

THE STATUS OF *RORIPPA COLUMBIAE* AND *LESQUERELLA DOUGLASII*
ON THE HANFORD REACH OF THE COLUMBIA RIVER
IN SOUTH CENTRAL WASHINGTON

By

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Abstract

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Limited scientific research on the ecological factors affecting relative abundance of both rare and common plant species warrants the need for more extensive research for conservation and management purposes. The purpose of this study was to identify and assess the most important factors that contribute to rarity in two rare endemics, *Rorippa columbiae* and *Lesquerella tuplashensis*. I hypothesized that fluctuating water levels along the Columbia River and continuous inundation of *R. columbiae* populations was reducing their growth and flower production. To assess the effects, I monitored populations of *R. columbiae* over six years to document population trends and conducted a laboratory study to determine if artificial water flows were affecting the growth and flowering of *R. columbiae*. I found the number of *R. columbiae* stems counted in the field was inversely correlated with river flows. When river flows remained high, the number of stems was low. The results of the laboratory study

paralleled observed effects of water level fluctuations in the field. Inundation resulted in less growth and failure of the plants to flower.

In a separate study, I compared several environmental attributes associated with *L. tuplashensis* with those associated with *L. douglasii*, a more common species. I hypothesized that restricted habitat may account for *L. tuplashensis*'s rarity, specifically the pH of the soil where *L. tuplashensis* populations are found would be significantly higher than where *L. douglasii* populations are found. I developed an autecological profile for each *Lesquerella* species including geographic location, morphological attributes, phenology, germinability, habitat, and community attributes. I did not detect any statistical differences in the pH of the soils or floral morphology among individuals from populations of *L. douglasii* and *L. tuplashensis*. Differences in community, soil, and habitat characteristics, however, did exist and could account for phenotypic differences that have been observed. My findings suggest *L. tuplashensis* is not a separate species, but an ecotype of *L. douglasii*.

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CHAPTER ONE

INTRODUCTION

Rare plants have always attracted the attention of botanists but not necessarily land managers. This changed when Congress passed the Endangered Species Act in 1972 which provided a measure of protection for rare species especially on federally-managed lands. Lists of endangered and threatened species have been prepared by the U. S. Fish and Wildlife Service and, in the case of Washington state, by the Washington Natural Heritage Program (1997). One of the first needs of land managers is to determine if listed species occur on their lands, the location, and the habitat characteristics.

Environments are always changing and species have always gone extinct. Recently, however, changes to the environment and the rate of extinctions have dramatically increased due to human activities (Chown 1997; Schemske *et al.* 1994; Noss and Cooperrider 1994; Stacey and Taper 1992; Wilson 1992; Hedrick and Miller 1992; Wilson 1988; Cody 1986; Ehrlich and Ehrlich 1981). Extinction or extirpation of species reduces the amount of biodiversity within the environment resulting in a reduction in the resiliency and stability of that environment (Franklin 1988; Pimm 1986). May (1974) emphasized the significant amount of evidence that had been assembled "to show that, in nature, species population stability is typically greater in structurally complex communities than in simple ones."

Because rarity is considered a precursor to extinction (Rosenzweig and Lomolino 1997), conservation biologists often focus their efforts on the conservation and preservation of rare species for the purpose of maintaining biological diversity and stability. Few studies on the causes and consequences of rarity in plants (and the subsequent management implications) have been conducted and results are mixed (Gaston and Kunin 1997). Pantone *et al.* (1995) observed: "unsuccessful recovery efforts largely reflect an inability to isolate and assess the most important factors that contribute to rarity in any one taxon." Without complete understanding and knowledge of the impacts of both extrinsic and intrinsic factors affecting these small, rare plant populations, effective management cannot be attained (Davy and Jefferies 1981). Extrinsic factors may include habitat destruction, predators, competitors (both native and exotic), and lack of pollinators. Intrinsic factors may include biological attributes that constrain the population's distribution and abundance such as low fecundity, short-range dispersal mechanisms, or lack of genetic variability. Habitat restoration experiments (i.e., attempts to improve habitat quality), standardized vegetation sampling, geographical information systems (utilized to locate and quantify quality habitat across the landscape), and microtopographic measurements have improved our ability to assess extrinsic factors. However, techniques for the rigorous assessment of intrinsic factors have only recently been developed and applied to rare plants (Pantone *et al.* 1995). Both extrinsic and intrinsic factors are important in the survival of rare plants and must be taken into account in order to develop effective management strategies.

Rarity

The definition of rarity has been debated for many years. Darwin (1859) wrote "rarity is the attribute of a vast number of species in all classes, in all countries." Orians (1997) suggests that all species are rare somewhere as are the majority of species comprising local biota. Harper (1981) states that the concept of rarity is a phenomenon in space as well as in time. Fiedler and Ahouse (1992) maintain that "plants may be rare for an astonishingly large number of reasons; some but not all of which work in concert to maintain a rare taxon's distribution, abundance or both."

According to Primack (1993), rare or extinction-prone species tend to exhibit several of the characteristics typically associated with rarity which may include:

- only one or a few populations
- a very narrow geographical range
- small-size populations
- low population densities
- low rates of population increase
- limited dispersal
- low genetic variability
- specialized niche requirements, and
- aggregated populations.

Rabinowitz (1981) classifies rare species into seven flexible categories based on range, habitat specificity, and local abundance. These three attributes are dichotomized and displayed in a 2 x 2 x 2 typology (Figure 1). Seven of the cells in Figure 1 contain rare

species with the eighth cell (species with wide ranges, several habitats and locally high abundances) containing species that are common. Gaston (1997), however, favors a definition of rarity based on abundance and/or range size, but relates that the inclusion of habitat specificity has problems associated with it. First, there may be a prejudgment of the causes of rarity and second, habitat specificity may be tied to beliefs that species occupying fewer habitats are at greater risk of extinction. According to Rabinowitz *et al.* (1986), it is necessary to specify precisely what kind of rarity one is dealing with to preserve a species.

