Comparison of Populations of *Lesquerella ludoviciana* Throughout Its Range

A. Claerbout and J. Coons

ABSTRACT

Lesquerella ludoviciana (silvery bladderpod) (Brassicaceae) is a threatened and endangered plant of Midwestern sand prairies. Populations of *L. ludoviciana* are limited in Illinois, Minnesota, and Wisconsin but occur commonly in western states. The objective of this study was to compare populations of *L. ludoviciana* throughout their range. Regions where *L. ludoviciana* populations are on the fringe of their range in IL, MN, WI, and MT as well as those in the central part of their range in CO, ND, and UT were visited in June 2002. Populations of *L. ludoviciana* were surveyed for: 1) flower, fruit, and seed production per plant, 2) insects visiting flowers, 3) plant density including seedling, vegetative, and reproductive stages, 4) soil samples, 5) dominant associated species, and 6) atmospheric and locality descriptions, including area. The Illinois population had the greatest number of flower stalks per plant (6.2 stalks). North Dakota population had the greatest number of flowers/stalk (6.3 flowers/stalk). Plants at Illinois and Minnesota had the greatest number of fruits/stalk with means of 23.7 and 21.7, respectively. Populations were not significantly different for seed production per 25 fruit. Five orders of visiting insects were identified including Coleoptera, Diptera, Hemiptera, Hymenoptera, and Orthoptera. The Illinois population had the greatest plant density with 0.5 seedlings/m^2, 1.5 vegetative plants/m^2, and 4.2 reproductive plants/m^2. Historic populations in Wisconsin were not located. Soils were loamy sand and sand with pH ranging from 7.9-8.1. Cation exchange capacity ranged from 8.2-23.2 Meq/100 g. Percent organic matter of soils ranged from 2.1-2.3%. Dominant associated species included *Artemisia frigida*, *Oenothera* sp., *Opuntia* sp., *Rhus aromatica*, and *Schizachyrium scoparium*. All sites had full sun exposure on southwestern facing

slopes. A comparison of populations throughout their range will help to explain the statewide limitations of *L. ludoviciana* in Illinois by determining if the endangered populations are limited by reproductive biology, breeding systems, seed biology, population viability, or growing conditions in comparison to more widespread populations in western states. This information will increase our understanding of the ecology of this *L. ludoviciana* and will allow for better management decisions in populations near the fringe of its range.

INTRODUCTION

Lesquerella ludoviciana (silvery bladderpod) (Brassicaceae) is listed as an endangered plant in Illinois, yet it occurs in other parts of the western United States. The nationwide distribution for *L. ludoviciana* extends from Montana east to Wisconsin, south to Illinois, west to Nevada, and north to Montana (Figure 1) (USDA, NRCS, 2002b). Throughout its range, *L. ludoviciana* flowers from April into August on sandy soils (Rollins and Shaw, 1973). The flower stalk elongates from a basal rosette of silvery leaves, and yellow flowers are borne on a raceme. The globose silicles begin maturing on the lower portion of the flower stalk, and fruit set can occur on the lower portion of the stalk while flowers at the top are still opening.

Other than descriptions of its habitat and reports of its existence, little is known about *L. ludoviciana* populations throughout their range (Rollins and Shaw, 1973). Populations of various species of the genus *Lesquerella* were studied mostly from a taxonomic perspective. Al-Shehbaz and O'Kane (2002) renamed species of *Lesquerella,* including *L. ludoviciana*, under the genus *Physaria* based on findings from DNA sequencing.

The most studied populations are those within Illinois, which are limited to three *L. ludoviciana* colonies in a sand prairie at the Henry Allan Gleason Nature Preserve. In Illinois, flowering is in late spring, and mature seed is set in early summer (Beach *et al.*, 2002). In

Illinois, *L. ludoviciana* is associated with other grassland and sand prairie species such as *Asclepias viridiflora*, *Aster* sp., *Bouteloua hirsuta*, *Euphorbia corollata*, *Liatris aspera*, *Oenothera rhombipetala*, *Opuntia humifusa*, *Rhus aromatica*, and *Schizachyrium scoparium* (Ebinger and McClain, 1999).

Plants at the preserve grow on remnant sand dunes that are fully exposed and have been eroded by the wind into 2 distinct bowl-shaped depressions. Of the 3 colonies at the preserve, the North Colony-Lower Bowl was the largest and in 2000 was estimated with an area of 3,248 m^2. The North Colony-Upper Bowl was 1,025 m^2 and the South Colony was 270 m^2 (Beach *et al.*, 2001). Number of reproductive plants for the colonies was 3,573, 103, and 378 for North Colony-Lower Bowl, North Colony-Upper Bowl, and South Colony, respectively (Beach *et al.*, 2001). For the largest colony, North Colony-Lower Bowl, plants produced an average of 3.2 flower stalks/plant and 46.2 fruits/plant (Beach *et al.*, 2001). Plant density was greatest for the North Colony-Lower Bowl at 3.1 seedlings/m^2, 4.4 vegetative plants/m^2, and 8.6 reproductive plants/m^2. Total number of plants in 2000 was estimated at 27,933, 1,846, and 1,296 for North Colony-Lower Bowl, North Colony-Upper Bowl, and South Colony, respectively (Beach *et al.*, 2001). Based upon 2.4 seeds per fruit counted in 1999, estimated North Colony-Lower Bowl population area (3,278 m^2), and density of reproductive plants at North Colony-Lower Bowl (1.1/m^2), the estimated number of seeds produced for the North Colony-Lower Bowl was 396,174 in 2000.

Visiting insects have not previously been identified for *L. ludoviciana* but presumably include bees and flies (Rollins and Shaw, 1973). *L. fendleri*, a native perennial of southwestern U.S. and northern Mexico, is primarily pollinated by small bees (Halictidae, Andrenidae) and beeflies (especially *Pantarbes pubsio*) (Roll *et al.*, 1997).

The objective of this work was to compare reproductive biology, breeding systems, seed biology, population viability, and growing environment of *L. ludoviciana* populations throughout their range in the United States. This information will increase our understanding of the ecology of this plant and allow for better management in Illinois and other areas near the edge of its range.

MATERIALS AND METHODS

Populations of *L. ludoviciana* near the edge of their range (Illinois, Minnesota, Wisconsin, and Montana) and near the center of their range (North Dakota, Colorado, and Utah) were sampled in May and June 2002. On May 6, 2002 the largest of 3 IL colonies, North Colony-Lower Bowl was sampled. From June 2 to June 24, 2002, 7 populations were investigated for *L. ludoviciana* colonies. (Population 1: the Henry Allan Gleason Nature Preserve, Mason County, Illinois; Population 2: Sterling, Logan County, Colorado; Population 3: Grand Staircase-Escalante National Monument, Garfield County, Utah; Population 4: Great Falls, Cascade County, Montana; Population 5: Theodore Roosevelt National Park, Billings County, North Dakota; Population 6: Redwing, Goodhue County, Minnesota; Population 7: Hager City, Pierce County, Wisconsin). An overall map of the populations is shown in Figure 2. These populations were located with information from herbarium specimen vouchers. Individual populations and subsequently smaller distinct colonies were located on the day of collection with the help of local botanists (Appendix A). Data were collected to evaluate reproductive biology, breeding systems, seed biology, population viability, and growing conditions of *L. ludoviciana.*

H. A. Gleason Nature Preserve, Illinois (IL). The population in the H. A. Gleason Nature Preserve, Mason County, Illinois, located 2 km S of Goofy Ridge, Illinois (N40° 22.786', W89° 55.733'), was sampled on May 6 and June 3, 2002. This sand prairie contained the only population of the endangered *L. ludoviciana* in the state (Herkert and Ebinger, 2002). Although 3 distinct flowering

colonies of *L. ludoviciana* were found, only the largest colony, North Colony-Lower Bowl was sampled in this study (Figure 3). *Figures 3-11 are maps of each site visited, and are in separate files saved on this CD.* Plants were concentrated within a bowl-like depression (Photo 1). *Photos 1-7 are pictures of each site visited, and are in separate files saved on this CD.* Population viability was sampled with quadrats placed at random distances from a transect and with quadrats placed directly adjacent to a transect. The transect was stretched towards the southwest across the center of the bowl. The soil was very sandy and sampled easily with a shovel. The vegetation was mostly grasses and other prairie plants.

Sterling, Colorado (WCO and ECO). The population in Logan County, Colorado near Sterling, Colorado was sampled on June 6, 2002. *Lesquerella ludoviciana* is not listed as threatened or endangered in Colorado. Two colonies were located on eroded soil, rocky outcrops. One colony (WCO), located 39 km NW of Sterling, Colorado, E of County Route 13 (N40° 55.901', W103°27.393'), was small enough to measure all of the plants (Figure 4). The second colony (ECO), located 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24 (N40° 35.860', W103° 02.178'), was larger with plants clustered on the top of a hill and widely spread along the slope (Photo 2 and Figure 5). On top of the hill, population viability was sampled with quadrats placed directly along a transect, parallel to lip of an escarpment, stretched towards the southwest across the concentration of plants. Along the slope, population viability was sampled with quadrats placed at random distances from a transect and with quadrats placed directly adjacent to a transect. The transect was stretched towards the southwest across the approximate center of the plant distribution along the slope from top to bottom. At both colonies, the soil was mostly rock and impenetrable to a shovel, making soil sampling impossible with equipment available. Vegetation was grassland or short grass prairie used mainly as rangeland.

Grand Staircase-Escalante National Monument, Utah (UT1 and UT2). The population at Grand Staircase-Escalante National Monument, Garfield County, Utah was sampled on June 13 and June 14, 2002. *Lesquerella ludoviciana* is not listed as threatened or endangered in Utah. On June 13 one colony (UT1) was located 6 km S of Escalante, Utah along Mitchell Canyon (N37° 43.031', W111° 38.046'). Plants at UT1 were widely spread along the seasonal streambed of Canaan Creek (Photo 3 and Figure 6). In many parts of UT1 distance between plants was greater than 45 m, therefore transects were not used to sample population viability of UT1. On June 14 a second colony (UT2), located 8.3 km SE of Escalante, 100 m S of Old Escalante Rd. (N37° 45.816', W111° 41.692'), was small enough to measure all of the plants (Figure 7). At both colonies, plants were growing in a small area along the seasonal streambed of Birch Creek. The soil was very sandy with pebbles, and sampled easily with a shovel. The vegetation was mostly sagebrush.

After closer examination of the *Lesquerella* sp. plants that were taken as voucher specimens from UT1, it was determined that the colony was *Physaria arenosa* subsp. *arenosa* (Al-Shehbaz and O'Kane, 2002) (formerly *L. arenosa* subsp. *arenosa)*. The Grand Staircase-Escalante National Monument collection permit restricted whole plant collections to colonies of at least twenty individuals, so no voucher specimen was taken from the smaller UT2 population. It was impossible to verify the species of *Lesquerella* at UT2 without a voucher specimen. Thus, data collected from Utah populations was not included in comparisons with the other sites, but are included in the Appendix B.

Great Falls, Montana (MT1 and MT2). The population in Cascade County, Montana near Great Falls, Montana was sampled on June 20, 2002. *Lesquerella ludoviciana* is not listed as threatened or endangered in Montana. Two colonies of *Lesquerella* sp. were located at the

Crooked Falls Managed Area along the banks of the Missouri River. The 2 colonies were separated by a County road (Figure 8). The colony with the greatest amount of plants (MT1) was located 10 km NE of Great Falls on the S side of Rainbow Loop Road at the Crooked Falls Managed Area (N47° 33.032', W111° 09.966') (Photo 4). Population viability was sampled with quadrats placed at random distances from a transect and with quadrats placed directly adjacent to a transect. The transect was stretched towards the southwest across the approximate center of the plant distribution parallel to the river. The colony with the least amount of plants (MT2) was located 10 km NE of Great Falls on the N side of the Rainbow Loop Road 700 m to the NW of MT1 at the Crooked Falls Managed Area (N47° 33.183', W111° 10.078'). Plants in this colony were counted but not sampled. At both colonies, plants were very widespread. The soil was more clayey with large rocks. The vegetation was mostly grasses, and the area was used as rangeland.

