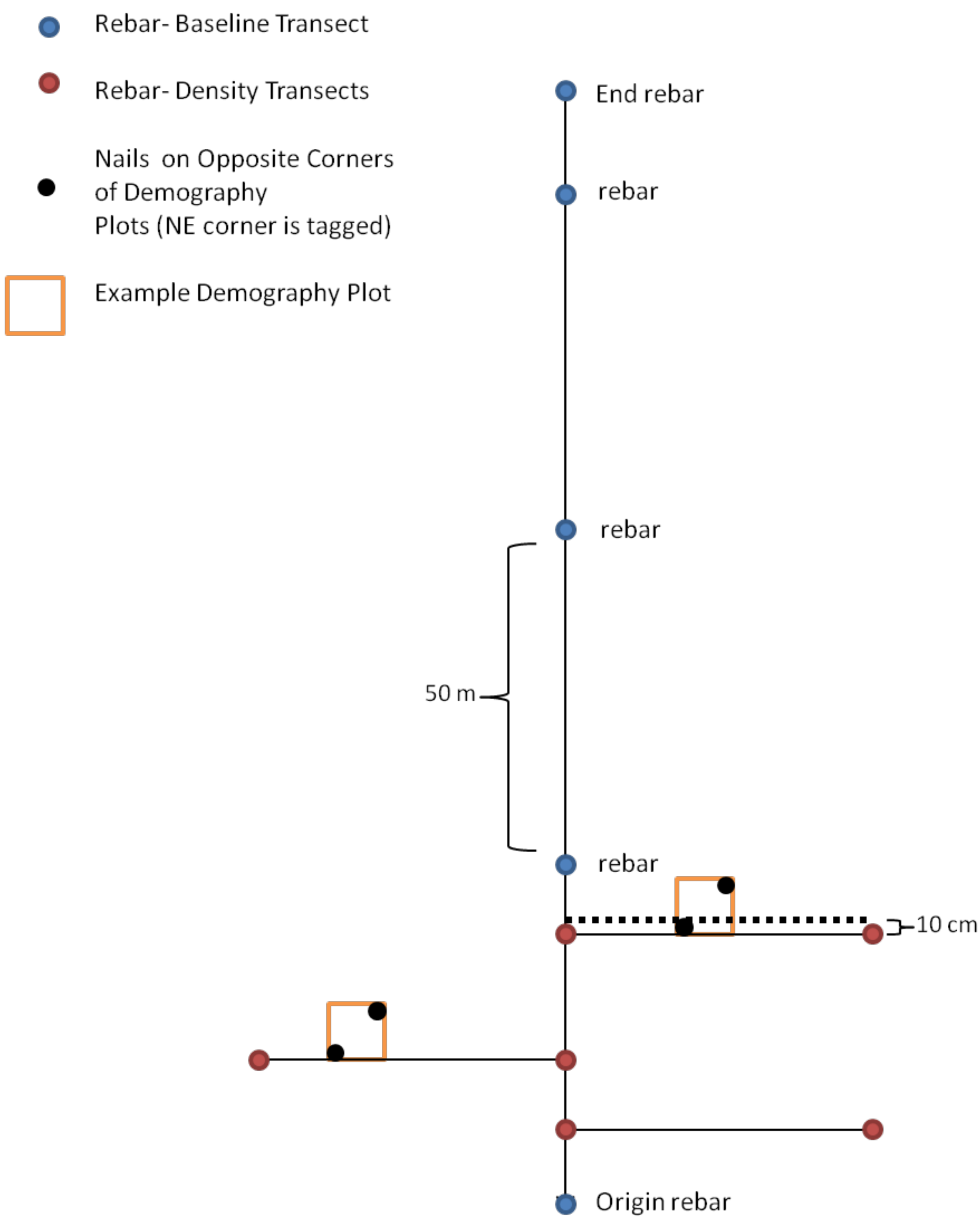


**Figure 4. Layout of new density and demography plots established in 2012 at French Flat South and in 2013 at Middle. Density plots run perpendicular to the baseline to the east or west, and are monitored in 10 cm strips on the south side of the transect line. Demography plots are marked in the northeast and southwest corners (NE is tagged).**

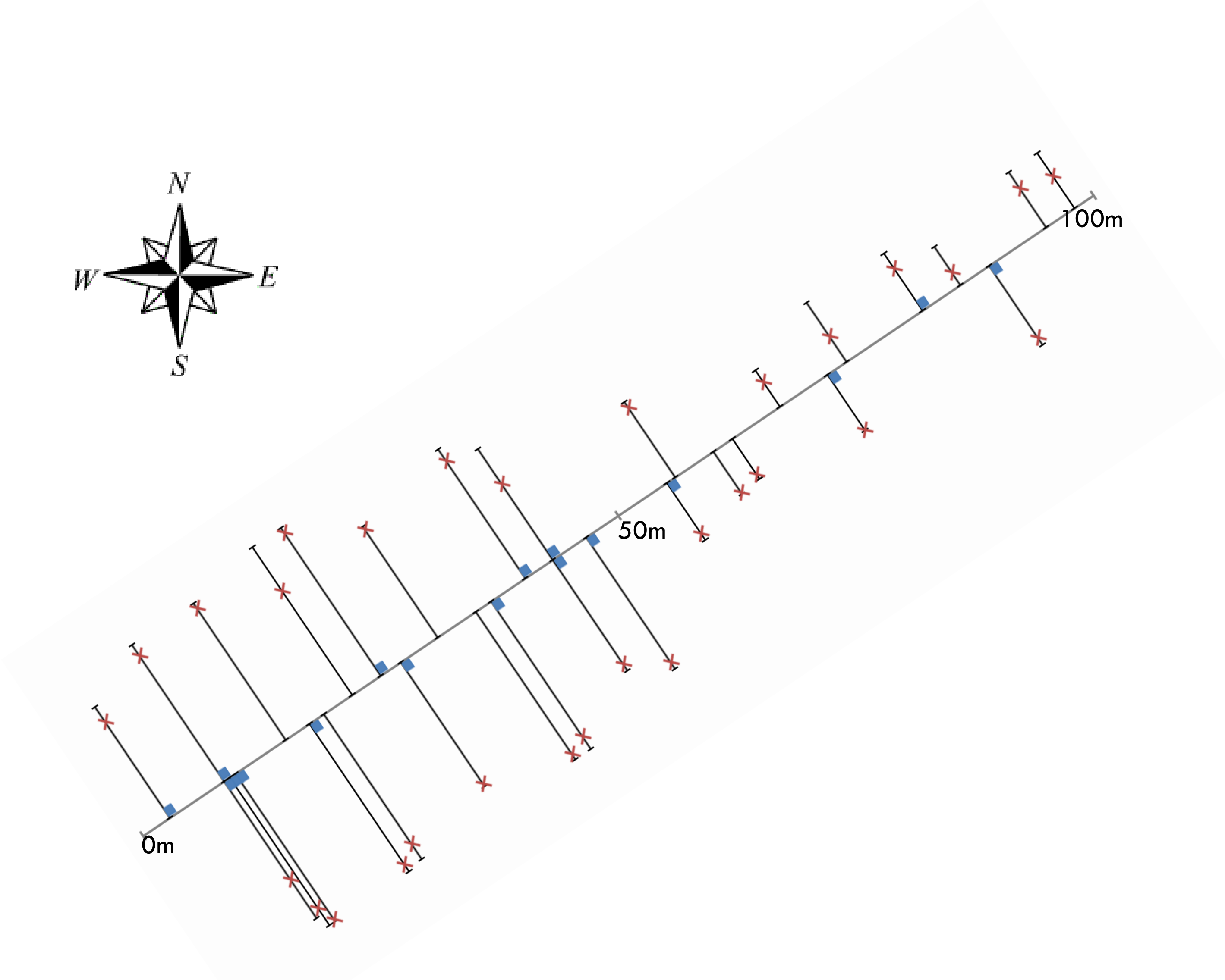


**Figure 5. Location of French Flat Middle demographic and density plots established in 2013. Baseline transect is 100m with a bearing of north 34° east. Last plants located on density plots are indicated by red crosses. Demography plots are indicated by blue squares and are not located along the baseline transect as shown here. See Table 1 for exact locations of all density and demography plots.**