Geographic Range:	Large		Small	
Habitat Specificity:	Wide	Narrow	Wide	Narrow
Population Size: Large, dominant somewhere	Locally abundant over a large range in several habitats (common)	Locally abundant over a large range in a specific habitat	Locally abundant in several habitats, but restricted geographically	Locally abundant in a specific habitat, but restricted geographically
Population Size: Small, non-dominant	Constantly sparse over a large range and in several habitats	Constantly sparse in a specific habitat, but over a large range	Constantly sparse and geographically restricted in several habitats	Constantly sparse and geographically restricted in a specific habitat

Figure 1. A typology of rare species based on three characteristics: geographic range, habitat specificity, and local population size (after Rabinowitz 1981).

Effects of processes leading to long-term changes in biological communities (e.g., vegetation succession, global climate change, acid rain) are often hidden from a short-term perspective. The effects of such changes in the environment may lag many years behind the initial causes. To distinguish normal year-to-year fluctuations in ecosystem processes from long-term trends, long-term monitoring of these processes is necessary. Long-term monitoring of environmental factors (e.g., temperature, precipitation, soil pH, water quality), communities (e.g., species present, amount of vegetation cover, biomass present), and population numbers (i.e., number of individuals present of a particular species) can provide early detection of changes to species, communities, and ecosystem function and is necessary to protect biological diversity (Primack 1993). Knowledge of species richness in an area and how it varies in relation to site characteristics is important in order to identify and protect areas with high diversity. Additionally, knowing the relationship between site characteristics and species richness will enable conservationists to predict where other species-rich areas might exist (Ashton 1992).

Assessing the biological status of rare plants is necessary for developing recovery guidelines. Assessment requires the identification of life history stages that are most critical to population growth and of the biological causes of demographic variation at these stages. Critical life-history stages that are missing or poorly represented within a population can demonstrate "senescent" populations that are at risk of extinction (Schemske *et al.* 1994). Demographic studies are important in determining if a population is declining, stable, or growing (Byers and Meagher 1997; Thomas and

Carey 1996; Schemske *et al.* 1994; Menges 1990; Crompton 1981). Determination of the growth or decline of a population requires information on the vital rates (i.e., birth, growth, death) within the population. Many ecological and genetic factors (including stochastic processes) influence these rates with the population size, in turn, affecting the demographic and genetic composition of the population. Comparisons between rare and common species are essential because there is a tendency for them to exhibit somewhat different suites of characteristics (Kunin 1997; Gaston and Kunin 1997). The comparison is necessary to minimize the chance of comparing nonhomologous features in a study that relies (at least in part) on the morphology of growing structures (Robson and Maze 1995).

The Hanford Site

Since 1943, the U. S. government has restricted public access and, therefore, provided protected areas on the 1450 km² Hanford Site, which is located in south central Washington state. Limited access prevented increased development from nearby towns and cities. Disturbed areas within the borders of the site have been invaded by a few alien plant species; however, much of the environment remains undisturbed (Pabst 1995). The mission of the Site changed in 1990 from the production of weapons-grade plutonium to environmental cleanup and, under the U. S. Department of Energy's jurisdiction, scientists often conduct research and surveys on wildlife and identifying and quantifying vegetation and habitat types (Sackschewsky *et al.* 1992; Downs *et al.* 1993; Pabst 1995).

The Hanford Site is located in the southwest corner of the Columbia Plateau. The overall climate is described as semi-arid with an average precipitation between 16.5 cm at lower elevations to 29 cm at higher elevations. Precipitation occurs primarily in the winter (Sackschewsky *et al.* 1992). Summers are hot and dry, winters are cold. The vegetation in the Columbia Plateau is referred to as shrub-steppe by Daubenmire (1970). These are communities with moisture relations adequate to support an appreciable cover of perennial grasses and consisting of stands of desert shrubs with grasses as the primary understory

Within the Hanford Site is the Hanford Reach, an 80-km free-flowing (but regulated by upstream dams) stretch of the Columbia River. The Reach runs from just below Priest Rapids Dam to just north of Richland, Washington (Sauer and Leder 1985; Gehring 1992; Rickard and Gray 1995). Because the Reach remains unimpounded, alteration of the riparian and/or riverine vegetation is less dramatic than other reaches along the river (Geist 1995). The Hanford Reach is a relatively undisturbed and highly diversified ecosystem. Populations of some plant species once common, such as *Rorippa columbiae*, have declined radically in recent years primarily due to human activities, including construction of hydroelectric dams and the introduction of highly aggressive non-native species. Because of its protected status, many rare plants can be found on the Hanford Site. Recent surveys of the Site recorded the presence of 47 rare plant species from 20 families (Sackschewsky *et al.* 1992, The Washington Natural Heritage Program 1997; Soll *et al.* 1999). The name and status of rare plant taxa currently found on Hanford are listed in Table 1. With so many rare plant species and

continued protected status, the Hanford Site is an ideal setting for long-term monitoring of rare plant populations.

Table 1. Status of rare plant taxa found on the Hanford Site (from the Washington Natural Heritage Program 1997; Hitchcock and Cronquist 1973; Soll *et al.* 1999)

Taxon	Common name	Family	Status *
<i>Allium constrictum</i>	Douglas' constricted onion	Liliaceae	Sensitive
<i>Allium robinsonii</i>	Robinson's onion	Liliaceae	Watch
<i>Allium scilloides</i>	Squill onion	Liliaceae	Watch
<i>Ammannia robusta</i>	Grand redstem	Lythraceae	Review Group 1
<i>Arenaria franklinii</i> var. <i>thompsonii</i>	Thompson's sandwort	Asteraceae	Review Group 2
<i>Artemisia campestris</i> spp. <i>borealis</i> var. <i>wormskioldii</i>	Northern wormwood	Asteraceae	Endangered
<i>Artemisia lindleyana</i>	Columbia River mugwort	Asteraceae	Watch
<i>Astragalus columbianus</i>	Columbia milkvetch	Fabaceae	Threatened
<i>Astragalus conjunctus</i> var. <i>rickardii</i>	Basalt milkvetch	Fabaceae	Review Group 1
<i>Astragalus geyeri</i>	Geyer's milkvetch	Fabaceae	Sensitive
<i>Astragalus sclerocarpus</i>	Stalked-pod milkvetch	Fabaceae	Watch
<i>Astragalus speirocarpus</i>	Medick milkvetch	Fabaceae	Watch
<i>Astragalus succumbens</i>	Crouching milkvetch	Fabaceae	Watch
<i>Balsamorhiza rosea</i>	Rosy balsamroot	Asteraceae	Watch
<i>Calyptridium roseum</i>	Rosy pussypaws	Portulacaceae	Sensitive