After closer examination of the plants that were taken as voucher specimens from these colonies, MT1 was determined to be *Physaria reediana* subsp. *spatulata* (Al-Shehbaz and O'Kane, 2002) (= *Lesquerella alpina*). MT2 consisted of *Physaria reediana* subsp. *reediana* and *Physaria reediana* subsp. *spatulata* (Al-Shehbaz and O'Kane, 2002) (= *Lesquerella alpina*). Data collected from Montana colonies were not included in comparisons with the other populations, but are included in the Appendix B.

Theodore Roosevelt National Park, North Dakota (ND). The population at Theodore Roosevelt National Park, Billings County, North Dakota was sampled on June 22, 2002. *Lesquerella ludoviciana* is not listed as threatened or endangered in North Dakota. One large colony of *L. ludoviciana* was located 5 km NE of Medora, North Dakota along the Ridgeline Trail off of Scenic Loop Drive (N46° 55.286', W103° 27.797') (Photo 5 and Figure 9). A second smaller colony was found along Wind Canyon Trail but was not sampled. Plants were growing

on a bowl-shaped hill in an area known as "badlands". *L. ludoviciana* plants were mostly growing along the ridges and slopes of steep escarpments. Population viability was sampled with quadrats placed at random distances from transects and with quadrats placed directly adjacent to transects. One transect was stretched towards the north along the top of a ridge. A second transect was stretched down a southwest facing slope. Soil was mostly sand and sampled easily with a shovel. The vegetation was grassland that was grazed by free-range bison.

Redwing, MN (MN). The population in Goodhue County, Minnesota, located across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota (N44° 32.744', W92° 32. 744' 24) was sampled on June 24, 2002 (Photo 6 and Figure 10). *Lesquerella ludoviciana* is an endangered plant in Minnesota (Minnesota Department of Natural Resources Non-game Wildlife, 1996). In Redwing, plants were growing along exposed, sandy areas on the slope of a steep bluff. Population viability of one colony was sampled with quadrats placed at random distances from transects and with quadrats placed directly adjacent to transects. One 30 m transect was stretched north to south parallel to the slope. A second 15 m transect was stretched east to west perpendicular to the slope at the center of the 30 m transect. The sandy soil was eroded in several places, and was sampled easily with a shovel. The vegetation was mainly grasses with encroaching hardwoods.

Hager City, WI (WI). The historic population in Pierce County, Wisconsin, located at Trenton Bluff Prairie along County Highway E, 2 km northwest of Hager City (N44° 37.175', W92° 32.008')(Sect. 28 W ½ of SE ¼; T25N, R18W), was visited on June 24, 2002 (Photo 7, Figure 11). *Lesquerella ludoviciana* is threatened in the state of Wisconsin (Wisconsin Department of Natural Resources, 2003). According to University of Wisconsin herbarium records this location near Hager City historically contained the only colony recorded in the state.

The most recent voucher from 1977 described the population as 35 plants found growing mostly on ledges and cracks of limestone cliffs near the top of cliffs and on the dry prairie just below the cliffs. When visited in June 2002 for this study, no plants were found, so WI was not included in comparisons of reproductive biology, breeding systems, seed biology, population viability, or growing environment.

Reproductive biology. At IL, ECO, MT, ND, and MN, 45 plants were sampled randomly throughout colonies. At UT 1 the first 45 plants east to west along the streambed were sampled. All of the plants in smaller colonies of WCO and UT2 were measured. The number of flower stalks/plant was recorded. The tallest flower stalk was identified on plants. Height of tallest flower stalk was measured, and counts were taken on number of flowers, pedicels, fruits, and fruits with holes for the tallest flower stalk. Flowers and fruits of plants at ND had galls that were not seen at any other site. Number of galls/tallest flower stalk was counted on the 45 sampled plants.

Breeding systems. Insects visiting flowers were collected at IL, WCO, ECO, UT1, and MT on May 6, June 6, June 6, June 13, and June 20, 2002, respectively. Insects were collected randomly from 12:30 pm-2:30 pm, 11:30 am-12:00 pm, 3:30 pm-6:30 pm, 10:30 am-11:30 am, and 1:30 pm–2:30 pm, throughout colonies, respectively. Insects at ND were collected only in designated plots. Plants at MN were past flowering at the time of sampling, so no insects were collected. For designated plot collections, at H. A. Gleason Nature Preserve insects were collected from 1:30 pm–2:30 pm from a 1 m^2 plot containing 65 flower stalks. Insects at UT1 were collected from 2:45 pm-3:45 pm from a 1 m^2 plot containing one plant with 13 flower stalks. Insects at ND were collected from 10:20 am-11:20 am only from a 9 m^2 plot containing 68 flower stalks. Visitations were calculated per m^2. Insects were collected with nets, placed in

killing jars containing cyanide, and stored in a plastic tackle box with absorbent "changing pad" material until September, 26 2002. Insects were pinned and identified by entomologists at the Illinois Natural History Survey, Urbana, Illinois under the direction of Dr. Don Webb. One to two flower stalks were collected from larger flowering populations (IL, ECO, ND) and preserved in Formalin-Acetic acid-Alcohol (FAA) fixative [50 cc ethanol (95%), 5 cc glacial acetic acid, 10 cc of formalin (37% formaldehyde), 35 cc deionized water] (Ruzin, 1999). Flower stalks were transferred to 70% ethanol on July 14, 2002.

Seed biology. One hundred fruit (less than 10% of seed present per each population) were collected from large colonies (IL, ECO, UT1, MT1, ND, MN). Twenty-five of these fruit collected from different plants were placed into each of 4 seed envelopes. Fruit were stored at room temperature until November 2002 when they were dissected under a microscope. Number of seeds per 25 fruit was recorded.

Population viability. Transects (45 m) were spread at large colonies (IL, ECO, ND, MT, MN) to determine average plant density, including estimates of seedlings (basal rosettes of 6 leaves or less), vegetative plants (basal rosettes with more than 6 leaves but no flower stalk), and reproductive plants (flower stalks present) in the population. Quadrats (0.25 m^2) were placed at every meter located at random distances from (IL, ECO, MT, ND, MN) and directly adjacent to the transect (ECO, MT, ND, MN) on alternating sides for every meter. At WCO and UT2 all the plant in the colony were counted and number of seedling, vegetative plants, and reproductive plants were determined. At UT1 the first 45 plants were counted and number of seedlings, vegetative plants, and reproductive plants were determined. Coordinates along the perimeter of major colonies (IL, ECO, ND, MN) were recorded using a Garmin GPS 12XL (accuracy ± 15 meters). For WCO, the length and width of colony was measured with tape measures. For UT1,

coordinates along the length of the colony were recording using GPS and later plotted to determine length, and width was measured with tape measure. Colony areas were calculated and maps were drawn with DeLorme Topo® 4.0 USA (DeLorme, 2002).

Growing conditions. Using a shovel, three samples of the top 10 cm of soil were taken randomly throughout the colony, except at Colorado sites. Soil at IL was sampled in November 2002. Samples were mixed together, and 455 ml sub-samples from colonies were sent to A & L Analytical Laboratories, Inc., Memphis, TN in January 2003 for pH and fertility analysis. Dr. Robert Darmody's lab at the University of Illinois ran texture analysis on soil sub-samples in February 2003. Soil surveys and soil coverage maps (accessed with ERSI ArcView™ 8.2) (ERSI, Inc. 1999–2002)were used to determine soil series descriptions for IL, ECO, UT1, MT1, ND, and MN (Amen *et al.*, 1974; Calsyn, 1995; Clark *et al.*, 1982; NRCS, 1996; Poch, 1976; USDA, NRCS, 2002a; USDA, NRCS, 2002c). Associated plant lists were compiled to include the following: those species identified on-site by local botanists, specimens collected at the site and later identified by botanists, and species listed in recent plant lists for sites (when available). A list of local botanists assisting in identification of associated species on-site is shown in Appendix A. Dr. Janice Coons and Kathryn Yurkonis identified associated species on-site at MN. Plant specimens of *L. ludoviciana* and associated species were collected, pressed, and later identified by botanists at the Illinois Natural History Survey in Urbana, IL (Drs. Rick Phillippe and Ken Robertson); Eastern Illinois University in Charleston, IL (Dr. John Ebinger); and University of Northern Iowa in Cedar Falls, IA (Dr. Steve O'Kane). Recent plant lists included those by Ebinger and McClain (1999), Siddoway (2002), Taylor (1992), and Welsh and Atwood (2001). Leaf tissue (3 leaves from each of 3 plants per population) also was collected, stored in Victoria's Silica Gel Flowering Drying Crystals (Kokomo, IN), and sent to the University of

Northern Iowa in February 2003 for DNA analysis. Soil temperature at 10 cm was determined with a Mannix digital thermometer, relative humidity was determined by a Mannix PTH8708 thermo-hygrometer, and wind speed and air temperature were recorded with an Extech 45118 thermo-anemometer. Coordinates and altitude of each colony were determined by a Garmin GPS 12XL (accuracy ±15 meters). Exposure and direction of slope were estimated at each colony. Habitat was documented with digital photography.

Data were analyzed using Microsoft Excel (Microsoft Corporation, 2000) and SAS 8.2 (SAS Institute, Inc., 2001). Mean separations were determined using Duncan's multiple range test at 5%. Means are expressed plus or minus standard error.

RESULTS

Reproductive biology. At the time of sampling, colonies in IL, ECO, WCO, and ND had flowers, and MN had only fruit. Larger colonies with greater than 6 plants (IL, ECO, ND, MN) were significantly different for number of stalks per plant, height of tallest stalk, number of flowers/stalk, number of pedicels/stalk, number of fruits/stalk, and number of fruits with holes/stalk (Table 1). IL had the greatest number of stalks per plant. Plants at ND had the tallest flower stalks and the greatest number of flowers. Plants at ND and IL had the greatest number of pedicels/stalk. Plants at IL and MN had the greatest number of fruits/stalk. IL had the highest number of fruits with holes/stalk. WCO had 6 plants in the colony and results for reproductive biology are shown in Table 1. Percent of pedicels containing flowers, fruits, and other (including pedicels that are missing flowers or fruits) are shown in Table 2. The galls on flowers and fruit found only at ND were present on 33% of the 45 sampled flower stalks with an average of 0.7 galls/stalk. Results for reproductive biology of UT1, UT2, and MT1 are listed in Appendix B.

Breeding systems. Twenty-nine insects were collected at all of the colonies of *L. ludoviciana* (Table 3). The H. A. Gleason Nature Preserve had insects visiting the plot at a frequency of 13 insects/m^2/hour in June 2002. At the time of sampling, MN was past flowering with no open flowers. ND had insects visiting the plot at a frequency of 0.7 insects/m^2/hour. Results for breeding systems of UT1 and MT1 are shown in Appendix B.

Seed biology. Colonies were not significantly different for number of seeds per 25 fruit. Mean number of seeds per 25 fruit and calculated average seeds per fruit are shown in Table 4. Results for seed biology of UT1 and MT1 are shown in Appendix B.

Population viability. For colonies sampled with randomly located quadrats (IL, ECO, ND, MN), IL had greatest seedling, vegetative plant, and reproductive plant densities (Table 5). For colonies sampled with quadrats located adjacent to the transect (ECO, ND, MN), MN had greatest seedling and vegetative plant densities, and colonies were not significantly different for density of reproductive plants (Table 6). In Illinois, no significant differences were found in the number of seedlings, vegetative plants, or reproductive plants between May and June 2002 (Table 7). All 6 plants at WCO were reproductive plants. Areas of colonies are shown in Table 8. Estimated flower stalks, flowers, pedicels, fruits, fruits with holes, and seed production/colony are shown in Table 8. Estimated flowers, pedicels, fruits, fruits with holes, and seeds/plant on a per reproductive plant basis are shown in Table 9.

Growing conditions. Soils were basic, with poor fertility, low percent organic matter, and mostly sand (Table 10). Descriptions of soil series from soil surveys and soil coverage maps are found in Table 11. *Artemesia* sp., *Bouteloua* sp., *Euphorbia* sp., *Oenothera* sp., *Opuntia* sp., *Rhus aromatica*, and *Schizachyrium scoparium* were frequently occurring associated species across many populations of *L. ludoviciana*. Lists of associated species are listed by site in Tables

12, 13, 14, 15, and 16. Table 17 shows altitude, soil temperature, air temperature, relative humidity, and wind speed for each research site. All colonies were in full sun on a southwestern facing slope.