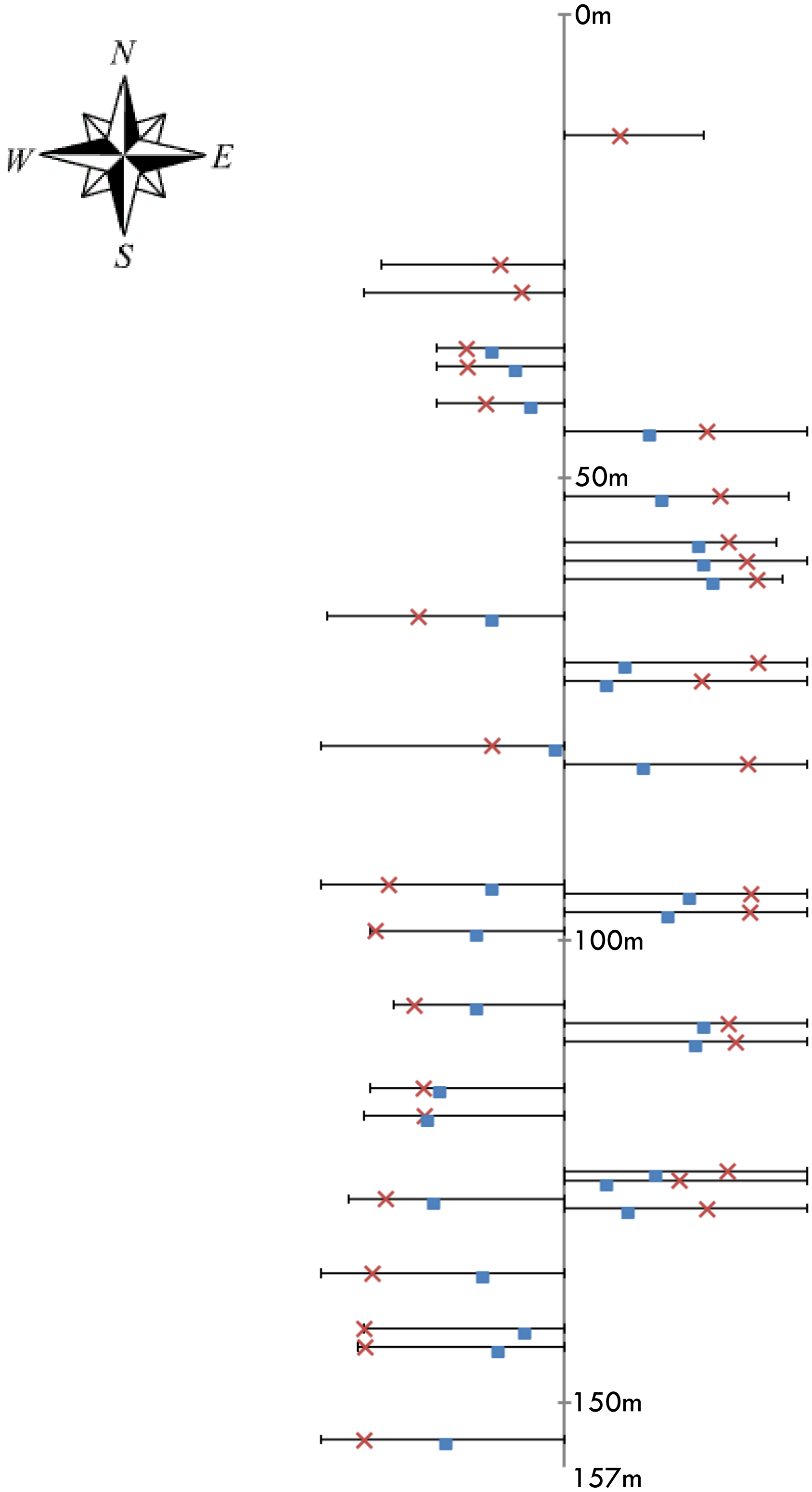


**Figure 6. Location of French Flat South demographic and density plots established in 2012. Baseline transect is 157m with a bearing due south. Last plants located on density plots are indicated by red crosses. Demography plots are indicated by blue squares. See Table 2 for exact locations of all density and demography plots.**

### 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 2008-2013, the Middle subpopulation was re-sampled and the updated information is presented below. Demographic monitoring at the South subpopulation has been consistent through the present year. In 2012 due to vandalism at French Flat South, new demographic plots were established (see below for details).

**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 (Table 1 and Table 2). 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. In 2012 at French Flat South the demographic plots were removed by vandals. We were not able to re-establish the plots, which had been monitored from 1993-2011, thus 30 new plots were monumented in 2012 (Table 2 and Figure 6). Location of the demographic plots were randomly selected along the randomly selected density transects. Two opposite corners of the 0.5m x 0.5m monitoring plot were marked with nails and the northeast corner is tagged (Figure 4).

**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 calculated 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 1994-1999 and 2008-2013 for the Middle subpopulation and from 1994-2011 and 2012-2013 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 1994-2011 and 2012-2013, and for the Middle subpopulation from 1994-1999 and 2008-2013. For this analysis, we calculated both deterministic and stochastic measures of population growth [lambda, and stochastic lambda] 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 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 lambda is greater than 1.0, the population will grow (a viable population), given that current conditions remain constant. For each site, we calculated lambda for each year of observation. 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 lambda greater than one. Demographic stochasticity was also ignored by our models, but it usually generates little variation in population dynamics relative to environmental stochasticity, except at very low population sizes (Menges 1992). Our model assumed that population growth is a first-order Markov process, in which the probability that a plant will make a transition is independent of its stage in the previous year. 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), converted to R (R Core Team 2013), 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 74,694 for the Middle subpopulation and 54,612 for the South subpopulation (the 1993 sizes), distributed among the six stages as follows: S=10%, V2=26%, V3=38%, R1=14%, R2=10%, and R3=2%. These proportions represent the average South subpopulation 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 (Mathworks 1998) and converted to R (R Core Team 2013), 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 statistical software R ver. 3.0.2 (R Core Team 2013) to calculate elasticities, as well as all other simulations and analyses.

## Rough and Ready Creek

The population at Rough and Ready Creek was first documented in 1993 (Kagan 1994). In 1994, we established three transects for long-term monitoring of the two densest patches of *L. cookii* on BLM-managed land at this site (plants in the remaining patches were simply counted and the patches were mapped; Figure 7). 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 8). 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 7). 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 2011 transect tapes were laid out along wheel ruts to define patches B, C, D, E and F.

In 2012 due to changes in plot set-up at French Flat South, all plants were monitored in a 10cm strip along the south side of 40m transects set-up perpendicular to the baseline transect. The starting location on the baseline transect is marked with rebar/PVC and tagged. The ends of the density transects are marked with tagged and capped rebar/PVC (Table 2). The location along the baseline transect and the side of the baseline monitored (East or West) were determined using a random number generator. Thirty-three density transects were established in 2012.

Life-history categories were originally developed for *Lomatium 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).

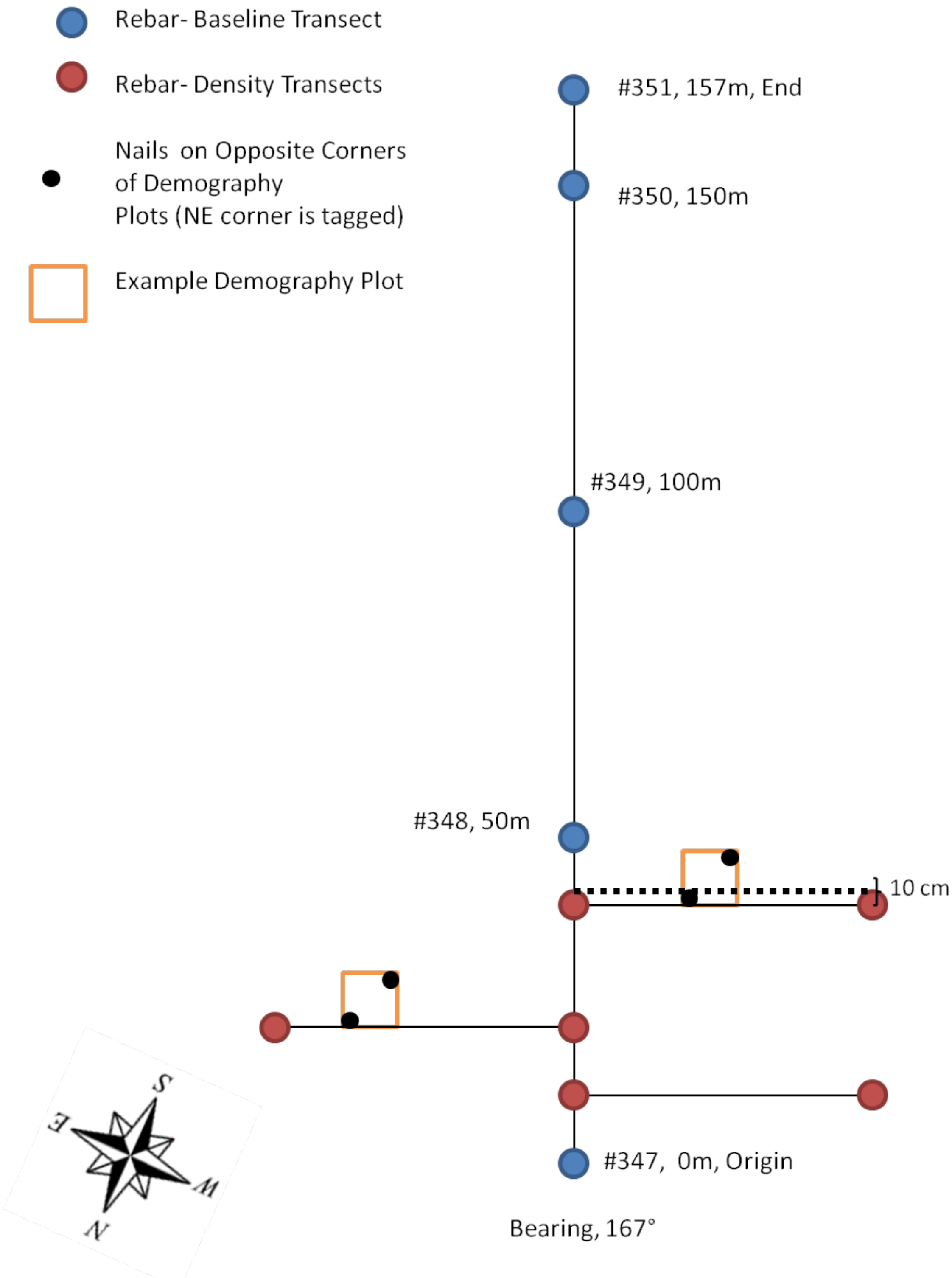


**Figure 7. Layout of new density and demography plots established in 2012 at French Flat South. Baseline transect is 157m long. Density plots are run perpendicular to the baseline to the east or west. Density plots are monitored in 10 cm strips on the south side of the transect line. Demography plots are marked in the northeast and southwest corners (NE is tagged.) A table with locations of all density and demography plot locations can be found in Table 2.**