Taxon	Common name	Family	Status * .
<i>Camissonia minor</i>	Smallflower evening primrose	Onagraceae	Review Group 1
<i>Camissonia pygmaea</i>	Dwarf evening primrose	Onagraceae	Threatened
<i>Carex densa</i>	Dense sedge	Cyperaceae	Sensitive
<i>Castilleja exilis</i>	Small-flower annual paintbrush	Scrophulariaceae	Review Group 1
<i>Centunculus minimus</i>	Chaffweed	Primulaceae	Review Group 1
<i>Cirsium brevifolium</i>	Palouse thistle	Asteraceae	Watch
<i>Cryptantha leucophaea</i>	Gray cryptantha	Boraginaceae	Sensitive
<i>Cryptantha scoparia</i>	Miner's candle	Boraginaceae	Review Group 1
<i>Cryptantha spiculifera</i>	Snake River cryptantha	Boraginaceae	Sensitive
<i>Cuscuta denticulata</i>	Desert dodder	Cuscutaceae	Sensitive
<i>Cyperus bipartitus</i>	Shining flatsedge	Cyperaceae	Sensitive
<i>Eatonella nivea</i>	White eatonella	Asteraceae	Threatened
<i>Erigeron piperianus</i>	Piper's daisy	Asteraceae	Sensitive
<i>Eriogonum codium</i>	Umtanum desert buckwheat	Polygonaceae	Endangered
<i>Gilia leptomeria</i>	Great Basin gilia	Polemoniaceae	Review Group 1
<i>Hypericum majus</i>	Canadian St. John's-wort	Hypericaceae	Sensitive
<i>Lesquerella tuplashensis</i>	White Bluffs bladderpod	Brassicaceae	Endangered
<i>Limosella acaulis</i>	Mudwort	Scrophulariaceae	Watch
<i>Lindernia anagallidea</i>	False pimpernel	Scrophulariaceae	Review Group 2
<i>Lipocarpha aristulata</i>	Awned halfchaff sedge	Cyperaceae	Review Group 1
<i>Loeflingia squarrosa</i> var. <i>squarrosa</i>	Loeflingia	Caryophyllaceae	Threatened
<i>Lomatium tuberosum</i>	Hoover's desert-parsley	Apiaceae	Threatened
<i>Mimulus suksdorfii</i>	Suksdorf's monkey-flower	Scrophulariaceae	Sensitive

Taxon	Common name	Family	Status *
<i>Nama densum</i> var. <i>parviflorum</i>	Small-flowered nama	Hydrophyllaceae	Review Group 1
* <i>Oenothera caespitosa</i> ssp. <i>caespitosa</i>	Cespitose evening-primrose	Onagraceae	Sensitive
<i>Pectocarya linearis</i> var. <i>penicillata</i>	Winged combseed	Boraginaceae	Review Group 1
<i>Pectocarya setosa</i>	Bristly combseed	Boraginaceae	Watch
<i>Pellaea glabella</i>	Smooth cliffbrake	Polypodiaceae	Watch
<i>Pediocactus simpsonii</i> var. <i>robustior</i>	Mountain hedgehog-cactus	Cactaceae	Review Group 1
<i>Penstemon eriantherus</i> var. <i>whitedii</i>	Fuzzy beardtongue	Scrophulariaceae	Review Group 1
<i>Rorippa columbiae</i>	Columbia yellowcress	Brassicaceae	Threatened
<i>Rotala ramosior</i>	Lowland toothcup	Lythraceae	Review Group 1

***Endangered.** Taxa that are in danger of becoming Extinct in the state within the near future if factors contributing to their decline continue.

Threatened. Taxa that are likely to become Endangered in the state within the near future if factors contributing their decline continue.

Sensitive. Taxa that are vulnerable or declining, and could become Endangered or Threatened in the state without active management or removal of threats.

Review Group 1. Taxa for which there is insufficient data to support listing in the state as Threatened, Endangered, or Sensitive.

Review Group 2. Taxa with unresolved taxonomic questions.

Watch. Taxa that are more abundant and/or less threatened in Washington than previously assumed.

The Plants and Hypotheses

Rorippa columbiae (Suskd.) Rollins (Brassicaceae/Cruciferae), commonly known as Columbia yellowcress, is listed as threatened by the Washington Natural Heritage Program (1997) and is a candidate for federal listing (Federal Register 45: 82480-82569, 15 December 1982). *Rorippa columbiae* is a weak-stemmed, rhizomatous perennial (Hitchcock and Cronquist 1973). This plant was recognized as a separate species by Stuckey (1972) based on fruit and flower pubescence and geographic distribution (Sauer and Leder 1985); previously, it was thought to be a variety of *R. calycina* (Hitchcock and Cronquist 1964; Munz and Keck 1968). Plants grow in small cobble or gravelly-silty areas in two disjunct distributions in Washington state, both along the shores of the Columbia: 1) below Bonneville Dam and 2) on the Hanford Reach (Gehring 1992). This and other more common species of *Rorippa* can be described as emergent wetland plants, spending much of the season with their roots and shoots growing beneath the water. Flowering and seed production occur on aerially-exposed stems in late summer or early fall (Salstrom and Gehring 1994; Gehring 1993; Harris 1992; Scherer and Young 1992; Sauer and Leder 1985).

Due to operations of hydroelectric dams on the Columbia River, water levels fluctuate throughout the day in response to power demands rather than to natural seasonal flow patterns. This study was undertaken to determine if the artificially fluctuating water levels and continuous inundation of the cobble beaches along the Hanford Reach of the River is contributing to the decline of Columbia yellowcress. I

hypothesized that continuous inundation of Columbia yellowcress populations was negatively affecting their growth and flower production.