DISCUSSION

Populations were sampled at various stages of development, which allowed reproductive biology to be characterized only at the time of sampling. Results did not represent populations at peak flower or fruit production. ND had the greatest number of flowers indicating the colony was sampled at a developmental stage closer to peak flowering. Similarly, IL and MN had the greatest number of fruit indicating the colonies were at developmental stages closer to peak fruiting. IL produced considerably more fruit per plant in 2002 compared to 2000 (Beach *et al.*, 2001). These differences in fruit production across seasons also could be attributed to sampling at various stages of development. *L. ludoviciana* produces a fixed number of flower stalks at the onset of flowering, and those flower stalks continue to elongate and produce pedicels while in the flowering stage. Therefore, height of flower stalk and number of pedicels is dependent on the plant's developmental stage, while number of flower stalks is independent. Number of flower stalks produced per plant in 2002 is about the same as those produced in 2000 even though colonies were sampled at different developmental stages. Without repeated sampling to verify peak flowering and fruiting stages, estimates of reproductive biology are considered conservative.

Herbivory was not found to affect strongly seed production in populations of *L. ludoviciana* sampled in 2002. Number of fruit with holes, found to be the greatest in IL, was seen in only 8% of fruit/stalk. Although galls were found on a large percentage of flowers and fruits at ND, the number of seeds per 25 fruit was the same as other populations. In some colonies a large

percentage of pedicels are missing flowers and fruit indicating that flowers as well as fruit are being removed, naturally abscising, or possibly being eaten. Future studies should identify causal agents of flower and fruit herbivory and investigate herbivory at different times of the season.

Population viability of *L. ludoviciana* is not limited by pollinators or seed production. Few visiting insects were collected; however, species diversity spanned five orders, and no endangered insects were identified. Throughout the range of *L. ludoviciana,* plants grow widely scattered throughout areas, and visiting insects with small ranges may be deterred by low reproductive plant densities. Also, insect visitations could be more frequent at times of peak flowering. Seeds are consistently being produced in large amounts per plant, but few colonies showed evidence of seedling regeneration.

Population viability varied throughout the sampled colonies. The state endangered population at IL had the leading number of seedlings, vegetative plants, and reproductive plants indicating high population viability. When colonies were sampled with quadrats located at random distances from transects, IL was the only colony with seedlings. When colonies were sampled with quadrats located directly adjacent to transects, MN also produced seedlings. Despite the inability of quadrats located away from transects to detect seedlings in MN, this method of sampling was preferred in order to insure more random sampling of plants that were found very widely dispersed throughout an area. Plant densities for the state endangered plant at MN were similar to other sites surveyed, but population viability at MN may soon suffer due to encroaching hardwoods and loss of exposed sand prairie habitat. At WI, where the only recorded plants in the state historically occurred, the population has been seriously affected by loss of dry prairie habitat that was being replaced with sumac and other more aggressive vegetation. Plants that were recorded there in 1977 were not found in 2002.

The area of the IL colony was determined to be 69% smaller than was estimated by Beach *et al.* (2001). The IL colony could have gotten smaller. Since these are slow to establish, perennial plants, we would most likely not see that large of a difference in population sizes over only a few years. This difference in area could be contributed to the fact that sampling methods with a GPS unit is more precise. By plotting coordinates taken around the perimeter of the colony, areas of irregular polygons were calculated easily.

Differences in number of associated species at each site are most likely due to the partial identification of the species at each sight. Associated species lists are incomplete and would require a quantitative assessment of each species at different times of the season to more accurately depict the associated species. Specimens that were identified in the field or identified later as herbarium vouchers were those that were most noticeable due to developmental stage or flowering. Species from reference lists were added to associated species lists in order to provide a high estimate of species found at different parts of the season.

The ability for *L. ludoviciana* to survive harsh growing conditions is the most striking similarity between populations throughout their range. *L. ludoviciana* prefers a sandy soil habitat with low soil fertility and the low water holding capacity situated on fully exposed southwestern slopes. Associated species are consistent throughout the range of *L. ludoviciana* and are identified as grassland and dry prairie species.

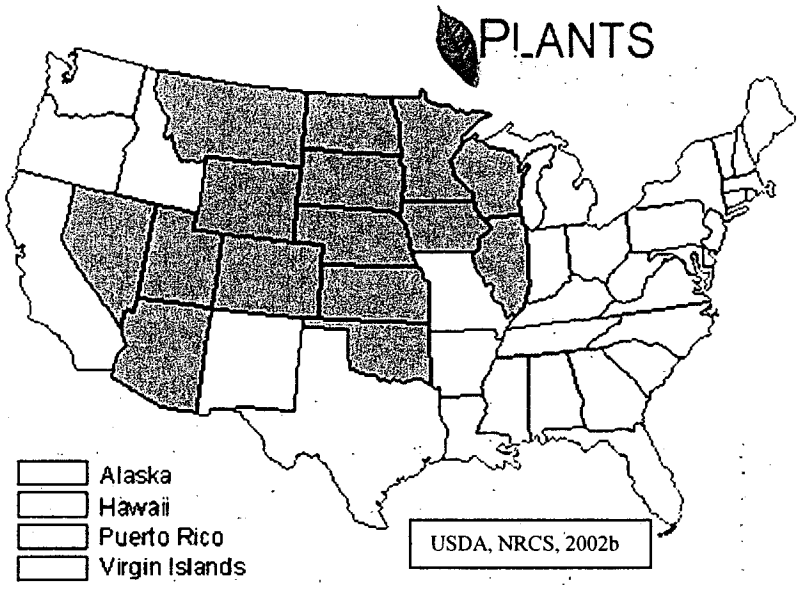
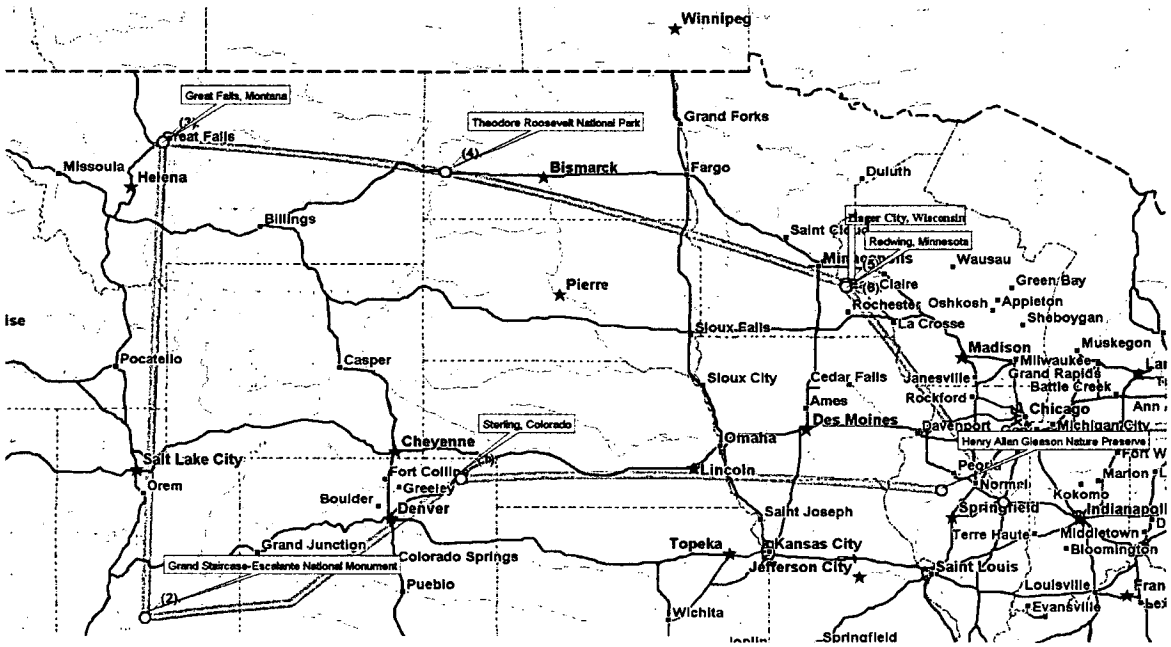


Figure 1. Distribution of *Lesquerella ludoviciana* throughout the United States (USDA, NRCS, 2002b).



Population 1: Henry Allan Gleason Nature Preserve, Illinois
Population 2: Sterling, Colorado
Population 3: Grand Staircase-Escalante National Monument, Utah
Population 4: Great Falls, Montana
Population 5: Theodore Roosevelt National Park, North Dakota
Population 6: Redwing, Minnesota
Population 7: Hager City, Wisconsin.

Figure 2. Route of June 2002 collection trip to compare populations of *Lesquerella ludoviciana* throughout their range.

Table 1. June 2002 reproductive biology in colonies of *Lesquerella ludoviciana* with more than 6 plants at the Henry Allan Gleason Nature Preserve, Mason County, Illinois (IL); Sterling, Logan County, Colorado (ECO); Theodore Roosevelt National Park, Billings County, North Dakota (ND); and Redwing, Goodhue County, Minnesota (MN) and in colonies with less than 6 plants at Sterling, Logan County, Colorado (WCO).

Colony	Stalks/plant	Height of tallest stalk (cm)	Flowers/stalk	Pedicels/stalk	Fruits/stalk	Fruits with holes/stalk
IL[a]	6.2 ± 0.6[w] a[x]	19.6 ± 0.9 b[x]	0.6 ± 0.3 b[x]	30.9 ± 2.1 a[y] b	23.7 ± 1.7 a[x]	1.8 ± 0.3 a[x] (8%)[z]
ECO[b]	2.6 ± 0.3 c	8.5 ± 0.5 c	1.2 ± 0.4 b	19.1 ± 1.8 c	7.5 ± 0.9 c	0.4 ± 0.1 b c (5%)
ND[c]	3.4 ± 0.4 c	23.3 ± 1.0 a	6.3 ± 0.8 a	35.0 ± 3.4 a	17.4 ± 1.9 b	0.1 ± 0.1 c (1%)
MN[d]	4.9 ± 0.4 b	18.6 ± 0.8 b	0.0 ± 0.0 b	25.1 ± 1.6 b c	21.7 ± 1.4 a	0.8 ± 0.1 b (4%)
WCO[e]	3.0 ± 0.4	4.1 ± 1.1	1.7 ± 0.4	13.0 ± 3.5	1.0 ± 0.8	0.0 ± 0.0 (0%)

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.

[b]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.

[c]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.

[d]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

[e]WCO was located in Logan County, Colorado, 39 km NW of Sterling, Colorado, 177 m E of County Route 13. Results for WCO were not included in statistical comparisons with other colonies, since sampling methods were different.

[w]Means are expressed ± standard error.

[x]Mean separation within column based on Duncan's multiple range test at 5%, n=45. Means followed by different letters are significantly different.

[y]Mean separation within column based on Duncan's multiple range test at 5%, n=45 for IL, ECO, and MN, and n=44 for ND, due to incomplete data set. Means followed by different letters are significantly different.

[z]Numbers in parentheses are percent of fruit with holes per stalk in individual populations.

Table 2. Percent of pedicels containing flowers, fruits, and other (pedicels that are missing flowers or fruits) in colonies of *Lesquerella ludoviciana* in June 2002.

Colony	% Pedicels with flowers	% Pedicels with fruits[x]	% Pedicels with other[y]
IL[a]	2%[z]	83%	15%
ECO[b]	6%	41%	53%
ND[c]	18%	50%	32%
MN[d]	0%	90%	10%

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.

[b]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.

[c]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.

[d]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

[x]Pedicels with fruits includes fruits with holes.

[y]Pedicels missing flowers or fruits include those being removed from herbivory or naturally abscising.

[z]Percentages determined by dividing number of flowers/stalk and fruits and fruits with holes/stalk by number of pedicels/stalk. % Pedicels with other was the difference of number of pedicels/stalk and number of flowers, fruits and fruits with holes/stalk divided by number of pedicels/stalk. No standard error was determined, since percentages were calculated based on stalk data.

Table 3. Insects visiting flowers of *Lesquerella ludoviciana* at colonies in May and June 2002.