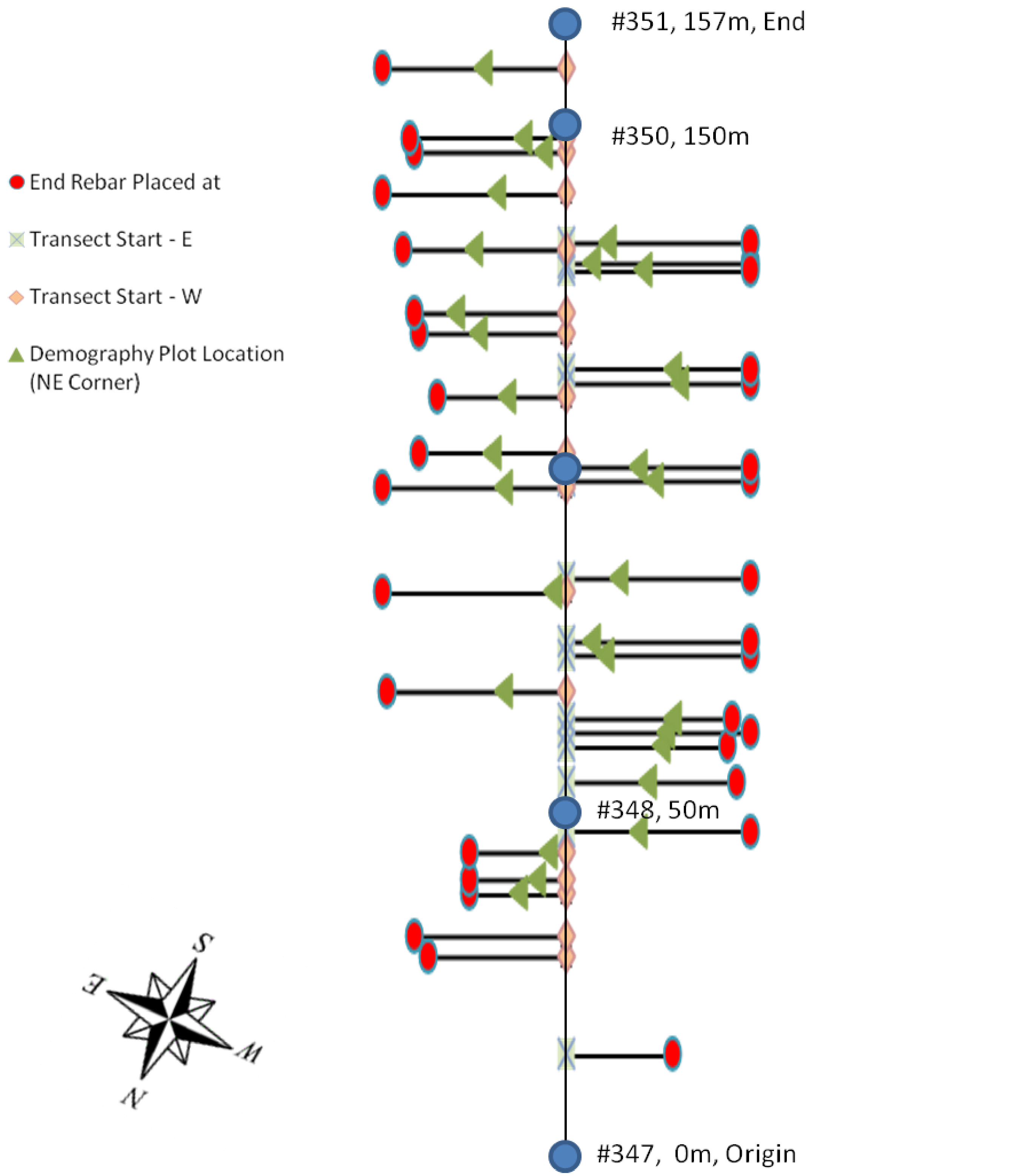


**Figure 8. Location of demographic and density plots established in 2012. See Table 2 for exact locations of all density and demography plots.**

### 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 2008-2012, 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. In 2012 due to vandalism at French Flat South, new demographic plots were established (see below for details).

**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 (Table 1 and Table 2). 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. In 2012 at French Flat South the demographic plots were removed by vandals. We were not able to re-establish the plots, which had been monitored from 1993-2011, thus 30 new plots were monumented in 2012 (Table 2 and Figure 7). Location of the demographic plots were randomly selected along the randomly selected density transects. Two opposite corners of the 0.5m x 0.5m monitoring plot were marked with nails and the northeast corner is tagged (Figure 6).

**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 calculated 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 2012 for the Middle subpopulation and from 1994 through 2011 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 1994-2011, and for the Middle subpopulation from 1994-1999 and 2008-2012. For this analysis, we calculated both deterministic and stochastic measures of population growth [lambda, and stochastic lambda] 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 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 lambda is greater than 1.0, the population will grow (a viable population), given that current conditions remain constant. For each site, we calculated lambda for each year of observation (i.e., 1994-99 and 2008-2012 at Middle, and 1994-2011 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 lambda greater than one. Demographic stochasticity was also ignored by our models, but it usually generates little variation in population dynamics relative to environmental stochasticity, except at very low population sizes (Menges 1992). Our model assumed that population growth is a first-order Markov process, in which the probability that a plant will make a transition is independent of its stage in the previous year. 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), converted to R (R Core Team 2012), 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 82,275 for the Middle subpopulation and 59,600 for the South subpopulation (the 2011 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 South subpopulation 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 (Mathworks 1998) and converted to R (R Core Team 2012), 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 statistical software R ver. 2.15.2 (R Core Team 2012) to calculate elasticities, as well as all other simulations and analyses.

## Rough and Ready Creek

The population at Rough and Ready Creek was first documented in 1993 (Kagan 1994). In 1994, we established three transects for long-term monitoring of the two densest patches of *L. cookii* on BLM-managed land at this site (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 2011 transect tapes were laid out along wheel ruts to define patches B, C, D, E and F.

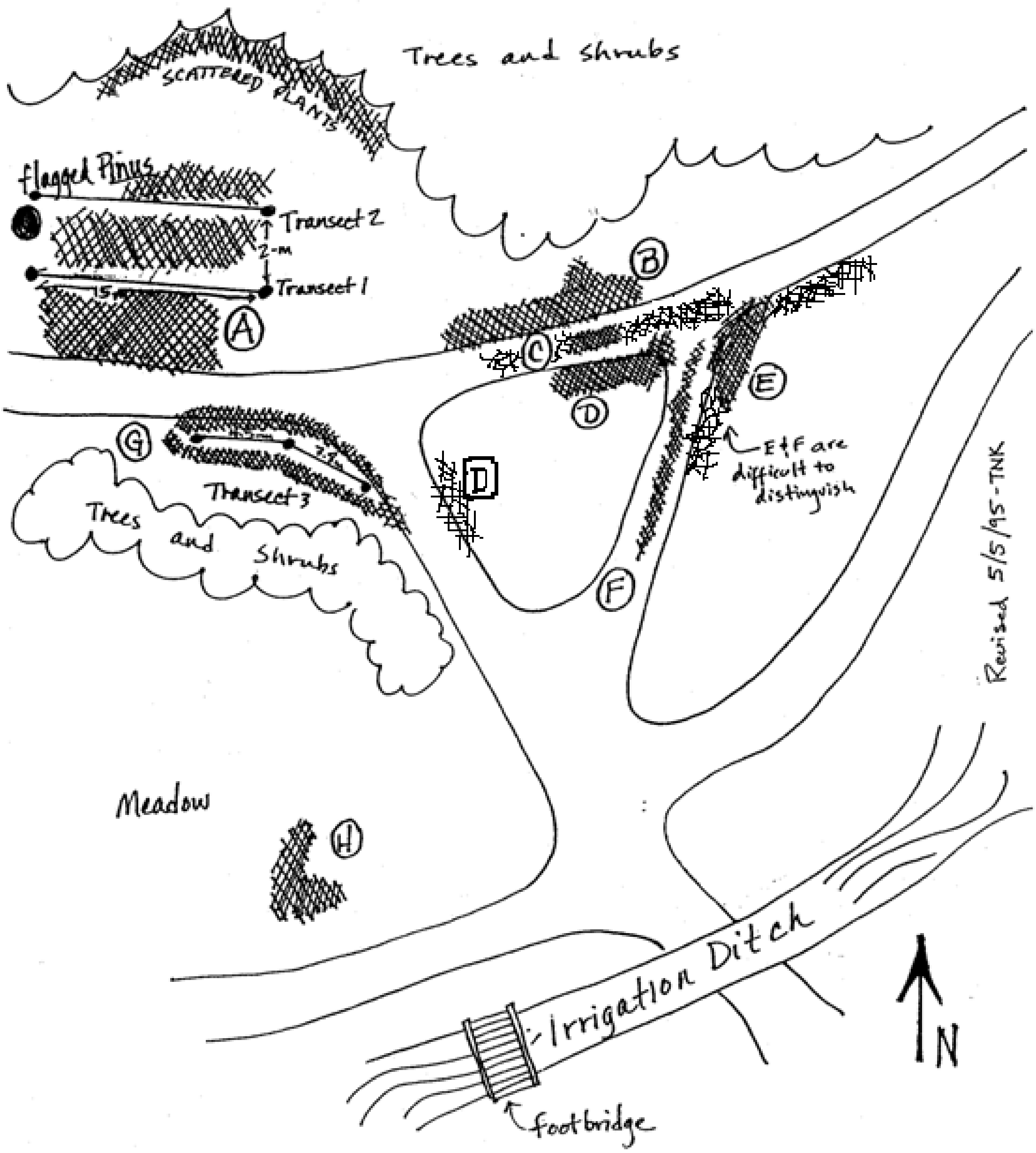


**Figure 9. Sketch map of the *L. cookii* patches located at Rough and Ready Botanical Wayside. Cross-hatching indicates patches of plants. The long-term monitoring transects are also indicated in the drawing. Note that the patches are distinguished by the letters A-H.**

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:

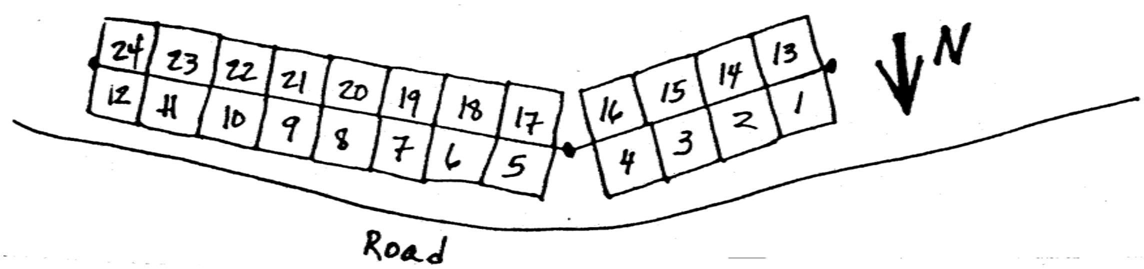


**Figure 10. Orientation of the sampling plots around transects 1, 2 and 3 at the Rough and Ready Botanical Wayside population.**

## 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 *Perideridia* sp., which may resemble *L. cookii*, occur in this area and were encountered in the sampling plots (Figure 9).