Lesquerella tuplashensis sp. novum (Brassicaceae/Cruciferae) is listed as endangered in Washington state (Pabst 1995) and is a candidate for federal listing. A previously non-reported population of *L. tuplashensis* plants was discovered in 1995 that appears to be restricted to a caliche layer in a patch 17 km long and 2 to 7 m wide along the rim of the White Bluffs located on the Hanford Reach in Franklin County, Washington. *Lesquerella tuplashensis* is a perennial with densely pubescent stems mostly arising below the leaf rosette. The yellow flowers of *L. tuplashensis* bloomed twice in 1995. The slightly obovoid to subglobose siliques are densely pubescent on the exterior, glabrous on the interior. The characteristics of the siliques, including the stipitate trichomes, and the imbricated cauline leaves currently separate this species from other known species of *Lesquerella* (Rollins, Beck, and Caplow 1995).

I compared characteristics of *L. tuplashensis* to those of *L. douglasii*, which is a widespread species occurring from British Columbia to northern Oregon and east to Nez Perce County in Idaho in a variety of habitats including sagebrush deserts, juniper woodlands, and ponderosa pine woodlands (Hitchcock and Cronquist 1973). Because *L. tuplashensis* plants appear to be restricted to the caliche layer along the rim of the White Bluffs (Rollins, Beck, and Caplow 1995), I hypothesized that the restricted habitat accounts for *L. tuplashensis*'s rarity, specifically that the pH of the soils where *L. tuplashensis* populations are found would be significantly higher than the pH of the soils where *L. douglasii* populations are found.

Journal Publications

The following two chapters present the results of my research on *Rorippa columbiae* and *Lesquerella tuplashensis* in the format of the journals to which they will be submitted. The first paper, "Effects of artificially fluctuating water levels on *Rorippa columbiae* on the Hanford Reach," will be submitted to Biological Conservation. The second, "The revitalization of the ecotype concept and its application to *Lesquerella tuplashensis*," will be submitted to Conservation Biology. The concluding chapter (4) recapitulates and summarizes the major findings.

CHAPTER TWO

Effects of artificially fluctuating water levels on *Rorippa columbiae* on the Hanford Reach

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Formatted for Biological Conservation

Abstract

Due to operation of hydroelectric dams on the Columbia River, water levels fluctuate in response to power demands rather than to natural seasonal flow patterns. This study was undertaken to determine if the artificially fluctuating water level along the Hanford Reach portion of the River is contributing to the decline of *Rorippa columbiae*, Columbia yellowcress, a threatened plant species. The number of stems counted in a field population was inversely correlated with the flow rate of the River. When flows remained high, the number of stems was low. In addition to monitoring a field population, an experiment was conducted in which water levels were manipulated in two concrete raceways. Stems were measured weekly to record growth and flower production. Results of the experimental manipulations paralleled observed effects of water level fluctuations in the field. Inundation resulted in reduced growth and failure of the plants to flower.

Key words: Columbia yellowcress, rare plants, Columbia River, water-level fluctuation, hydroelectric dams.

Introduction

Columbia yellowcress, *Rorippa columbiae* (Robbins) Howell (Brassicaceae), is listed as threatened in Washington state (Washington Natural Heritage Program 1997) and is a candidate for federal listing (Federal Register 1982). This perennial species is weak-stemmed and rhizomatous (Hitchcock and Cronquist 1973) with roots and shoots beneath the water for much of the year. Its habitat is gently-sloped cobble and gravelly-silty beaches along the shores of the Columbia River. Flowering occurs on aerially-exposed stems usually in late summer or early fall when water levels are low. I have observed plants in flower earlier in the year, but only when water levels were unusually low for extended periods of time.

In Washington, small populations occur on Pierce Island below Bonneville Dam and larger populations occur on islands and shorelines on the Hanford Reach (subsequently referred to as the Reach). The Reach is a free-flowing, 80-km segment of the Columbia River located between Priest Rapids and McNary Dams (Figure 2). This disjunction of populations is not historical, but most likely a result of the construction of four hydroelectric dams and their associated reservoirs located between the Reach and Bonneville Dam (Stuckey 1972, Sauer and Leder 1985, Gehring 1992, Rickard and Gray 1995).

According to Stuckey (1972), specimens of Columbia yellowcress collected by Suksdorf from the Bingen area along the Columbia River in 1890 were distributed as herbarium holotypes. In 1963, Stuckey (1972) failed in his attempts

to locate new specimens along the Columbia River from The Dalles, Oregon downstream to Sauvies Island. A few isolated populations of Columbia yellowcress are known to exist in areas of the Columbia Gorge, Harney, Lake, and Klamath counties in south-central Oregon, and in northern California in Modoc and Siskiyou counties. According to Gehring (1993), the largest and most vigorous populations are those on the Reach.

Harris (1992) attributes the loss of populations of Columbia yellowcress since the 1930's to the loss of suitable beach habitats by flooding from the construction of a series of hydroelectric dams along the main stem of the Columbia River from Bonneville Dam upriver to Grand Coulee Dam (USDOE/BPA 1994). In addition to the dams and their associated reservoirs, habitat loss has occurred due to agriculture, urbanization, road building, dredging, cattle trampling, and grazing, as well as recreational activities (Gehring 1992).

Columbia yellowcress persists on the Reach because it is the only segment of river not yet impounded by a dam and due to the presence of nine nuclear materials production facilities located along the shoreline of the river (Geist 1995, Rickard and Watson 1985). As part of the Hanford Site since 1943, shoreline access to the Reach is restricted affording protection from commercial and residential development and other activities. However, restricted access has not protected native shoreline vegetation from the effects of river flows dictated by the operation of upriver dams. Moreover, dam operations have exposed beach

habitats to encroachment by exotic plant species that appear to be better adapted to the artificial flow regime.

Hydrologic changes on the Reach due to operations of upstream dams consist of lower peak flows, attenuated floods, and higher year-round flows (Dauble and Watson 1997). Harris (1992) observed the inundation of riparian habitat and decrease in riverbank scour has effectively eliminated much suitable *Rorippa* habitat.

To determine if altered river flows were contributing to the decline of Columbia yellowcress on the Reach, a population was monitored from 1994 to 1999. In addition, an experiment to manipulate water levels was conducted in concrete raceways to determine the effects of fluctuating and constant water depths on growth and flower production. Recent changes in the flow regime appear to reduce the growth and flowering of Columbia yellowcress populations along the Hanford Reach. I discuss some of the most probable effects continuous inundation would have on those populations.