Colony	Collection Information	Insect species	Number collected
IL[a]	May 6 1:30 pm–2:30 pm from 1 m^2 plot	*Dialictus* sp. (Hymenoptera: Halictidae)	2
		Dialictus vierecki (Hymenoptera: Halictidae)	7
		Orthoptera (identified to order only)	3
		Toxomerus marginatus (Diptera: Syrphidae)	1
IL	May 6 1:30–2:30 random collection	*Dialictus* sp. (Hymenoptera: Halictidae)	3
		Dialictus vierecki (Hymenoptera: Halictidae)	1
IL	June 3 12:30 pm-2:30 pm random collection	Hemiptera: Pentatomidae (identified to family only)	1
WCO[b]	June 6 11:30 am-12:00 pm random collection	*Dialictus* sp. (Hymenoptera: Halictidae)	1
		Parancistrocerus sp.(Hymenoptera: Vespidae)	2
ECO[c]	June 6 3:30 pm-6:30 pm random collection	*Exochomus sp.* (Coleoptera: Coccinellidae)	1
		Hemiptera: Pentatomidae (identified to family only)	1
ND[d]	June 22 10:20 am-11:20 am from 9 m^2 plot	*Exoprosopa* sp. (Diptera: Bombyliidae)	1
		Adrena sp. (Rhacandrena) (Hymenoptera: Adrenidae)	3
		Dialictus sp.(Hymenoptera: Halictidae)	2
Total			29

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.

[b]WCO was located in Logan County, Colorado, 39 km NW of Sterling, Colorado, 177 m E of County Route 13.

[c]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.

[d]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.

Table 4. June 2002 seed biology in colonies of *Lesquerella ludoviciana.*

Site	Seeds/25 fruit	Seeds/fruit
IL[a]	85.5 ± 13.3[y] a[z]	3.4
ECO[b]	111.8 ±20.2 a	4.5
ND[c]	107.8 ± 0.1 a	4.3
MN[d]	105.6 ± 3.2 a	4.2

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.
[b]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.
[c]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.
[d]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.
[y]Means are expressed ± standard error.
[z]Mean separation within column based on Duncan's multiple range test at 5%, n=4. Means followed by different letters are significantly different.

Table 5. June 2002 population viability of *Lesquerella ludoviciana* colonies sampled with quadrats placed at every meter located at random distances on alternating sides of a 45-meter transect.

	Number of Seedlings/m^2	Number of Vegetative Plants/m^2	Number of Reproductive Plants/m^2	Total
IL[a]	0.5 ± 0.3[x] a[y] (8%)[z]	1.5 ± 0.4 a (24%)	4.2 ± 0.9 a (68%)	6.2
ECO[b]	0.0 ± 0.0 b (0%)	0.0 ± 0.0 b (0%)	0.1 ± 0.1 c (100%)	0.1
ND[c]	0.0 ± 0.0 b (0%)	0.1 ± 0.1 b (5%)	1.8 ± 0.6 b (95%)	1.9
MN[d]	0.0 ± 0.0 b (0%)	0.2 ± 0.1 b (10%)	1.9 ± 0.5 b (90%)	2.1

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.

[b]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.

[c]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.

[d]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

[x]Means are expressed ± standard error.

[y]Mean separation within column based on Duncan's multiple range test at 5%, n=45. Means followed by different letters are significantly different.

[z]Numbers in parentheses indicate percent of total plants per population counted as seedlings, vegetative plants, or reproductive plants.

Table 6. June 2002 population viability of *Lesquerella ludoviciana* colonies sampled with quadrats placed at every meter located directly adjacent to a 45-m transect on alternating sides of the transect.

	Number of Seedlings/m^2	Number of Vegetative Plants/m^2	Number of Reproductive Plants/m^2	Total
ECO[a]	0.0 ± 0.0[x] b[y] (0%)[z]	0.0 ± 0.0 b (0%)	0.2 ± 0.1 a (100%)	0.2
ND[b]	0.0 ± 0.0 b (0%)	0.0 ± 0.0 b (0%)	1.1 ± 0.4 a (100%)	1.1
MN[c]	0.4 ± 0.2 a (27%)	0.4 ± 0.2 a (27%)	0.7 ± 0.3 a (46%)	1.5

[a]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.

[b]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.

[c]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

[x]Means are expressed ± standard error.

[y]Mean separation within column based on Duncan's multiple range test at 5%, n=45. Means followed by different letters are significantly different.

[z]Numbers in parentheses indicate percent of total plants/population counted as seedlings, vegetative plants, or reproductive plants.

Table 7. Plant density for *Lesquerella ludoviciana* in North Colony-Lower Bowl at H. A. Gleason Nature Preserve in Mason County Illinois (IL) sampled in May and June 2002 with quadrats placed at every meter located at random distances on alternating sides of a 45-meter transect.

Month	Seedlings/m^2	Vegetative Plants/m^2	Reproductive Plants/m^2	Total
May	0.2 ± 0.1[y] a[z]	1.0 ± 0.5 a	4.6 ± 1.4 a	5.8
June	0.5 ± 0.3 a	1.5 ± 0.4 a	4.2 ± 0.9 a	6.2
Average	0.4 ± 0.2	1.3 ± 0.3	4.4 ± 0.8	6.1

[y]Means are expressed ± standard error

[z]Mean separation within column based on Duncan's multiple range test at 5%, n=45. Means followed by different letters are significantly different.

Table 8. Estimated number of flower stalks, flowers, pedicels, fruits, fruits with holes, and seeds produced per colony of *Lesquerella ludoviciana* in June 2002.

Colony	Flower stalks/colony	Flowers/colony	Pedicels/colony	Fruits/colony	Fruits with holes/colony	Seeds/colony	Colony area (m^2)
IL[a]	28,410	17,045	877,858	673,308	51,137	2,289,249	1,091
ECO[b]	514	617	9,823	3,857	206	17,357	1,978
ND[c]	56,537	356,180	1,978,780	983,736	5,654	4,230,065	9,238
MN[d]	7,718	0	193,722	167,480	6,174	703,418	829

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.
[b]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.
[c]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.
[d]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

Table 9. Estimated number of flowers, pedicels, fruits, fruits with holes, and seeds produced per reproductive plant in colonies of *Lesquerella ludoviciana* in June 2002.

Colony	Flowers/plant	Pedicels/plant	Fruits/plant	Fruits with holes/plant	Seeds/plant
IL[a]	4	192	147	11	500
WCO[b]	5	39	3	0	--[z]
ECO[c]	3	50	20	1	88
ND[d]	21	119	59	<1	254
MN[e]	0	123	106	4	447

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.
[b]WCO was located in Logan County, Colorado, 39 km NW of Sterling, Colorado, 177 m E of County Route 13.
[c]ECO was located in Logan County, Illinois, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route.
[d]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.
[e]MN was located in Goodhue County, Minnesota, located across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.
[z]Seed was not collected at WCO since colony consisted of only 6 plants and 100 fruit would have been greater than 10% of seed produced.

Table 10. pH, soil fertility, and texture analysis for soil samples[z] from colonies of *Lesquerella ludoviciana* in June 2002.

Site	pH	P (kg/h)	K (kg/h)	Ca (kg/h)	Mg (kg/h)	OM (%)	CEC (Meq/100g)	K (%)	Mg (%)	Ca (%)	H (Meq/100g)	Texture	% Sand	% Silt	% Clay
IL[a]	8.1	13	102	5,299	291	2.3	10.5	1	9	89	0	Sand	96	3	1
ND[b]	7.9	32	354	11,328	833	2.2	23.2	2	12	86	0	Loamy sand	73	22	5
MN[c]	7.9	47	94	3,911	358	2.1	8.2	1	15	84	0	Sand	95	4	1

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.

[b]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.

[c]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

[z]Soil was sampled using a shovel, three samples of the top 10 cm of soil were taken randomly throughout the population. Samples were mixed together, and 455 ml sub-samples from populations were sent to A & L Analytical Laboratories, Inc., Memphis, TN for pH and soil fertility and University of Illinois for texture analysis.

Table 11. Soil series descriptions for colonies of *Lesquerella ludoviciana* sampled in June 2002 (Amen *et al.*, 1974; Calsyn, 1995; NRCS, 1996; Poch, 1976; USDA, NRCS, 2002c).

Site	Soil series	Soil name	Series drainage	Soils formed in	Permeability
IL[a]	Plainfield Series	Plainfield sand, 1 to 7 percent slope	Excessively drained and moderately well drained	Wind- and water-deposited sands	Rapid or very rapid
ECO[b]	Dix Series	Dix-Eckley complex, 5 to 25 percent slopes	Excessively drained	Gravelly alluvium; on upland ridges and alluvial fans	Rapid to very rapid
ND[c]	Rhame Series	Rhame-Chinook fine sandy loams, 6 to 15 percent slopes	Well drained	Material weathered from sandstone	Moderately rapid
	Chinook Series	Rhame-Chinook fine sandy loams, 6 to 15 percent slopes	Well drained	Alluvium from glaciofluvial material or eolian deposits	Moderately rapid
MN[d]	Gotham Series	Gotham fine sand, 12 to 35 percent slopes	Somewhat excessively drained	Sandy outwash	Rapid

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.
[b]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.
[c]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.
[d]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

Table 12. Associated species found with *Lesquerella ludoviciana* in stabilized blowouts at the H. A. Gleason Nature Preserve in Mason County, Illinois (IL) (Ebinger and McClain, 1999) .

Associated species	Common name	Associated species	Common name
Ambrosia psilostachya	Cuman ragweed	*Koeleria macrantha*	June grass
Asclepias virdiflora	green milkweed	*Leptoloma cognatum*	Carolina crabgrass
Aster ericoides	white aster	*Lespedeza capitata*	bush lespedeza
Aster oblongifolius	aromatic aster	*Liatris aspera*	rough blazing star
Bouteloua hirsuta	grama	*Oenothera rhombipetala*	primrose
Brickellia eupatoriodes	false boneset	*Opuntia humifusa*	prickley pear
Calamovilfa longifolia	prairie sandreed	*Panicum villosissimum*	whitehair rosette grass
Cassia fasciculata	partridge pea	*Paspalum bushii*	thin paspalum
Chamaesyce geyeri	Geyer's sandmat	*Phlox bifida*	cleft phlox
Commelina erecta	whitemouth dayflower	*Poinsettia dentata*	toothed spurge
Conyza canadensis	horseweed	*Rhus aromatica*	fragrant sumac
Croton glandulosus	vente conmigo	*Salsola iberica*	prickly Russian thistle
Eragrostis trichodes	sand lovegrass	*Schizachyrium scoparium*	little bluestem
Euphorbia corollata	flat-topped spurge	*Strophostyles helvola*	Canada germander
Heterotheca camporum	lemonyellow false goldenaster	*Teucrium canadense*	American germander

Table 13. Associated species found with *Lesquerella ludoviciana* in Logan County west of Sterling, Colorado (WCO).

Associated species	Common name
Aristida sp. [a]	threeawn
Astragalus sp.[b]	vetch
Comandra umbellata[a]	bastard toadflax
Dalea sp.[a]	prairie clover
Erigonium flavum[b]	sulfur flower
Rhus aromatica[a]	fragrant sumac

[a]Species identified on-site.
[b]Specimen collected and later identified.

Table 14. Associated species found with *Lesquerella ludoviciana* in Logan County east of Sterling, Colorado (ECO).

Associated species	Common name
Astragalus adsurgens[a]	standing milk vetch
Artemesia sp.	sage
Bouteloua sp.	grama
Hymenopappus sp.	hymenopappus
Medicago sativa	alfalfa
Oenothera sp.	primrose
Opuntia sp.	prickley pear cactus
Cleomella palmeriana	stickweed
Rhus aromatica	fragrant sumac
Yucca glauca	yucca

[a]All species identified on-site.

Table 15. Associated species found with *Lesquerella ludoviciana* at Theodore Roosevelt National Park in Billings County, North Dakota (ND).