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

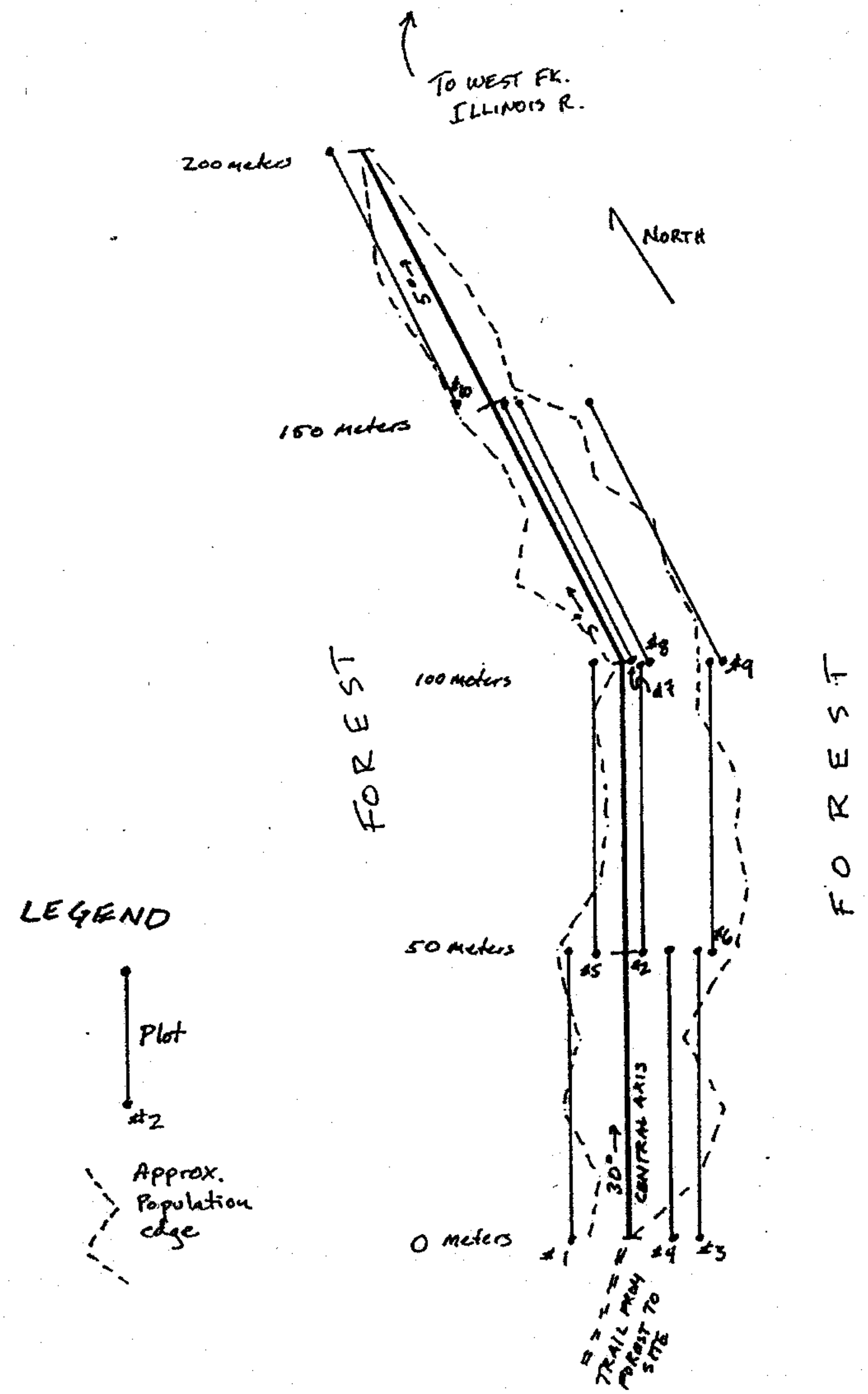


**Figure 12. Plot layout of the *Lomatium cookii* population at Indian Hill. Sample plots are 50 meters x 0.5 meters, marked at either end by a rebar post (with a copper tag and flagging). The plots are monitored on the east side of the tape.**

# RESULTS

## French Flat

### Population size and density

From 2010 to 2013, population size at the South subpopulation decreased 17% to 114,296 (95% C.I.: 78,565 – 150,027) (Figure 11). Earlier increases in population size (from 1993 to 1998, Table 3) were likely due to several years of high seedling recruitment. 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 and Figure 13). This proportion peaked in 2008 at 37%, but has steadily decreased to its current 11%. In 2013, the density at the South subpopulation was 13.0 ± 2.2 (±1 S.E.) plants $m^{-2}$, 67% of the long-term average. Density in this subpopulation has ranged from a low of 7 plants $m^{-2}$ in 1993 to a high of 33 plants $m^{-2}$ in 1997 and 1998 (Table 3).

The Middle subpopulation mirrors the trends of the South subpopulation, although there was an increase in 2013 at Middle (Figure 11, Figure 12). Population size grew from an initial 74,694 (95% C.I: 53,954 – 95,433) in 1993 to a high of 195,057 (90% C.I.: 154,956 – 235,157) in 1998. The population decreased to its lowest size of 37,142 (24,181 – 50,102) in 2012 then increased 118% to 81,067 (63,488 – 98.645) in 2013. The proportion of reproductive plants peaked at 41% in 2003 and 2008, but has steadily declined since 2008, to 10% in 2013 (Figure 13). In 2013, the density at the middle subpopulation was 17.3 ± 1.9 (S.E.) plants $m^{-2}$, 74% of the long-term average. Density in this subpopulation ranged from a low of 7.9 plants $m^{-2}$ in 2012 to a high of 41.7 plants $m^{-2}$ in 1998 (Table 3).

### Population structure

In 2013, the Middle and South subpopulations at French Flat were dominated by vegetative (V1-3) and small reproductive (R1) individuals (Figure 14). The large increase at Middle in 2013 (Table 3) was due to increased densities of vegetative plants from 5.6 and 5.1 $m^{-2}$ in 2012 to 16.6 and 19.5 $m^{-2}$ in 2013 for V1-2 and V3 plants respectively. On average, the vegetative classes were dominant, with V3 plants in the highest proportion. 1994, 1996-1998, and 2012 were the only years when V3 plants were not in the highest proportion for the South or Middle subpopulations.

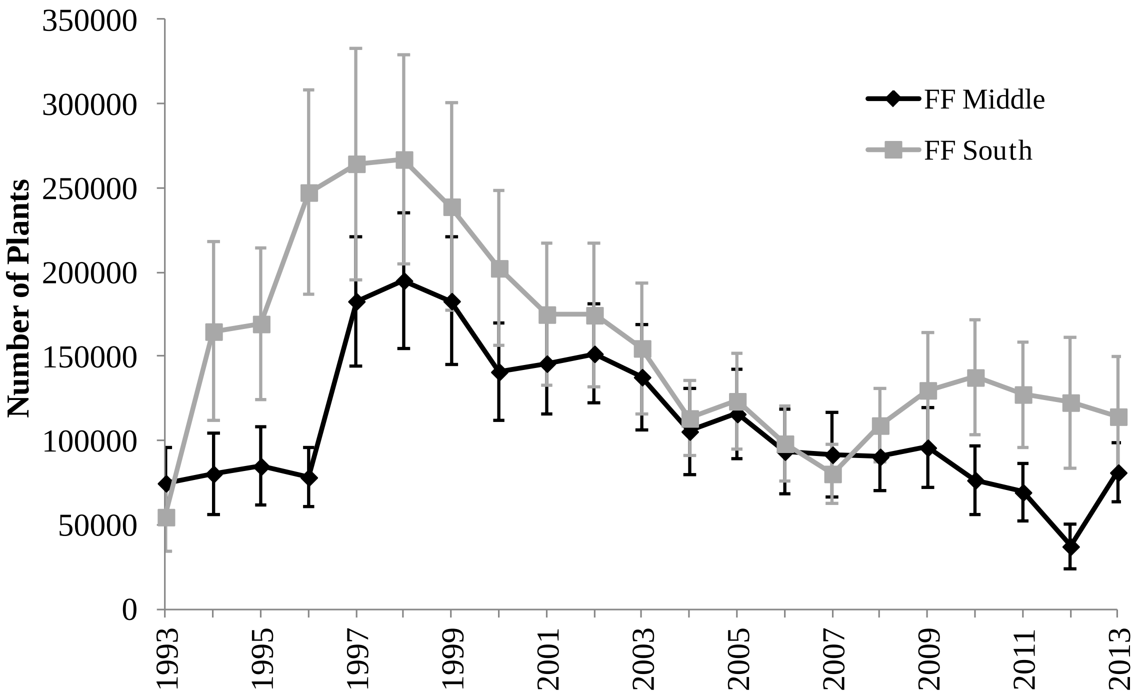


**Figure 13. The total number of Lomatium cookii at Middle and South French Flat, 1993-2013. Error bars represent a 95% confidence interval.**