Methods

Field monitoring

There were two components to the field monitoring. One component consisted of visual surveys of five areas along the Hanford Reach in 1994 and 1998 in which the number of Columbia yellowcress stems was counted in patches that had few stems and estimates of the number of stems were made in patches that had a large number of stems.

The other component consisted of a detailed survey of a permanently-marked macroplot in which all the stems within the plot were counted over a six-year period. In the macroplot study, a Columbia yellowcress population on the Reach was visited periodically from 1994 to 1999 to count the total number of stems and the number of flowering stems in a permanently-marked macroplot. This population occurs as many scattered patches located on a wide, gently-sloping, sparsely-vegetated cobble beach downstream from the 100F area (Figure 2). In 1994, one-meter lengths of 0.95-cm diameter steel rod were hammered 30 cm into the soil to serve as permanent markers for the macroplot. The macroplot was established according to the method described by Elzinga, Salzer and Willoughby (1998) to census all of the individual stems within the patch which would more accurately track the population and to reduce sampling error. Three ten-by-one-m subplots were established within the macroplot in a patch with many stems (Figure 3). The sampling unit was a 0.5- by 1-m quadrat subdivided into 50-decimeter squares for ease in counting large numbers of stems. Location and the number of stems in each one-dm² within each quadrat were recorded. Stems in all 60 quadrats (20 consecutive quadrats in each subplot) were tallied at times when river levels were low enough to aerially expose the stems in July 1994, November 1996, September 1998, and October 1999. No counts were made in 1997 because the beach was continuously inundated.

Experimental manipulation

Columbia River water was piped into two concrete raceways located near the shore of the river at the Pacific Northwest National Laboratory's fish-rearing facility in Richland, Washington. One raceway served as the treatment raceway and the other served as the control. Eighty stems were collected from a Columbia River beach by excavation and transplanted into twelve 19-L plastic buckets (20 stems at each water level in the treatment raceway and 20 stems in the control raceway). Buckets contained alternating layers of riverine rock and sand/silt combination in an attempt to simulate natural rooting substrates as closely as possible. Holes approximately two centimeters in diameter were punched in the sides and bottoms of the buckets to allow water to freely enter and exit. Because Columbia yellowcress plants had not survived in previous attempts to grow them under semi-controlled conditions, transplanted plants were grown in the buckets for two weeks before the experiment began to ensure the plants were alive and growing.

Concrete blocks were placed beneath the buckets within the raceways to simulate high, moderate and low river levels. Nine buckets containing Columbia yellowcress plants were set on the blocks in the treatment raceway, three buckets each at deep, moderate and shallow levels. The control raceway consisted of concrete blocks set at only one level with the three buckets placed on the blocks (Figure 4). Water levels in the control raceway were adjusted manually three times daily according to water releases at Priest Rapids Dam. When flow rates

from the Dam were high and the macroplot was inundated on the beach area, plants in the control raceway were also inundated. Similarly, when flow rates were low and the macroplot was exposed on the beach, plants in the buckets were exposed. Soils in the buckets in the control raceway ranged from being damp to completely saturated. Water level was held constant in the treatment raceway. Plants at the deepest level were submerged 10 cm below the surface of the water at all times. Plants at the moderate level were rooted in continuously-saturated soil, but shoots were always aerially exposed. Plants at the shallowest level had their shoots elevated above the water level, but were always rooted in wetted soil. Measurements of stem height from the base of the stem to the top of each stem and foliar spread at the widest point (leaf tip to leaf tip) were made weekly in August through September 1994 using a ruler. The number of flowering stems and date of flowering were also recorded.

Results

Field monitoring

There was an inverse correlation between number of stems in the field and the flow rate of the Columbia River. When river flow remained high, the number of stems was low. A one-year lag in the effect of flows on the number of stems shows a strong inverse correlation in the relationship (Figure 5). The lag effect is due to the fact that high flows in the previous year or season result in even further reduction in the number of stems. None of the stems in the macroplot flowered or produced buds in the six years the plot has been

monitored (Table 2), including 1994 which was the lowest water year. No counts were made in 1997 because the macroplot was inundated throughout the entire year. Figure 6 illustrates the percent frequency of Columbia yellowcress stem presence in each 20-quadrat subplot within the macroplot for all three subplots for the years 1994, 1996, 1998, and 1999.

The data for the visual surveys parallels what I found in the macroplot. In 1994, many scattered Columbia yellowcress populations along the shoreline were visited. Stands of more than 10,000 stems were found on several of the islands in the Reach. In 1998, five sites were revisited and 194 Columbia yellowcress stems were found in places that had thousands of stems in 1994. Many of the small patches along the shoreline and one of the islands surveyed had no stems. Locke Island (Figure 2), which supported a population of more than 10,000 stems in 1994, had an observed total of only 117 stems in 1998.

Experimental Study

Using the STATISTIX program (Analytical Software, Tallahassee, FL), I ran a one-way analysis of variance and Fisher's Least Significant Difference test (Snedecor and Cochran 1980) to compare the mean change in height and foliar spread at each water level (Table 3). For mean change in height, plants in the control raceway differed significantly ($p=0.0326$) from plants at the deep and moderate water levels, but plants at the shallow level did not differ significantly from plants at the control, moderate or deep water levels. The average change in height of plants in the control raceway was at least a factor of three times greater

than plants at the shallow, moderate and deep water levels. For mean change in foliar spread, plants at all water levels in the treatment raceway differed significantly ($p=0.0012$) from plants in the control raceway, with all treatments declining in foliar spread while the control was increasing.

In the treatment raceway, the continuously-submerged plants exhibited leaf chlorosis, weak stems, and negative growth (leaf tips and stem ends rotted off). Plants at the moderate level were generally healthier in appearance, but growth was less than plants at the shallow level. Plants in the control raceway grew more and appeared healthier than those in the treatment raceway (Table 3).

My attempt to simulate natural conditions in the raceway experiment proved to be difficult. The edge, color and small available rooting volume of the buckets likely influenced the results. Nevertheless, I consider the experiment to be important because this was the first time Columbia yellowcress was successfully transplanted and grown under semi-controlled conditions using flowing river water. Several stems including one at the deep level flowered in the raceway experiment compared to none in the field. None of the flowering stems produced seeds, however, because all of the stems were eaten by unidentified insect larvae, effectively terminating the experiment.