Associated species	Common name	Associated species	Common name
Agropyron cristatum	crested wheatgrass	*Heuchera richardsonii*	alum root
Agropyron smithii	Western wheatgrass	*Helianthus rigidus*	stiff-leaved sunflower
Allium textile	white, wild onion	Juniperus sp.	juniper
Amelanchier alnifolia	Juneberry	*Koeleria pyramidata*	Junegrass
Anemone patens	pasque flower	*Lactuca oblongifolia*	blue flax
Antennaria sp.	pussytoes	*Lappula* sp.	stickseed
Arabis holboellii	rock cress	*Linum perenne*[a]	narrow-leaved puccoon
Artemesia cana	silver sage	*Linum rigidum*	yellow flax
Artemesia frigida	fringed sage	*Lithospermum incisum*	blue lettuce
Artemesia sp.	sage	*Lepidium densiflorum*	peppergrass
Astragalus sp.	vetch	*Lygodesmia juncea*	skeletonweed
Bouteloua gracila	blue grama	*Lupinus* sp.	lupine
Bromus inermus	smooth brome	*Melilotus officianalis*	yellow sweet clover
Bromus japonicus	Japanese brome	*Oenothera albicaulis*	white-stemmed primrose
Calamovilfa longifolia	prairie sandreed	*Opuntia polyacantha*	prickley pear
Calochortus gunnisonii[a]	sago lilly	*Oryzopsis hymenoides*	indian ricegrass
Campanula rotundifolia[a]	harebell	*Penstemon angustifolius*	narrow beardtongue
Carex filifolia	needle-leaved sedge	*Penstemon nitidus*	blue beardtongue
Cirsium undulatum	prairie/wavyleaf thistle	*Plantago elongata*	slender plantain
Coryphantha vivipara	common ballcactus	*Poa* sp.	bluegrass
Descurainia pinnata	tansy mustard	*Polygala alba*[a]	white milkwort
Erigeron sp.	fleabane	*Prunus virginiana*	chokecherry
Eriogonum flavum	sulfer flower	*Potentilla fruticosa*	shrubby cinquefoil
Euphorbia spathulata	spurge	*Psoralea argophylla*	scurf pea
Erysimum asperum	Western wallflower	*Psoralea exculenta*	indian breadfoot
Festuca octoflora	six-weeks fescue	*Rhus aromatica*	fragrant sumac
Galium boreale[a]	northern bedstraw	*Schizachyrium scoparium*	little bluestem

[a]Specimen collected and later identified. All other species identified on-site.

Table 16. Associated species found with *Lesquerella ludoviciana* in Goodhue County, Minnesota (MN).

Associated species	Common name
Ambrosia cornopofolia	ragweed
Andropogon gerardii	big bluestem
Anemone sp.	anemone
Artemesia frigida	fringed sage
Asclepias verticillata[a]	Milkweed
Asclepias viridiflora[a]	Milkweed
Bouteloua hirsuta	grama
Carex sp.	sedge
Comandra sp.	toadflax
Delphinium carolinianum[a]	delphinium
Erigeron strigosus[a]	fleabane
Euphorbia corollata[a]	flat-topped spurge
Lobelia spicata[a]	palespike lobelia
Lithospermum sp.	puccoon
Melilotus officianalis	yellow sweet clover
Monarda fistulosa	wild bergamont
Panicum oliosanthes	Scribner's panic grass
Penstemon sp.	beardtongue
Scutellaria leonardii[a]	Leonard's skullcap
Solidago graminifolia	Texas goldentop
Sporobolus cryptandrus	sand dropseed
Rhamnus cathartica	buckthorn
Tradescantia ohiensis[a]	spiderwort
Schizachyrium scoparium	little bluestem
Verbena stricta[a]	hoary verbena

[a]Specimen collected and later identified. All other species identified on-site.

Table 17. Altitude, soil temperature, air temperature, relative humidity, and wind speed for colonies of *Lesquerella ludoviciana* in June 2002.

Colony	Collection info	Altitude (m)	Soil temp. (°C) at 10 cm depth	Air temp. (°C)	Relative humidity (%)	Wind speed (m/s)
IL[a]	June 3 12:30 pm	182	27.7	36	40.0	3.2
WCO[b]	June 6 11:30 am	1,433	--	35	17.5	0.8
ECO[c]	June 6 3:30 pm	1,514	27.4	33	14.1	5.7
ND[d]	June 22 8:30 am	917	20.5	25	65.9	1.1
MN[e]	June 24 8:30 am	317	21.6	28	60.2	0.2

[a]IL was located in Mason County, Illinois, 2 km S of Goofy Ridge, Illinois at the H. A. Gleason Nature Preserve.
[b]WCO was located in Logan County, Colorado, 39 km NW of Sterling, Colorado, 177 m E of County Route 13.
[c]ECO was located in Logan County, Colorado, 11 km SE of Sterling, Colorado on the SW side of an escarpment near North Reiradon Hill, 15 m N of County Route 24.
[d]ND was located in Billings County, North Dakota, 5 km NE of Medora, North Dakota, along the Ridgeline Trail off of Scenic Loop Drive in Theodore Roosevelt National Park.
[e]MN was located in Goodhue County, Minnesota, across from 2127 Twin Bluff Road just north of Twin Bluff Middle School in Redwing, Minnesota.

LITERATURE CITED

Al-Shehbaz. I.A. and S.L. O'Kane. 2002. *Lesquerella* is united within *Physaria* (Brassicaceae). Novon 12: 319–329.

Amen, A.E., D.L. Anderson, T.J. Hughes, T.J. Weber. 1974. Soil Survey of Logan County, Colorado. United States Department of Agriculture, Soil Conservation Service, in Cooperation with the Colorado Agricultural Experiment Station. 252 pp. +104maps.

Beach, S.E., J.M. Coons, H.R. Owen, B.L. Todd, and M.A.L. Smith. 2001. Comparison of seed production and germination in three distinct colonies of *Lesquerella ludoviciana*. Abstract in Proceedings of Botanical Society of America Meetings at Albuquerque, NM in August, 2001, p. 46.

Beach, S.E., J.M. Coons, H.R. Owen, B.L. Todd, M.A.L. Smith. 2002. Seed vigor of *Lesquerella ludoviciana* as affected by colony and maturity. Abstract in Transactions of the Illinois State Academy of Science 95: 99.

Calsyn, D.E. 1995. Soil Survey of Mason County, Illinois. United States Department of Agriculture, Natural Resources Conservation Service, in Cooperation with Illinois Agricultural Experiment Station. 211 pp. + 99 maps.

Clark, C.O., D.H. Farnsworth, F.T. Miller, and B.N. Weight. 1982. Soil Survey of Cascade County Area, Montana. United States Department of Agriculture, Soil Conservation Service, in Cooperation with Montana Agricultural Experiment Station. 329 pp. + 158 maps.

DeLorme, 2002. DeLorme Topo USA® 4.0. Yarmouth, ME.

Ebinger, J.E. and McClain, W.E. 1999. Floristic assessment of the Henry Allan Gleason Nature Preserve, Mason County, Illinois. Unpublished. 20 pp.

ERSI, Inc., 1999–2002. ERSI ArcView™ 8.2. Redlands, CA.

Herkert, J.R. and J.E. Ebinger. 2002. Endangered and Threatened Species of Illinois: Status and Distribution, Volume 1– plants. Illinois Endangered Species Protection Board, Springfield, IL. 161 pp.

Microsoft Coorporation, 2000. Microsoft Excel. Redmond, WA.

Minnesota Department of Natural Resources Non-game Wildlife. 1996. Alphabetical Index by Scientific Name of Endangered, Threatened, and Special Concern Species. St. Paul, MN. 10 pp.

NRCS (Natural Resources Conservation Service). 1996. Theodore Roosevelt–South Unit Soil Survey. (http://www.nps.gov/gis/park_gisdata/ndakota/thro.htm). Data accessed: March 2003.

Poch, G.A. 1976. Soil Survey of Goodhue County, Minnesota. United States Department of Agriculture, Soil Conservation Service, in Cooperation with the University of Minnesota Agricultural Experiment Station. 129 pp. + 124 maps.

Roll, J., R.J. Mitchell, R.J. Cabin, and D.L. Marshall. 1997. Reproductive success increases with local density of conspecifics in a desert mustard (*Lesquerella fendleri*). Conservation Biology 11:738-746.

Rollins, R.C. and E.A. Shaw. 1973. The Genus *Lesquerella* (Cruciferae) in North America. Harvard University Press, Cambridge, MA. 288 pp.

Ruzin, S.E. 1999. Plant Microtechnique and Microscopy. Oxford University Press, Oxford, UK. 322 pp.

SAS Institute, Inc. 2001. SAS 8.2 system for Windows 8th Edition. Cary, NC.

Siddoway, J. 2002. Crooked Falls Natural Area Plant List. Cascade County Conservation District, Great Falls, MT. Unpublished. 3 pp.

Taylor, R.J. 1992. Sagebrush Country, A Wildlife Sanctuary. Mountain Press Publishing Company, Missoula, MT. 211 pp.

USDA, NRCS. 2002a. Grand Staircase-Escalante National Monument Soil Survey. Unpublished Data.

USDA, NRCS. 2002b. The PLANTS Database, Version 3.5. (http://plants.usda.gov). National Plants Data Center, Baton Rouge, LA, USA. Data accessed: February 2003.

USDA, NRCS. 2002c. Soil Series Classification Data Access. (http://ortho.ftw.nrcs.usda.gov/osd/sc.html). USDA, NRCS Soil Survey Division, Washington DC, USA. Data accessed: March 2003.

Welsh, S.L. and N.D. Atwood. 2001. Flora of Bureau of Land Management Grand Staircase-Escalante National Monument and Kane County, Utah. Brigham Young University, Provo, UT. 161 pp.

Wisconsin Department of Natural Resources. 2003. Endangered and Threatened Species Factsheet-Plants. http://www.dnr.state.wi.us/org/land/er/factsheets/plants.htm. Data accessed: April 2003.

APPENDIX A—LOCAL BOTANISTS ASSISTING IN THE JUNE 2002 COLLECTION TRIP FOR *LESQUERELLA LUDOVICIANA*

Colorado

D. Bruce Bosley
Cropping Systems Agent
Sterling, CO 80751-3408
dbbosley@coop.ext.colostate.edu

North Dakota

Paula Anderson
Head Botanist
Theodore Roosevelt National Park
Medora, ND 58654
Paula_Anderson@nps.gov

Keir Morse
Seasonal Botanist
keir_morse@yahoo.com

Montana

Jon Siddoway
Rangeland Management Specialist
United States Department of Agriculture
Natural Resource Conservation Service
Great Falls, Montana 59404
jsiddoway@mt.usda.gov

Utah

Laura Welp
Botanist Bureau of Land Management
Grand Staircase-Escalante National Monument

Kanab, UT 84741

Laura_Welp@blm.gov

Holly Beck
Grand-Staircase-Escalante National Monument
Kanab, UT 84741
hollybeck@blm.gov

Olivia Messinger
olvia@biology.usu.edu

APPENDIX B—RESULTS FOR POPULATIONS OF *LESQUERELLA* SP. IN UTAH AND MONTANA SAMPLED IN JUNE 2002

Utah

Results for reproductive biology for the population of *Physaria arenosa* subsp. *arenosa* (= *Lesquerella arenosa* subsp. *arenosa*) (UT1) are shown in Table B1. One insect was collected from the plot and was identified to be *Paracosmus morrisoni* (Diptera: Bombyliidae). Plants produced a mean of 41.8 ± 7.5 seeds/25 fruit. The population had 73 plants (0 seedlings, 5 vegetative plants, 68 reproductive plants) in an area 938 m long and 15 m wide (13,598 m^2). Total seed production based on 21.5 fruits/stalk and 9.6 stalks/plant was estimated at 345 seeds/plant and 23,467 seeds for the entire population. Environmental conditions are shown in Table B2. Soil sampling results are shown in Table B3. Findings from soil survey are shown in Table B4. Associated species collected are shown in Table B5.

Results for reproductive biology data for the entire population of *Lesquerella* sp. (UT2) are shown in Table B1. No insects or fruit were collected at UT2. The population of *Lesquerella* sp. at UT2 had 9 plants (0 seedlings, 1 vegetative plant, and 8 reproductive plants) in an area 61 m long and 9 m wide (555 m^2). Environmental conditions are shown in Table B2. Soil was not sampled and soil series was not identified.