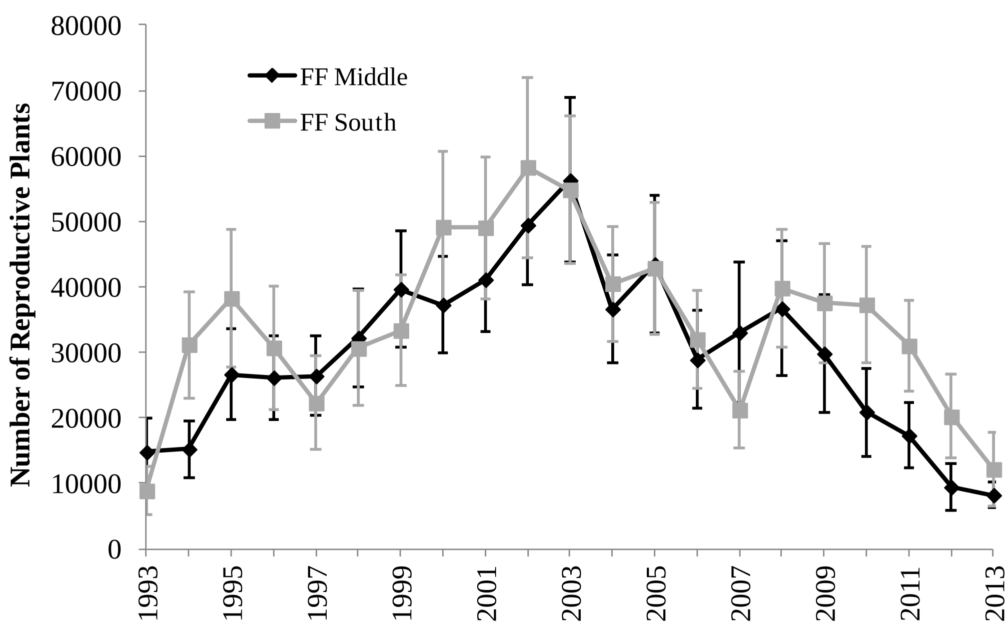


**Figure 14. The total number of reproductive *Lomatium cookii* at Middle and South French Flat, 1993-2013. Error bars represent a 95% confidence interval.**

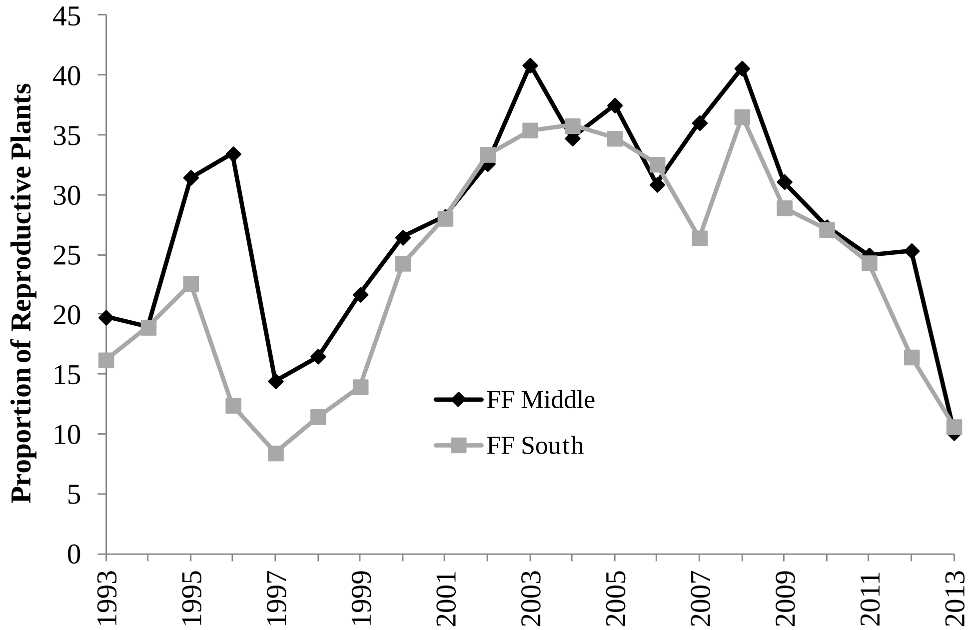


**Figure 15. The number of reproductive *Lomatium cookii* relative to the total subpopulation at Middle and South French Flat, 1993-2013.**

**Table 3. Summary of *Lomatium cookii* population data for the South and Middle French Flat subpopulations, 1993-2013. Population size and density estimates include all life-history stages from seedlings to large reproductive plants.**

### French Flat South

| Year | Population Size (95% CI) | Density (plant $m^{-2}$) ± 1 SE |
|---|---|---|
| 1993 | 54,612 (33,698 - 75,526) | 6.8 ± 1.3 |
| 1994 | 164,837 (111,579 - 218,095) | 20.6 ± 3.4 |
| 1995 | 169,350 (124,073 - 214,628) | 21.2 ± 2.9 |
| 1996 | 247,452 (186,779 - 308,125) | 31.0 ± 3.9 |
| 1997 | 264,524 (195,852 - 333,196) | 33.1 ± 4.4 |
| 1998 | 267,075 (204,835 - 329,316) | 33.4 ± 4.0 |
| 1999 | 239,014 (177,581 - 300,446) | 29.9 ± 3.9 |
| 2000 | 202,416 (156,353 - 248,479) | 25.3 ± 3.0 |
| 2001 | 174,943 (132,398 - 217,488) | 21.9 ± 2.7 |
| 2002 | 174,551 (131,737 - 217,365) | 21.8 ± 2.7 |
| 2003 | 154,829 (115,968 - 193,690) | 19.4 ± 2.5 |
| 2004 | 113,227 (91,201 - 135,253) | 14.2 ± 1.4 |
| 2005 | 123,432 (95,095 - 151,768) | 15.4 ± 1.8 |
| 2006 | 98,215 (76,262 - 120,168) | 12.3 ± 1.4 |
| 2007 | 80,260 (62,441 - 98,079) | 10.0 ± 1.1 |
| 2008 | 109,008 (87,290 - 130,726) | 13.6 ± 1.4 |
| 2009 | 129,907 (95,964 - 163,851) | 16.3 ± 2.2 |
| 2010 | 137,560 (103,514 - 171,606) | 17.2 ± 2.2 |
| 2011 | 127,454 (96,221 - 158,687) | 16.0 ± 2.0 |
| 2012 | 122,650 (83,841 - 161,460) | 15.4 ± 2.5 |
| 2013 | 114,296 (78,565 - 150,027) | 13.0 ± 2.2 |

### French Flat Middle

| Year | Population Size (95% CI) | Density (plant $m^{-2}$) ± 1 SE |
|---|---|---|
| 1993 | 74,694 (53,954 - 95,433) | 16.0 ± 2.3 |
| 1994 | 80,221 (56,402 - 104,040) | 17.2 ± 2.6 |
| 1995 | 84,706 (61,621 - 107,790) | 18.1 ± 2.5 |
| 1996 | 78,200 (60,376 - 96,023) | 16.7 ± 2.0 |

| | | |
|---|---|---|
| 1997 | 182,802 (144,335 - 221,269) | 39.1 ± 4.2 |
| 1998 | 195,057 (154,956 - 235,157) | 41.7 ± 4.4 |
| 1999 | 182,929 (145,214 - 220,643) | 39.1 ± 4.1 |
| 2000 | 140,860 (112,090 - 169,631) | 30.1 ± 3.2 |
| 2001 | 145,787 (115,652 - 175,922) | 31.2 ± 3.3 |
| 2002 | 151,598 (121,965 - 181,232) | 32.4 ± 3.3 |
| 2003 | 137,765 (106,531 - 168,999) | 29.5 ± 3.4 |
| 2004 | 105,424 (80,107 - 130,741) | 22.6 ± 2.8 |
| 2005 | 115,846 (88,950 - 142,743) | 24.8 ± 3.0 |
| 2006 | 93,486 (68,163 - 118,809) | 20.0 ± 2.8 |
| 2007 | 91,654 (66,336 - 116,971) | 19.6 ± 2.8 |
| 2008 | 90,391 (70,338 - 110,443) | 19.3 ± 2.2 |
| 2009 | 95,823 (72,378 - 119,268) | 20.5 ± 2.6 |
| 2010 | 76,494 (55,832 - 97,156) | 16.4 ± 2.3 |
| 2011 | 69,293 (52,478 - 86,109) | 14.8 ± 1.8 |
| 2012 | 37,142 (24,181 - 50,102) | 7.9 ± 1.4 |
| 2013 | 81,067 (63,488 - 98,645) | 17.3 ± 1.9 |