Discussion

The flow regime under which Columbia yellowcress now exists differs considerably from the regime prior to dam building (Figure 7). Before damming, Columbia River flow rates peaked in May, June or July as warm weather melted

mountain snowpacks, then the river gradually receded in August and September to its lowest level in late fall and winter. Water levels did not fluctuate on a daily basis and flow rates were usually less than 2800 cubic meters per second (m^3s^{-1}) throughout the fall, winter and early spring months (Dauble and Watson 1997, USGS 1999). Since the construction of the hydroelectric dams, however, water levels have been manipulated hourly depending upon power demands, irrigation demands, and water storage capacity in upriver reservoirs (Scherer and Young 1992, Harris 1992). As a result, Columbia yellowcress populations along the Reach may be inundated on a daily basis throughout the year. In the summer of 1994, water fluctuations during the day would often inundate the 100F beach and cover Columbia yellowcress plants with one to two meters of water. Flow rates at Priest Rapids Dam need to be less than $2800 m^3s^{-1}$ for most of this beach to be exposed (Sauer and Leder 1985). There were many days when plants were inundated for 24 hours. Often the plants were aerially exposed only for a few hours before being inundated again.

Figure 8 shows the variation in river flows to which the Columbia yellowcress plants were exposed from 1993 to 1999. Populations all along the Reach were aerially exposed for about 24 of this 84-month period. The majority of the exposure occurred during the late fall and winter seasons – seasons characterized by low air temperatures and weak sunlight. The average daily solar radiation values for the Hanford Site from 1953 through 1998 are shown in Figure 9 (Hoitink *et al.* 1999). The values for October and November (months

when Columbia yellowcress populations are currently exposed) are about one-third to one-fourth those recorded in July and August when the populations were exposed in the past. Such late seasonal exposure and reduced solar radiation would likely inhibit photoperiodic initiation and development of flowers. In addition, insect pollination is less likely to occur since insects are also less active during this period. Therefore, it is unlikely that populations of Columbia yellowcress along the Reach would have had the opportunity to produce viable seeds. In fact, no flowering individuals were observed on the Reach from 1994 to 1999. Crone and Gehring (1998) also reported "extremely infrequent" or no flowering stems in six Columbia yellowcress sites on Pierce Island (Figure 2) over many years.

Flow rates remained well above $2800 \text{ m}^3\text{s}^{-1}$ throughout most of 1996 and all of 1997, inundating beach habitats continuously for 29 consecutive months. Plant populations were then exposed only during April of 1998, then completely inundated again for the next four months. Columbia yellowcress populations are typically found in areas of full sun associated with little or no other vegetation. Because even clear water attenuates light, continuous inundation results in an environment with equivalent light levels of a densely-shaded environment (Smith 1990). Reductions in light levels affect important physiological processes such as photosynthesis, induction of flowering, and seed development.

Far-red wavelengths are important in the promotion of flower production in many species, whereas red wavelengths have been shown to inhibit flowering. Far-red wavelengths are strongly absorbed by water but not by terrestrial foliage. Submerged plants, therefore, are subjected to significantly higher red to far-red ratios of 3.6 to 4.7 at one meter below the water's surface compared to 1.15 for forest interiors (Taiz and Zeiger 1991). Because Columbia yellowcress is submerged more often than exposed aerially, it probably is subjected to higher red to far-red ratios than in the past, which could inhibit flower initiation.

Repeated inundations of the Columbia River beaches were observed to result in increased silt depositions which could lead to oxygen deficiency in the rooting zone. Root substrates are typically low in oxygen due to consumption by respiring roots and associated microorganisms and because atmospheric oxygen diffuses slowly into saturated, fine-textured soils. Oxygen content of silty soils could drop to a few volumes percent (or completely to zero) within a few hours. Hypoxia in the soil atmosphere produces an environment where anaerobic microorganisms impair nitrogen turnover and produce toxic levels of sulphides, lactic acid, and butyric acid, among others (Larcher 1995). Such flood-related reductions in oxygen concentrations in the rooting zone of Columbia yellowcress could result in the accumulation of toxic substances resulting in weak growth or death.

Small, isolated populations of plants in disjunct patches of habitat (with little or no dispersal between them) are vulnerable to extinction through

environmental stochasticity and catastrophes, demographic stochasticity, loss of genetic heterozygosity and rare alleles, edge effects, and human disturbance (Burkey 1995, Mangel and Tier 1994; Schemske, *et al.* 1994; Primack 1993; Allen, *et al.* 1993; Menges 1990; Major 1988; Gilpin and Soule' 1986; Davy and Jefferies 1981). Considering the changes to Columbia yellowcress habitats, lack of flowering, loss of habitats, isolation of populations, and declining numbers on both the Reach and Pierce Island (Gehring 1993, Scherer and Young 1992), vulnerability of local populations to extirpation is apparent.

The Washington Natural Heritage Program (1997) lists Columbia yellowcress as a "State Threatened" vascular plant taxon likely to become endangered in Washington within the near future if factors contributing to its population decline or habitat degradation or loss continue. Until recently, Columbia yellowcress had been listed as "State Endangered", but was downgraded to "Threatened" because of the large numbers of stems found in surveys conducted on the Reach in 1994 and 1995 (i.e., low river-flow years). "State Endangered" is defined by the Washington Natural Heritage Program (1994) as a vascular plant taxon in danger of becoming extinct or extirpated in Washington within the near future if factors contributing to its decline continue. Populations of these taxa are at critically low levels or their habitats have been degraded or depleted to a significant degree. Columbia yellowcress numbers appear to be at critically low levels. It is not known how long this species can persist under current conditions. In light of recent surveys, Columbia

yellowcress's status should probably be changed to "State Endangered" to provide the populations and habitats with greater protection from further loss or degradation.

Columbia yellowcress is not the only rare species on the Reach at potential risk of extirpation. I found a number of other rare plant species along the shorelines of the Reach (e. g. dense sedge, *Carex densa*, shining flatsedge, *Cyperus bipartitus*, false-pimpernel, *Lindernia anagallidea*, and southern mudwort, *Limosella acaulis*) that are likely to have also been affected by the changes in the Columbia River flow regime.