Montana

MT1 was a population of *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*). Results for reproductive biology for MT1 are shown in Table B6. No insects were collected at MT1. Plants produced a mean of 40.0 ± 2.8 seeds/25 fruit. Results for population viability by quadrats located at random distances and directly adjacent to

transects are shown in Tables B7 and B8. Total seed production based on 3.8 fruits/stalk and 13.2 stalks/plant and an area of 1,671 m^2 was estimated at 80 seeds/plant. Total seed production for the entire population based on 0.2–0.9 reproductive plants per meter is estimated at 26,736–120,312 seeds. The population is estimated to contain 0 seedlings, 0–334 vegetative plants, 334–1,504 reproductive plants. Ranges are based on values from non-random to random transects. Environmental conditions are shown in Table B2. Soil sampling results are shown in Table B3. Findings from soil survey are shown in Table B4. Associated plant species collected are found in Table B5.

MT2, a population of 17 plants consisting of both Physaria *reediana* subsp. *reediana* (formerly *Lesquerella* alpina) and *Physaria reediana* subsp. *spatulata* (formerly *Lesquerella* alpina), was not sampled for reproductive biology, seed biology, or population viability. No insects were collected. Environmental conditions were not sampled, soil was not sampled, and soil series was not identified.

Table B1. June 2002 reproductive biology of UT1 containing *Physaria arenosa* subsp. *arenosa* (= *Lesquerella arenosa* subsp. *arenosa*) and UT2 containing *Lesquerella* sp. located at Grand Staircase-Escalante National Monument, Garfield County, Utah.

	Stalks/plant	Height of tallest stalk (cm)	Flowers/stalk	Pedicels/stalk	Fruits/stalk	Fruits with holes/stalk
UT1[y]	9.6 ± 1.6[x]	9.9 ± 0.6	0.4 ± 0.2	29.9 ± 2.4	21.5 ± 2.4	0.3 ± 0.8
UT2[z]	3.0 ± 1.0	5.8 ± 1.9	0.8 ± 0.5	23.4 ± 7.9	20.6 ± 7.6	0.0 ± 0.0

[x]Means are expressed ± standard error, n=45.
[y]UT1 was located 4 miles S of Escalante, Utah along Mitchell Canyon (N37° 43.031', W111° 38.046').
[z]UT2 UT2 was located 1 mile SE of Escalante, Utah along a seasonal streambed adjacent to Highway 12 (N37° 45.816', W111° 41.692').

Table B2. Altitude, soil temperature, air temperature, relative humidity, and wind speed for populations of *Physaria arenosa* subsp. *arenosa* (formerly *Lesquerella arenosa* subsp. *arenosa*) and *Lesquerella* sp. at Grand Staircase-Escalante National Monument, Utah (UT1 and UT2) and populations of *Physaria reediana* subsp. *spatulata* (formerly *Lesquerella alpina*). Great Falls, Montana (MT1).

Site	Collection	Altitude (m)	Soil temp. at 10 cm depth (°C)	Air temp. (°C)	Relative humidity (%)	Wind speed (m/s)
UT1[a]	June 13 2:45 pm	1,844	38.2	33	4	0.3
UT2[b]	June 14 8:00 am	1,880	**	22	21	0.2
MT1[c]	June 20 11:00 am	990	24.8	34	15	0.5

[a]UT1 was located 6 km S of Escalante, Utah along Mitchell Canyon in Grand Staircase-Escalante National Monument.

[b]UT2 was located 8.3 km SE of Escalante, Utah 100 m S of Old Escalante Rd. in Grand Staircase-Escalante National Monument.

[c]MT1 was located 10 km NE of Great Falls, Montana on the S side of Rainbow Loop Road at the Crooked Falls Managed Area.

Table B3. pH, soil fertility, and texture analysis for soil samples[z] from populations of *Physaria arenosa* subsp. *arenosa* (formerly *Lesquerella arenosa* subsp. *arenosa*) and *Lesquerella* sp. at Grand Staircase-Escalante National Monument, Utah (UT1) and populations of *Physaria reediana* subsp. *spatulata* (formerly *Lesquerella alpina*).Great Falls, Montana (MT1).

Site	pH	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	OM (%)	CEC (Meq/100g)	K (%)	Mg (%)	H (Meq/100g)	Ca (%)	Texture	% Sand	% Silt	% Clay
UT1[a]	8.3	11	109	18,148	426	0.7	33.6	0.4	4.3	0.0	95.2	sand	95	2	3
MT1[b]	8.1	22	408	13,167	710	1.7	26.1	1.7	9.3	0.0	89.0	sandy loam	61	27	12

[a]UT1 was located 6 km S of Escalante, Utah along Mitchell Canyon in Grand Staircase-Escalante National Monument.
[b]MT1 was located 10 km NE of Great Falls, Montana on the S side of Rainbow Loop Road at the Crooked Falls Managed Area.
[z]Using a shovel, three samples of the top 10 cm of soil were taken randomly throughout the population. Samples were mixed together, and 455 ml sub-samples from populations were sent to A & L Analytical Laboratories, Inc., Memphis, TN for pH and soil fertility and University of Illinois for texture analysis.

Table B4. Soil series descriptions for populations of *Physaria arenosa* subsp. *arenosa* (= *Lesquerella arenosa* subsp. *arenosa*) and *Lesquerella* sp. at Grand Staircase-Escalante National Monument, Utah (UT1) and populations of *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*) at Great Falls, Montana (MT1) (Clark *et al.*, 1982; USDA, NRCS, 2002a; USDA, NRCS, 2002c).

Site	Soil series	Soil name	Series drainage	Soils formed in	Permeability
UT1[a]	Radnik Series	Radnik-Suwanee, Saline-Escavada complex, 2 to 8 percent slope	Well drained	Alluvium from sandstone and mudstone	Moderately slow and slow
	Suwanee Series	Radnik-Suwanee, Saline-Escavada complex, 2 to 8 percent slope	Well drained,	Alluvium from sandstone and siltstone	Moderately slow
MT1[b]	Lisam series	Lisam-Rock outcrop-complex, 4 to 50 percent slope	Well-drained	Shale on upland	Slow or very slow

[a]UT1 was located 6 km S of Escalante, Utah along Mitchell Canyon in Grand Staircase-Escalante National Monument.
[b]MT1 was located 10 km NE of Great Falls, Montana on the S side of Rainbow Loop Road at the Crooked Falls Managed Area.

Table B5. Associated species collected with *Physaria arenosa* subsp. *arenosa* (UT1) and *Physaria reediana* subsp. *spatulata* (MT1).

UT1	MT1
Chaenactis douglasii	*Allium textile*
Cryptantha flava	*Aristida purpurea*
Gilia tridactyla	*Artemisia absinthium*
Lepidium montaum	*Astragalus* sp.
Penstemon utahensis	*Astragalus crassicarpus*
Physaria chambersii	*Cardamine cordifolia*
Stanleya integrifolia	*Cirsium undulatum*
	Eriogonum flavum
	Eriogoum ovalifolium
	Erysimum inconspicuum
	Gaura coccinea
	Heterotheca villosa
	Hymenoxys acaulis
	Oryzopsis hymenoides
	Poa secunda
	Pseudoroegneria spicata
	Psoralea tenuiflora
	Rhus aromatica
	Senecio canus
	Stipa comata
	Thelesperma marginatum

Table B6. June 2002 reproductive biology of MT1 located at Great Falls, Cascade County, Montana containing *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*).

	Stalks/plant	Height of tallest stalk (cm)	Flowers/stalk	Pedicels/stalk	Fruits/stalk	Fruits with holes/stalk
MT1[a]	13.2 ± 1.7[z]	9.1 ± 0.5	4.0 ± 0.3	17.8 ± 1.4	3.8 ± 0.6	0.0 ± 0.0

[a]MT1 was located 6 miles NE of Great Falls, Montana on the south side of Rainbow Loop Road at the Crooked Falls Managed Area (N47° 33.032', W111° 09.966').
[z]Means are expressed ± standard error.

Table B7. June 2002 population viability of MT1 located at Great Falls, Cascade County, Montana containing *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*) sampled with quadrats placed at every meter located at random distances on alternating sides of a 45 meter transect.

	Number of Seedlings/m^2	Number of Vegetative Plants/m^2	Number of Reproductive Plants/m^2
MT1[a]	0.0 ± 0.0[z]	0.2 ± 0.3	0.9 ± 0.4

[a]MT1 was located 6 miles NE of Great Falls, Montana on the south side of Rainbow Loop Road at the Crooked Falls Managed Area (N47° 33.032', W111° 09.966').
[z]Means are expressed ± standard error.

Table B8. June 2002 population viability of MT1 located at Great Falls, Cascade County, Montana containing *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*) sampled with quadrats placed at every meter located directly adjacent to a 45 m transect on alternating sides of the transect.

	Number of Seedlings/m^2	Number of Vegetative Plants/m^2	Number of Reproductive Plants/m^2
MT1[y]	0.0 ± 0.0[z]	0.0 ± 0.0	0.2 ± 0.1

[y]MT1 was located 6 miles NE of Great Falls, Montana on the south side of Rainbow Dam Road at the Crooked Falls Managed Area (N47° 33.032', W111° 09.966').

Photo 1. Insect collection in the bowl-like depression of the *Lesquerella ludoviciana* colony at the H. A. Gleason Nature Preserve in Mason County, Illinois (IL).

Photo 2. Colony of *Lesquerella ludoviciana* in Logan County, Colorado (ECO).

Photo 3. Colony of *Physaria arenosa* subsp. *arenosa* (= *Lesquerella arenosa* subsp. arenosa) at Grand Staircase-Escalante National Monument in Garfield County, Utah (UT1).

Photo 4. Colony of *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*) in Cascade County, Montana (MT1).

Photo 5. Colony of *Lesquerella ludoviciana* at Theodore Roosevelt National Park in Billings County, North Dakota (ND).

Photo 6. Colony of *Lesquerella ludoviciana* in Goodhue County, Minnesota (MN).

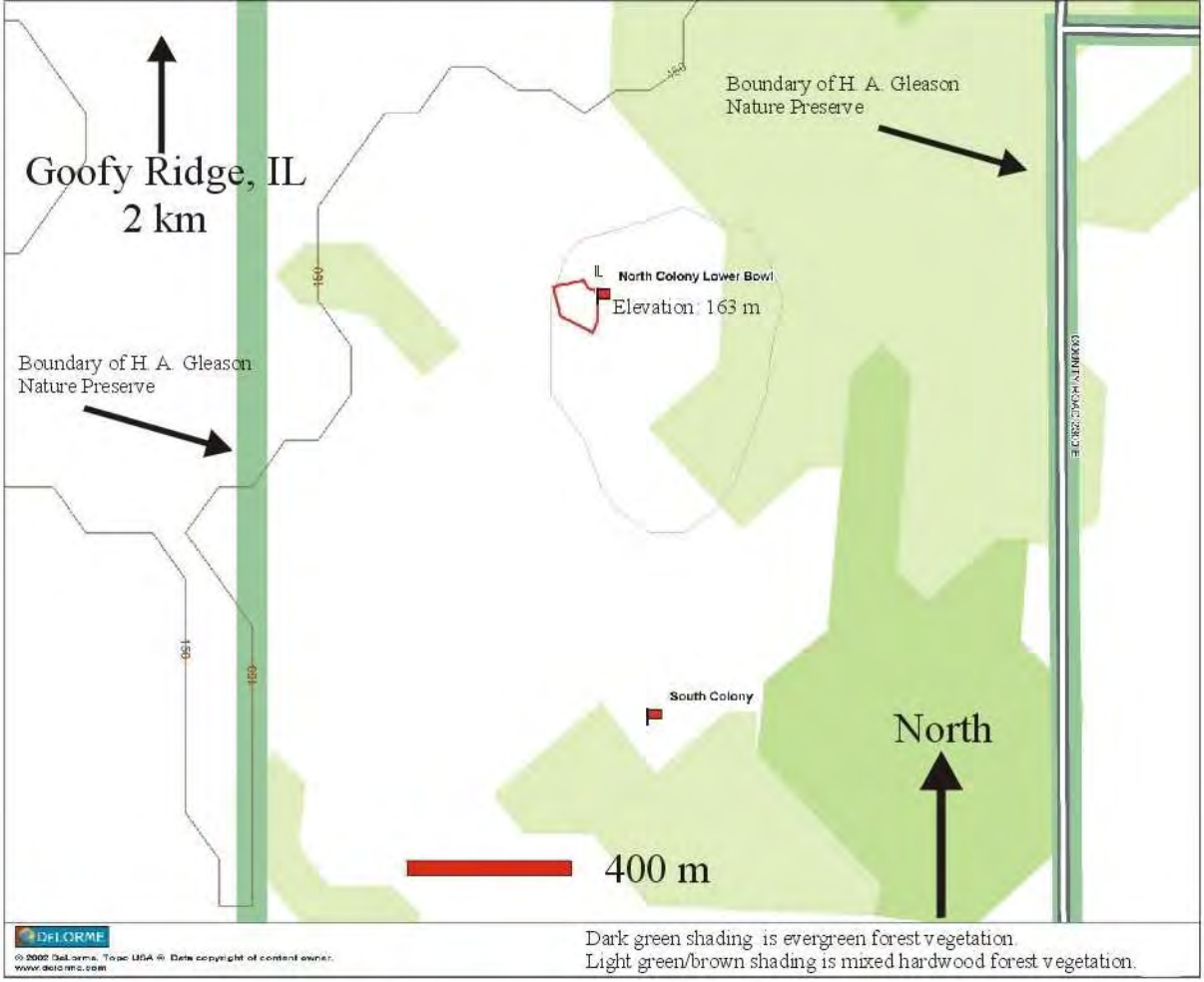


Figure 3. Colonies of *Lesquerella ludoviciana* at the H. A. Gleason Nature Preserve in Mason County, Illinois (IL). North Colony-Lower Bowl sampled on May 6 and June 3, 2002. Perimeter is outlined in red.