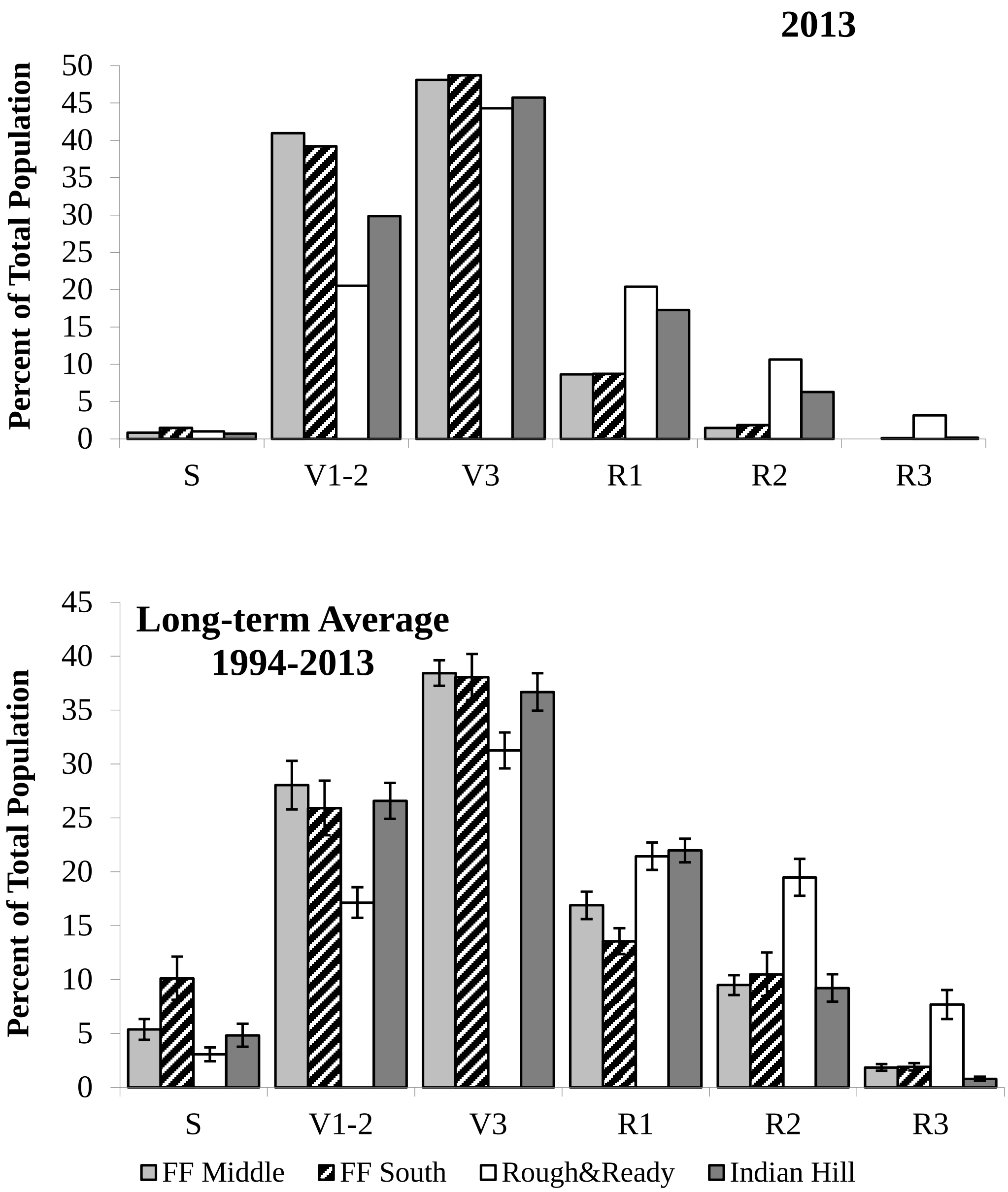


**Figure 16.** ***Lomatium cookii*** **population structure in 2013 (top) and averaged over the course of the study (bottom) for the Middle French Flat subpopulation (1994-2013), South French Flat subpopulation (1994-2013), Rough and Ready Creek (1995-2013), and Indian Hill (1997-2013). Bars indicate the mean percentage of plants in each stage. Error bars in the lower graph represent +1 SE. See text for explanation of life-history stages.**

### Demography and Population Viability Analysis

A total of 905 plants were mapped and categorized at the Middle subpopulation (1994-1999 and 2008-2013) and 828 and 338 at the South subpopulation (1994-2011 and 2012-2013) before and after plot re-establishment, respectively. Data from these 0.5 X 0.5 meter demographic plots were analyzed to construct transition matrices for Middle and South subpopulations (Table 4). In 2012, 286 new plants were mapped and categorized at the South subpopulation due to the loss of plot markers that year. Plants mapped prior to 2012 could not be identified to plants mapped in 2012, and thus there was not a 2011-2012 transition matrix for the South subpopulation. New plots were established at the Middle subpopulation to account for plots without plants for multiple years. Otherwise, plots prior to 2013 were identified, with exception of one, and a 2012-2013 transition matrix was constructed.

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 space and time (Table 5). In 2008-2012 at Middle, growth rates were below 0.86, with the lowest during 2011-2012 of 0.665. Growth rates at South have experienced a downward trend since 1995-1996, when the population grew at its highest recorded rate of 1.500. Except for 1994-1996, 2001-2002 and 2006-2007, growth rates at South have remained below 1.0. The lowest population growth rate, 0.687, was observed in 2002-2003, reflecting the low retention of large reproductive plants and low fecundity in 2003.

In stochastic simulations incorporating environmental variability from 1994-2011 and 2012-2013, South was projected to decline at an overall rate of 0.892. This reflects the overall poor annual growth rates at this site since monitoring began in 1994. At Middle, the stochastic growth rate was higher, 0.939, but this value represents observations from 1994-1999 and 2008-2013 only. The risk of sharp decline (50% loss) in 20 years was 98.9% at South and 82.0% at Middle. The risk of 99% decline was less than 1% at both the South and Middle subpopulations.

Thus, both deterministic and stochastic growth rates project that the South subpopulation will decline rapidly and substantially in the next two decades, while the Middle subpopulation will remain more stable. 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 and measures of their recent processes, 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 (0.143 at South and 0.144 at Middle) would have the single greatest effect on the population growth rate (Table 6). Overall, V3 plants had the highest cumulative elasticity (0.292 at South and 0.277 at Middle). The second highest cumulative elasticity was for the R2 stage at South (0.172) and the R1 stage at Middle (0.186). The seedling stage had the lowest cumulative elasticities (Table 6).

Annual mortality was generally lower in the Middle subpopulation than the South (Table 5). 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 the 69 plants mapped at South as seedlings in 1994, 3 were still present in 2011 and 1 of them was reproductive. On average, just over half of seedlings (51.2% at South and 53.8% at Middle) survive for two years. Only 38, or 5.9% on average, observed seedlings became reproductive after one year in the South subpopulation during this entire study. We found that, on average, 5.9% of seedlings became reproductive in 2 years, 9.3% in 3 years, and 9.9% in 4 years at the South subpopulation.

**Table 4. 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 1994-2011 and 2012-2013 for the South subpopulation and 1994-1999 and 2008-2013 for the Middle subpopulation.**

| South, average matrix (1994-2011 & 2012-2013), lambda = 0.908 | | | | | | |
|---|---|---|---|---|---|---|
| | S | V2 | V3 | R1 | R2 | R3 |
| S | 0.000 | 0.000 | 0.000 | 0.000 | 0.524 | 3.261 |
| V2 | 0.417 | 0.287 | 0.136 | 0.069 | 0.060 | 0.045 |
| V3 | 0.277 | 0.364 | 0.444 | 0.215 | 0.115 | 0.000 |
| R1 | 0.032 | 0.041 | 0.125 | 0.234 | 0.200 | 0.164 |
| R2 | 0.024 | 0.010 | 0.068 | 0.207 | 0.246 | 0.155 |
| R3 | 0.004 | 0.000 | 0.008 | 0.026 | 0.113 | 0.395 |
| Mortality | *0.247* | *0.298* | *0.219* | *0.249* | *0.265* | *0.240* |

| Middle, average matrix (1994-1999 & 2008-2013), lambda = 0.964 | | | | | | |
|---|---|---|---|---|---|---|
| | S | V2 | V3 | R1 | R2 | R3 |
| S | 0.000 | 0.000 | 0.000 | 0.000 | 0.749 | 2.211 |
| V2 | 0.527 | 0.391 | 0.139 | 0.065 | 0.107 | 0.000 |
| V3 | 0.215 | 0.301 | 0.501 | 0.201 | 0.128 | 0.078 |
| R1 | 0.039 | 0.034 | 0.146 | 0.376 | 0.251 | 0.301 |
| R2 | 0.011 | 0.027 | 0.048 | 0.172 | 0.263 | 0.247 |
| R3 | 0.004 | 0.007 | 0.011 | 0.041 | 0.117 | 0.310 |
| Mortality | *0.204* | *0.241* | *0.155* | *0.145* | *0.134* | *0.064* |

Table 5. Population growth and mortality rates at the French Flat Middle and South sub-populations from 1994-2013. [Note: Demographic data was not collected at the Middle subpopulation from 2000 through 2007, and plants mapped prior to 2012 were not relocated at the South subpopulation.]

| | Lambda | | Mortality (%) | |
|---|---|---|---|---|
| year | Middle | South | Middle | South |
| 1994-1995 | 1.132 | 1.142 | 18% | 40% |
| 1995-1996 | 1.568 | 1.500 | 17% | 15% |
| 1996-1997 | 1.016 | 0.811 | 11% | 32% |
| 1997-1998 | 1.135 | 0.931 | 10% | 25% |
| 1998-1999 | 0.897 | 0.692 | 12% | 30% |
| 1999-2000 | N/A | 0.789 | N/A | 18% |
| 2000-2001 | N/A | 0.771 | N/A | 26% |
| 2001-2002 | N/A | 1.114 | N/A | 24% |
| 2002-2003 | N/A | 0.687 | N/A | 35% |
| 2003-2004 | N/A | 0.837 | N/A | 23% |
| 2004-2005 | N/A | 0.830 | N/A | 33% |
| 2005-2006 | N/A | 0.934 | N/A | 20% |
| 2006-2007 | N/A | 1.012 | N/A | 32% |
| 2007-2008 | N/A | 0.906 | N/A | 18% |
| 2008-2009 | 0.854 | 0.855 | 20% | 28% |
| 2009-2010 | 0.848 | 0.993 | 24% | 22% |
| 2010-2011 | 0.823 | 0.846 | 25% | 22% |
| 2011-2012 | 0.665 | N/A | 25% | N/A |
| 2012-2013 | 0.787 | 0.794 | 39% | 21% |

**Table 6. 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 (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. The top two individual elasticities are shown in bold.**