Artificially controlled river flows effectively favor the encroachment of some species of exotic plants into the beach habitats. I noted that white mulberry, *Morus alba*, purple loosestrife, *Lythrum salicaria*, and reed canarygrass, *Phalaris arundinaceae*, have invaded beach habitats along the Reach. Once established, these taller, more robust, highly-competitive, non-native species appear to be less affected by the inundation because aerial portions of these species are elevated above the water level for longer periods. Although efforts to control purple loosestrife have worked to prevent it from taking over large areas along the river, reed canarygrass, and white mulberry have gained footholds into some areas and successfully out-competed the native species for space.

Survival of Columbia yellowcress likely depends upon changes in flow management practices that take into consideration its biological and ecological

requirements similar to strategies being formulated to protect spawning anadromous fish and their redds. Because Columbia yellowcress and other rare plant populations along the Reach were exposed in late summer and fall when flow rates were low in the past, I recommend flow rates be reduced at this time of the year to allow sufficient time for the populations to complete their life cycle. The populations need time to emerge, grow, produce flowers, set seed, and go dormant.

Conclusion

The effects of fluctuating water levels on Columbia yellowcress populations on the Hanford Reach of the Columbia River and long-term inundation resulted in reduced growth and failure of the plants to flower. There was an inverse correlation between number of stems in the field and the average annual flow rate of the River. A one-year lag in the effect of flows on the number of stems shows a strong inverse correlation in the relationship. The lag effect is due to the fact that high flows in the previous year or season result in even further reduction in the number of stems. When river flow remains high, the number of stems was low. Due to alteration of the flow regime to of the River, changes to the shorelines and beach habitats along the Reach have left Columbia yellowcress and other native plant species vulnerable to local extirpation through the loss of habitat, isolation of populations, and increased competition by non-native plant species.

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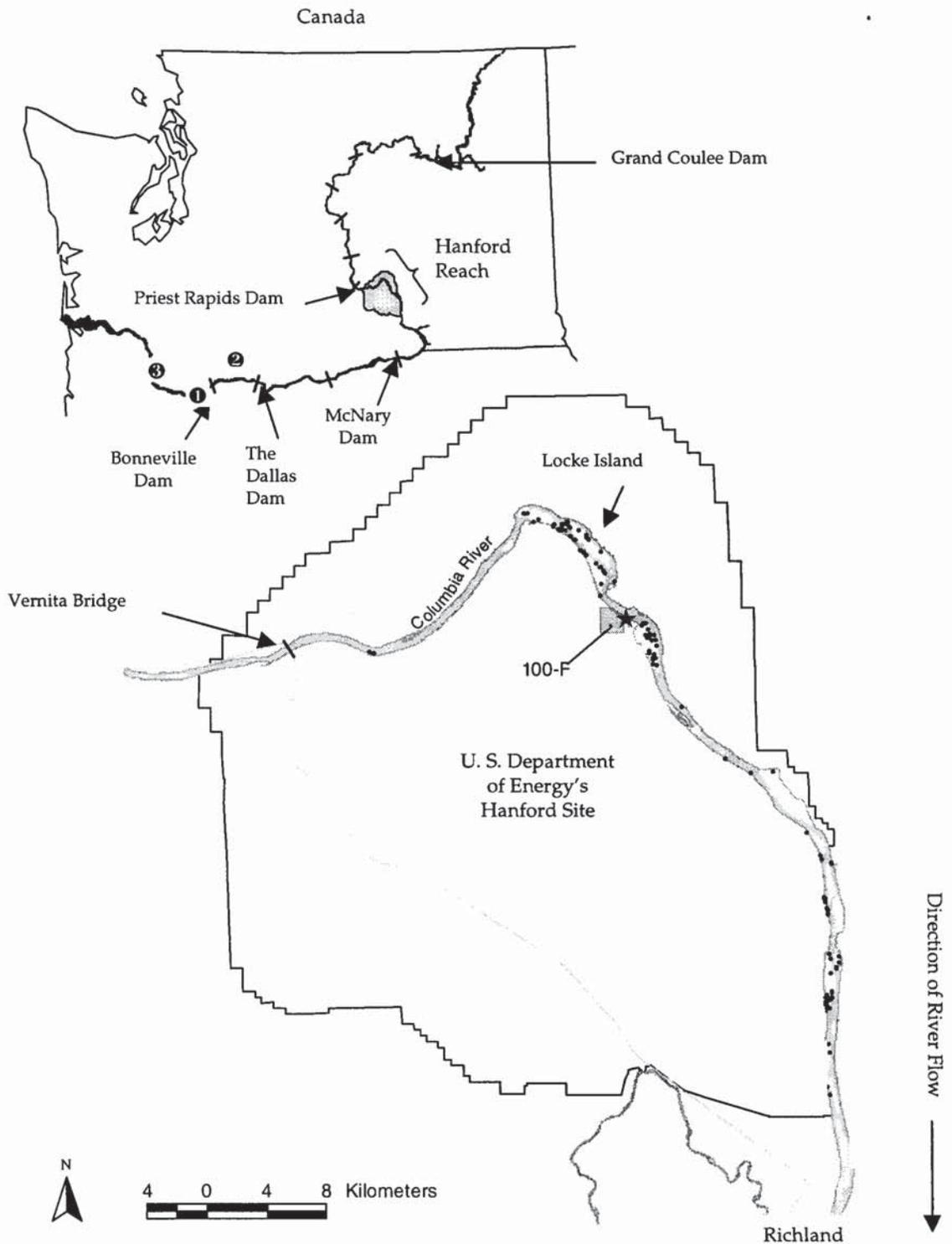


Figure 2. Location of populations of Columbia yellowcress (dots) along the Hanford Reach, the study plot (star) near the 100 F reactor area, and Pierce Island (❶), Bingen (❷), and Sauvies Island (❸).