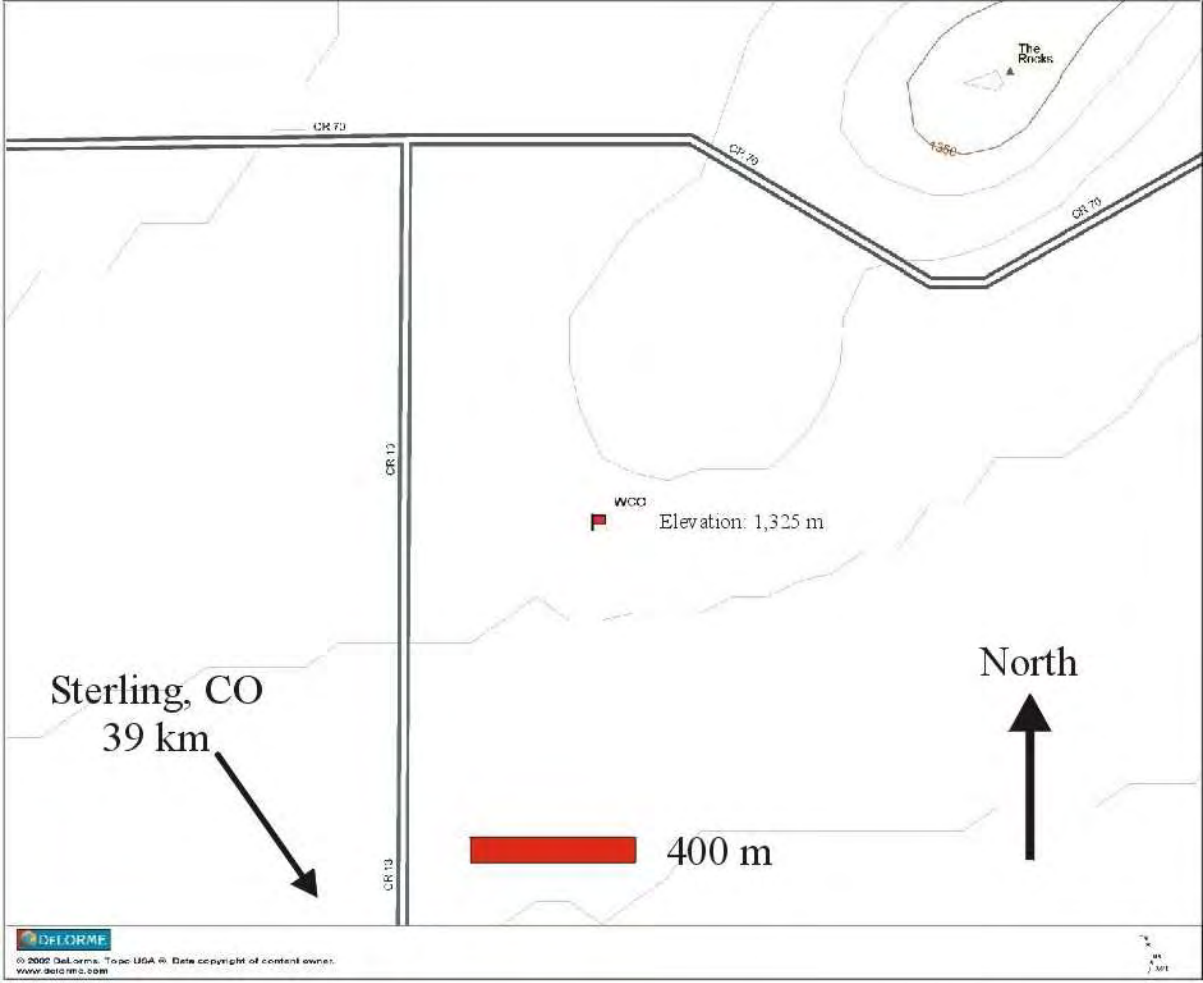


Figure 4. Colony of *Lesquerella ludoviciana* in Logan County, Colorado (WCO) sampled on June 6, 2002 . Center of population denoted with red flag.

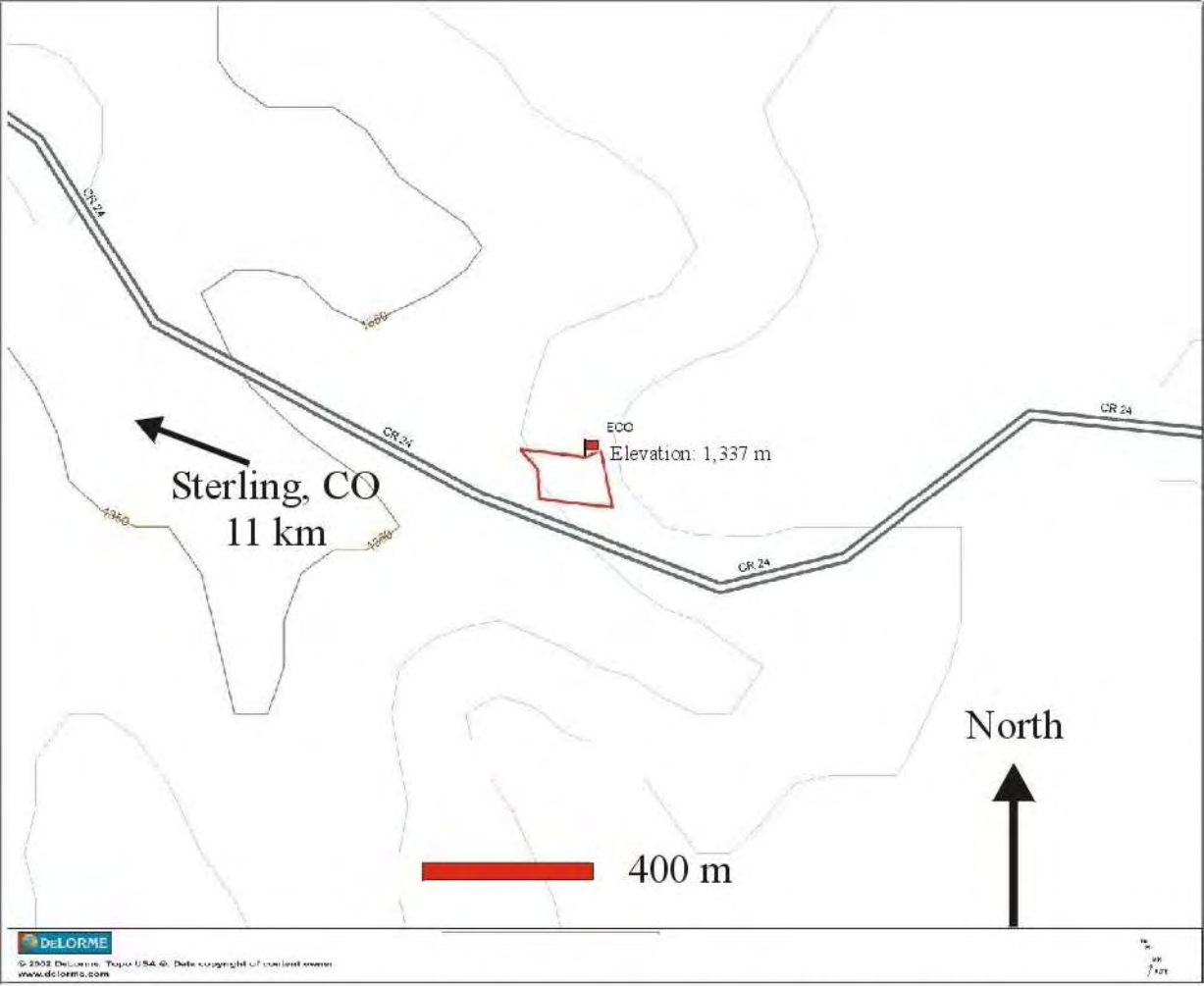


Figure 5. Colony of *Lesquerella ludoviciana* in Logan County Colorado (ECO) sampled on June 6, 2002. Perimeter of the population is outlined in red.

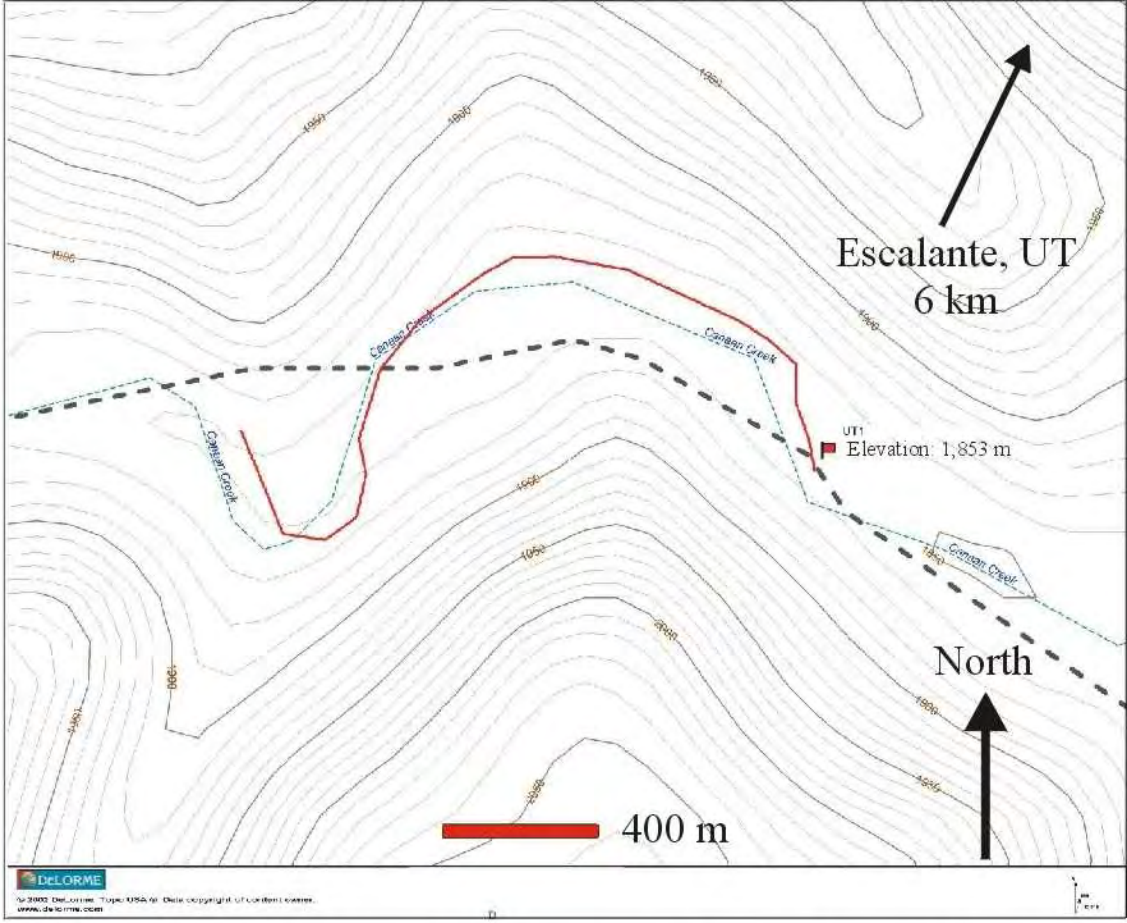


Figure 6. Colony of *Physaria arenosa* subsp. *arenosa* (= *Lesquerella arenosa* subsp. *arenosa*) in Grand Staircase-Escalante National Monument in Garfield County, Utah (UT1) sampled on June 13, 2002. Length of population outlined in red.