### South subpopulation

| | S | V2 | V3 | R1 | R2 | R3 |
|---|---|---|---|---|---|---|
| S | 0.000 | 0.000 | 0.000 | 0.000 | 0.033 | **0.075** |
| V2 | 0.046 | 0.040 | 0.031 | 0.005 | 0.004 | 0.001 |
| V3 | 0.044 | 0.072 | **0.143** | 0.024 | 0.010 | 0.000 |
| R1 | 0.007 | 0.011 | 0.053 | 0.034 | 0.022 | 0.007 |
| R2 | 0.008 | 0.004 | 0.050 | 0.052 | 0.047 | 0.011 |
| R3 | 0.004 | 0.000 | 0.015 | 0.018 | 0.057 | 0.072 |
| *sum* | *0.109* | *0.128* | *0.292* | *0.134* | *0.172* | *0.166* |

### Middle subpopulation

| | S | V2 | V3 | R1 | R2 | R3 |
|---|---|---|---|---|---|---|
| S | 0.000 | 0.000 | 0.000 | 0.000 | 0.042 | 0.050 |
| V2 | 0.051 | 0.065 | 0.030 | 0.007 | 0.006 | 0.000 |
| V3 | 0.028 | 0.065 | **0.144** | 0.028 | 0.010 | 0.002 |
| R1 | 0.007 | 0.010 | 0.058 | **0.073** | 0.026 | 0.013 |
| R2 | 0.003 | 0.013 | 0.032 | 0.055 | 0.045 | 0.017 |
| R3 | 0.002 | 0.006 | 0.013 | 0.024 | 0.036 | 0.039 |
| *sum* | *0.091* | *0.160* | *0.277* | *0.186* | *0.165* | *0.120* |

## Rough and Ready Creek

Due to its relatively small size we censused the entire *Lomatium cookii* population at Rough and Ready Creek. In 2013, we counted 1,973 *L. cookii* plants in eight patches at Rough and Ready Creek (Table 7, Figure 15, and Figure 16) - a 30% decrease from 2011, which had the highest number of plants recorded since monitoring began in 1994. While there is year to year stochasticity as well as variation among patches, overall, the population has increased since monitoring began.

The proportion of reproductive plants in the population in 2013 (34%) was lower than the long-term average of 47% and the lowest since 2002 (Figure 15). Small and large vegetative plants (V1-3) and small reproductive plants (R1) were the most abundant stages at Rough and Ready Creek in 2013. Yet in 2013 and the average of all years since 1994, the proportion of large reproductive plants (R2-3) was higher than any other population (Figure 14).

Table 7. Number of *L. cookii* individuals in each patch at Rough and Ready Creek. 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.

| | Number of plants per patch | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| Year | 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 |
| 2010 | 346 | 567 | 758 | 300 | 133 | 382 | 60 | 11 | 2,557 |
| 2011 | 480 | 394 | 389 | 404 | 406 | 671 | 71 | 15 | 2,830 |
| 2012 | 292 | 349 | 486 | 146 | 336 | 489 | 65 | 16 | 2,179 |
| 2013 | 360 | 432 | 393 | 188 | 141 | 392 | 58 | 9 | 1,973 |

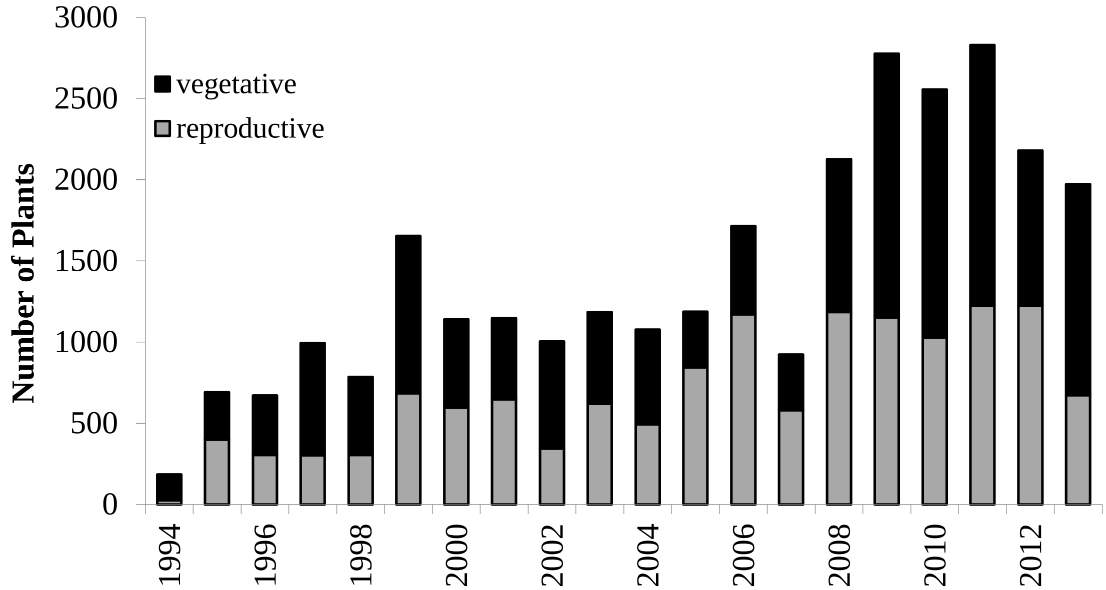


**Figure 17. Population trends and the total number of plants (reproductive and vegetative) at Rough and Ready Creek, 1994-2013. There were only 26 reproductive plants recorded in 1994.**

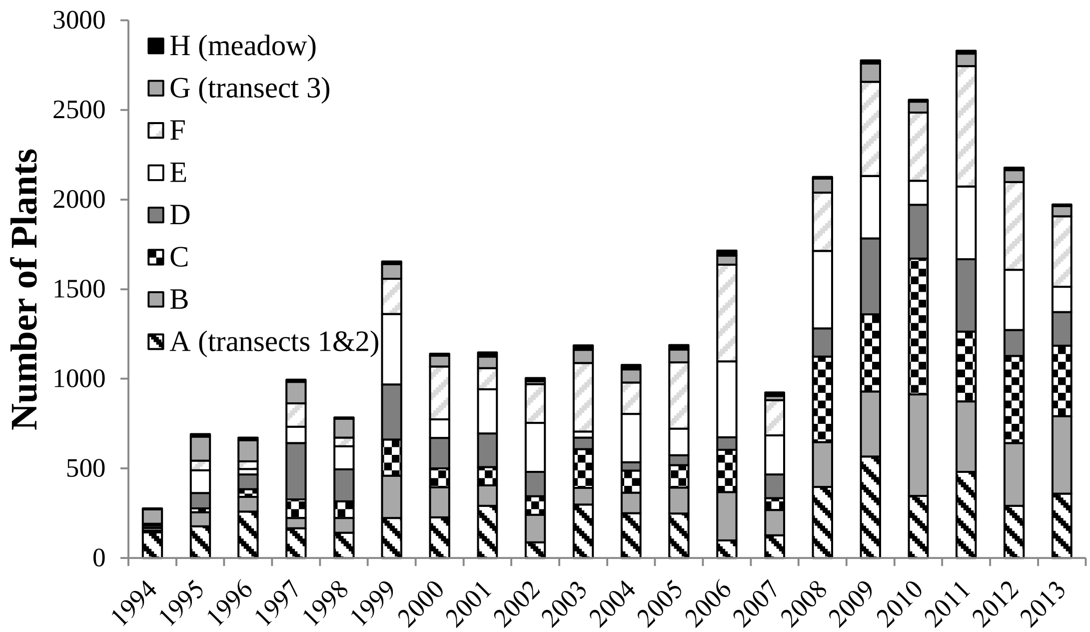


**Figure 18. Population fluctuations in *L. cookii* patches A-H at Rough and Ready Creek, 1994-2013.**

## Indian Hill

The total population size of *L. cookii* at Indian Hill has generally increased since monitoring was initiated in 1997. There were approximately 1,233 more plants in 2013 than in 2012, for a total of 10,543 (Figure 17 and Table 8). On average, reproductive plants have composed 32% of the population (minimum, 16% in 1997; maximum, 46% in 2003). In 2013, reproductive plants were 24% 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 $m^{-2}$ in 1997 to 0.81 plants $m^{-2}$ in 2004, 2005, and 2006. The density of reproductive plants in 2010 was 0.87 plants $m^{-2}$, the highest since monitoring began. In 2013, there was approximately 0.5 reproductive plants $m^{-2}$, an increase of 53% from the previous year.

The majority of plants at Indian Hill were vegetative (Figure 17). In 2013, the V1-V2 and V3 stages composed 30% and 46% of the population, respectively. The R1 stage also made a substantial contribution (17%) to the population in 2013. Many of the V3 and R1 plants are likely a result of the prolific seedling recruitment in 2005. Seedling numbers at the site have varied substantially. The proportion of seedlings decreased from 1.2% in 2012 to 0.7% in 2013.

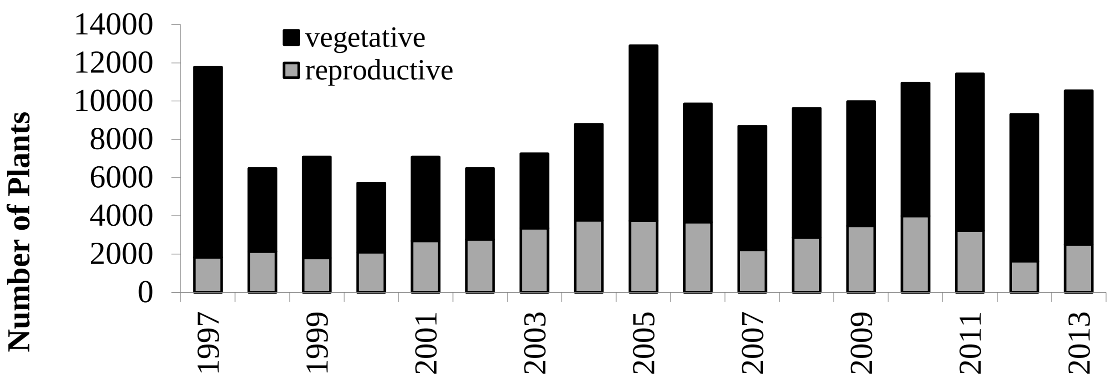


**Figure 19. Number of vegetative and reproductive plants at Indian Hill, 1997-2013.**

Table 8. Summary of population density and size (mean ± 95% confidence limit) for the Indian Hill population, 1997-2013.

| | density ($m^{-2}$) | | population size | |
|---|---|---|---|---|
| year | reproductive | total | reproductive | total |
| 1997 | 0.40 ± 0.20 | 2.56 ± 1.28 | 1,840 ± 913 | 11,776 ± 5,738 |
| 1998 | 0.46 ± 0.41 | 1.41 ± 1.00 | 2,134 ± 1,842 | 6,477 ± 4,466 |
| 1999 | 0.39 ± 0.30 | 1.54 ± 0.96 | 1,803 ± 1,335 | 7,084 ± 4,279 |
| 2000 | 0.46 ± 0.37 | 1.24 ± 0.87 | 2,098 ± 1,674 | 5,704 ± 3,904 |
| 2001 | 0.58 ± 0.57 | 1.54 ± 1.25 | 2,686 ± 2,562 | 7,084 ± 5,599 |
| 2002 | 0.60 ± 0.53 | 1.41 ± 1.05 | 2,778 ± 2,367 | 6,477 ± 4,698 |
| 2003 | 0.73 ± 0.60 | 1.58 ± 1.47 | 3,349 ± 2,668 | 7,250 ± 6,556 |
| 2004 | 0.82 ± 0.76 | 1.91± 1.62 | 3,772 ± 3,387 | 8,795 ± 7,259 |
| 2005 | 0.81 ± 0.63 | 2.80 ± 2.65 | 3,735 ± 2,826 | 12,898 ± 11,874 |
| 2006 | 0.80 ± 0.59 | 2.14 ± 1.75 | 3,680 ± 2,660 | 9,862 ± 7,849 |
| 2007 | 0.48 ± 0.44 | 1.89 ± 2.22 | 2,226 ± 1,969 | 8,685 ± 9,942 |
| 2008 | 0.60 ± 0.54 | 2.04 ± 2.03 | 2,870 ± 2,374 | 9,623 ± 9,018 |
| 2009 | 0.76 ± 0.61 | 2.17 ± 1.93 | 3,478 ± 2,721 | 9,973 ± 8,640 |
| 2010 | 0.87 ± 0.94 | 2.38 ± 2.52 | 3,993 ± 4,186 | 10,948 ± 11,263 |
| 2011 | 0.70 ± 0.71 | 2.48 ± 2.41 | 3,220 ± 3,161 | 11,426 ± 10,784 |
| 2012 | 0.36 ± 0.29 | 2.02 ± 1.53 | 1,638 ± 1,281 | 9,310 ± 6,822 |
| 2013 | 0.54 ± 0.52 | 2.29 ± 2.03 | 2,502 ± 2,306 | 10,543 ± 9,077 |

## Herbivory on *Lomatium cookii*

Herbivory by voles is relatively frequent on *Lomatium 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 *L. cookii* that are grazed.

Herbivory on *Lomatium cookii* has fluctuated between years, and the patterns are not synchronous among the sites (Figure 18). In 2012, French Flat Middle and Rough and Ready had increased herbivory while Indian Hill had a large decrease in herbivory. 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.

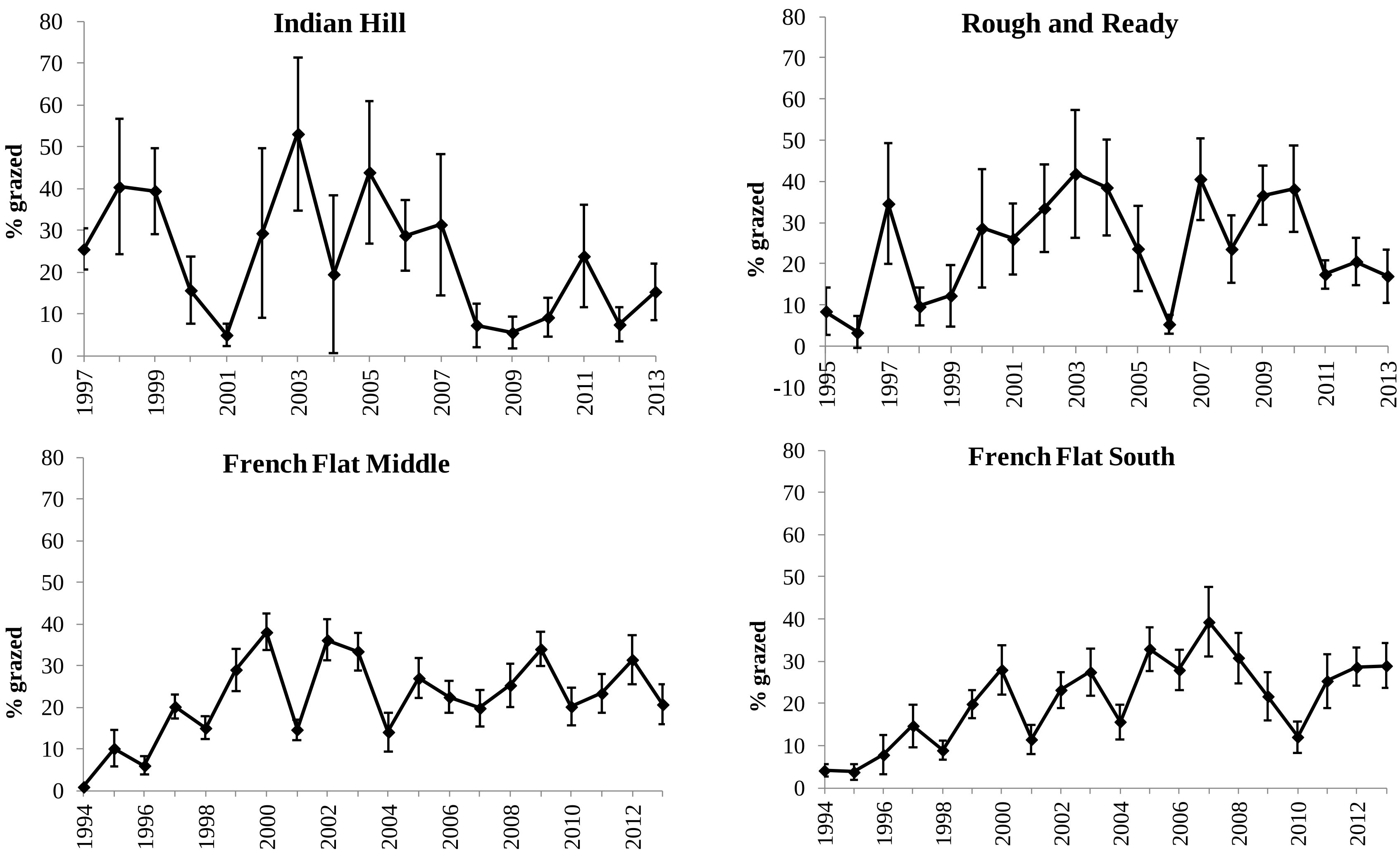


**Figure 20. Frequency of herbivory on *L. cookii* populations at four populations, 1994-2013. Error bars represent 95% confidence intervals.**

# DISCUSSION

## Current population status

In 2013, the number of *Lomatium cookii* decreased at Rough and Ready and French Flat South, but increased at Indian Hill and French Flat Middle.

### French Flat

Current population estimates at this site are approximately 81,067 plants at the Middle subpopulation and 114,296 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 19). IAE is analyzing the effects of climate on *Lomatium cookii* through Climate Driven Population Models and the results will be included in a separate report.

The Middle subpopulation hosted an estimated 195,057 individuals in 1998 when the population was at its highest, up from 74,694 when monitoring began in 1993 and almost three times 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 267,075 individuals. Since then, it has generally declined as well.

Results from population viability analyses based on information from 1994-1999 and 2008-2013 for Middle and 1994-2011 and 2012-2013 for South indicated that these subpopulations differed in their growth rates, although both are likely to decline. Stochastic simulations based on observed environmental variability indicated that the risk of extinction or catastrophic decline was moderately high 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-year period.

### Rough and Ready Creek

We counted 1,973 plants at Rough and Ready Creek in 2013. 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 this site and French Flat. While road use can reduce the number of plants in this population, we observed recruitment along the roadbeds in 1995-2006, likely due to the reduced competition in these areas. A large trash pile found on the western edge of Patch A in 2003 and fresh ORV tracks in multiple years are indicative of active road use and off-road habitat impact. Boulders placed to block vehicle traffic on some roads and grassland patches has resulted in effective protection of this habitat, and grasses are now colonizing the protected road beds.

### 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 2005-2013. 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, but the population size has been relatively stable in recent years, and the site does not appear to receive ORV use.

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

## 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 (Figure 19). Also, horse-back riders that use French Flat should be warned of the presence of rebar posts interspersed throughout the habitat.

Prescribed burning at this site is recommended and if implemented will allow for comparisons of population processes before and after burning. Currently no information is available on the response of *L. cookii* to fire, but a similar species, *L. bradshawii*, that occurs in grasslands in the Willamette Valley has been shown to respond positively to fall burns (Kaye et al. 2001).

### Rough and Ready Creek

The road leading through the Rough and Ready population is un-gated but some sensitive portions of habitat at this site have been blocked off from vehicle traffic with boulders. These obstacles appear to be having the desired effect of blocking vehicle access, which was a significant concern at this site in recent years. Vehicle access should be monitored at this site to confirm that the boulders remain in place and that habitat protection is succeeding.

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.

### 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 be having detrimental impacts on the *L. cookii* population through competition for light, water, and nutrients. We recommend that these shrubs be removed to improve habitat conditions. Monitoring at Indian Hill should be repeated annually to detect changes in population size and density.

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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 pin flags

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 4-5 hours. Park at turn-off for dirt road, unless conditions have been improved since 2010. May need to walk in from gate on Waldo Rd.
- Need vehicle with clearance for Indian Hill.