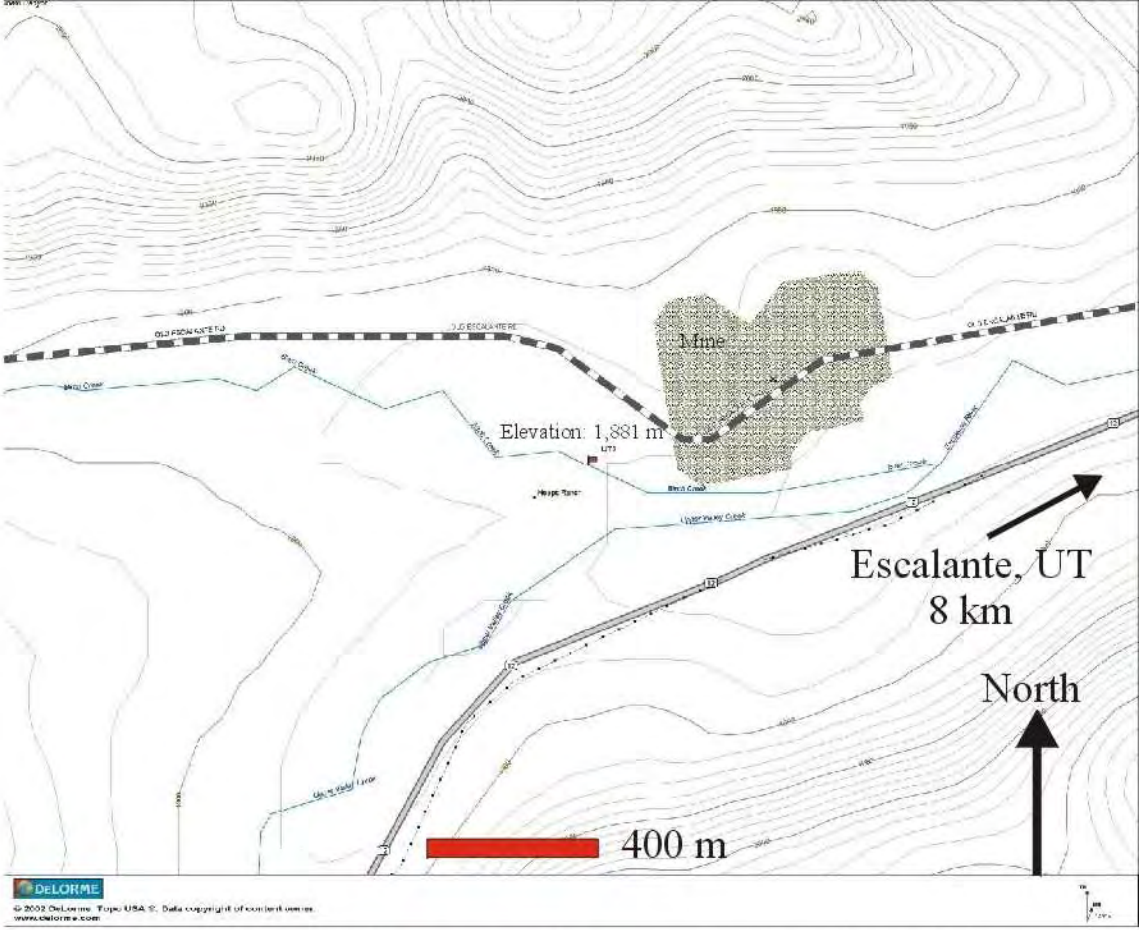


Figure 7. Colony of *Lesquerella* sp. in Grand Staircase-Escalante National Monument in Garfield County, Utah (UT2) sampled on June 14, 2002. Center of population denoted with red flag.

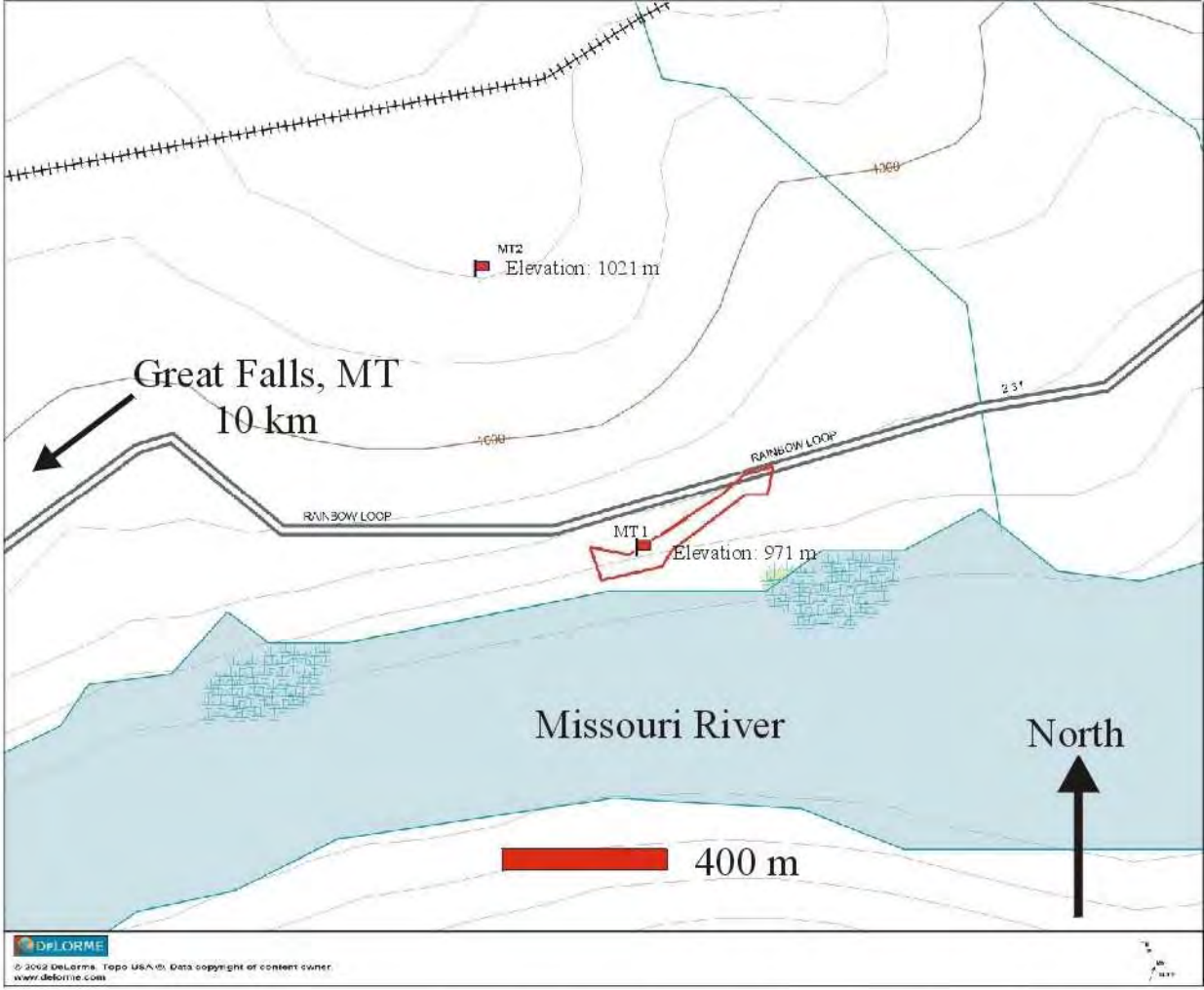


Figure 8. Colonies of *Physaria reediana* subsp. *reediana* and *Physaria reediana* subsp. *spatulata* (= *Lesquerella alpina*) in Cascade County, Montana (MT1 and MT2). Perimeter of MT1 sampled on June 20, 2002 is outlined in red.

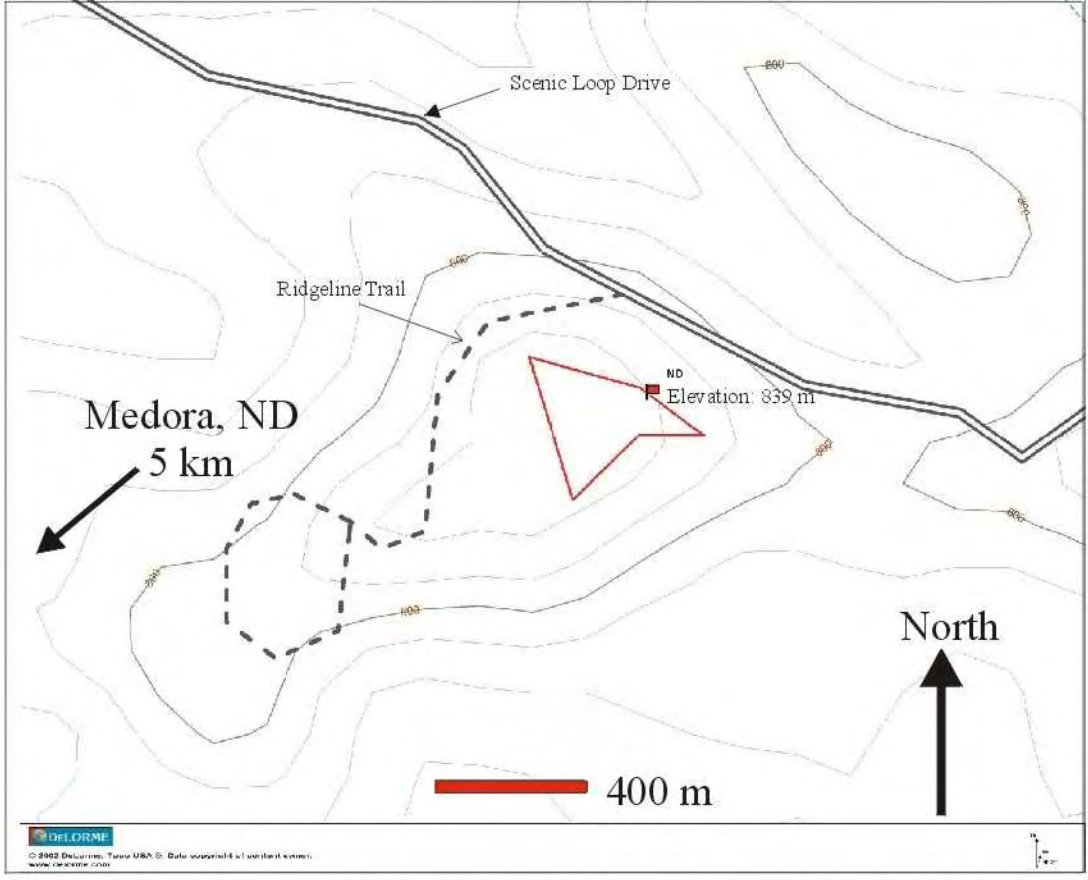


Figure 9. Colony of *Lesquerella ludoviciana* in Theodore Roosevelt National Park in Billings County, North Dakota (ND) sampled on June 22, 2002. Perimeter of the population is outlined in red.

Figure 10. Colony of *Lesquerella ludoviciana* in Goodhue County, Minnesota (MN) sampled on June 24, 2002. Perimeter of population is outlined in red.

Figure 11. Location of historic colony of *Lesquerella ludoviciana* in Pierce County, Wisconsin (WI). No *L. ludoviciana* plants were found when the site was visited on June 24, 2002.

Photo 7. Location of historic colony of *Lesquerella ludoviciana* in Pierce County, Wisconsin (WI).