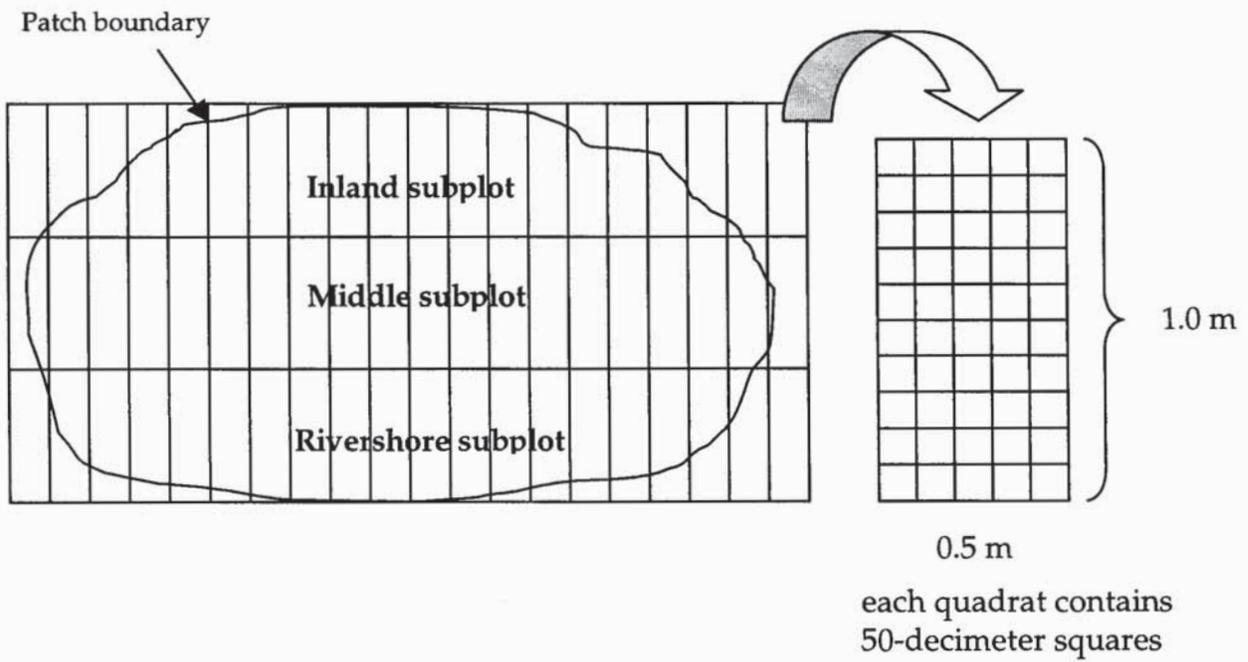


Figure 3. Macroplot with three 10- by 1-m subplots consisting of 20 consecutive 0.5m^2 quadrats spanning the patch of Columbia yellowcress.

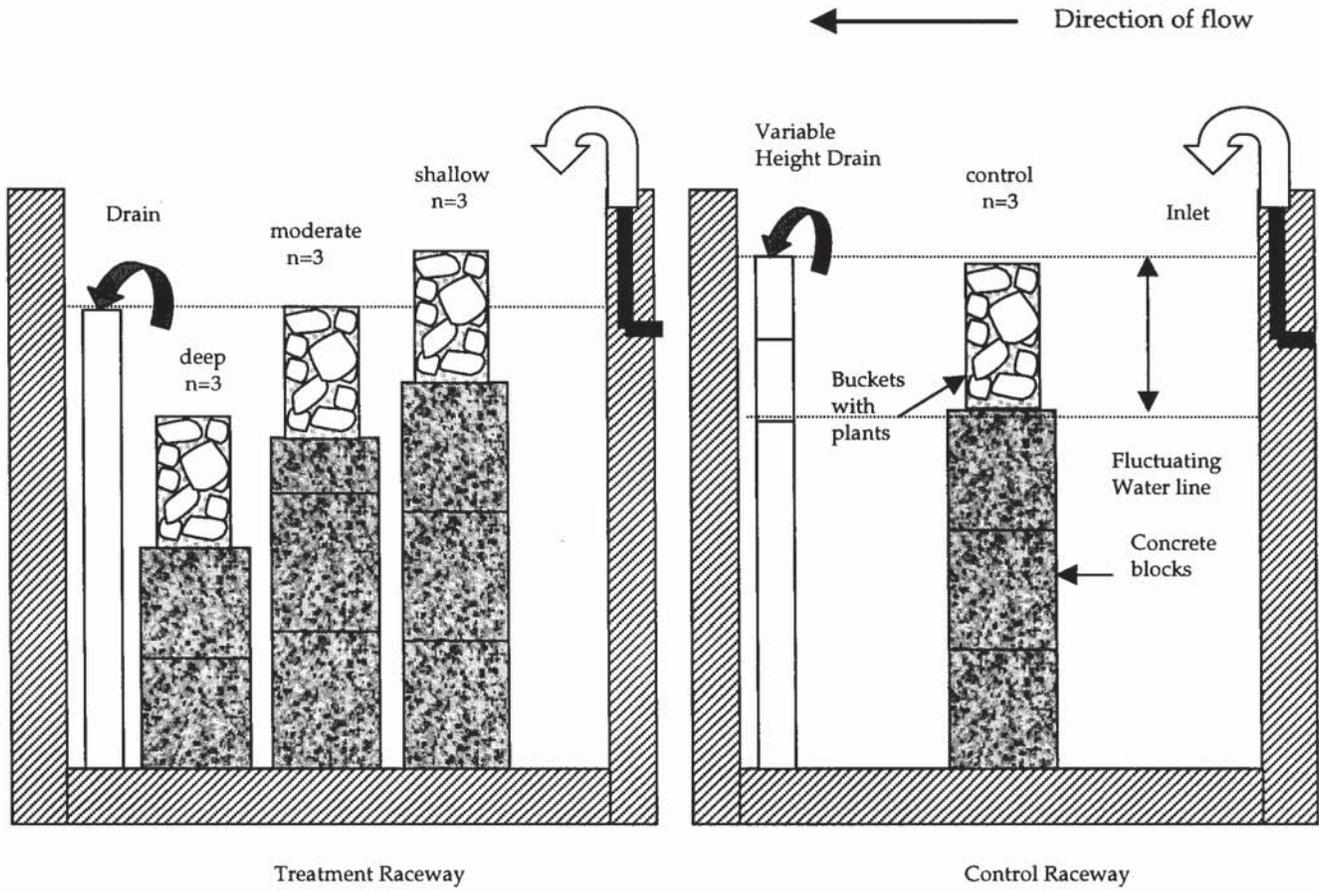


Figure 4. Side view of raceway experiment showing the positioning of buckets filled with river cobble, sand, and silt.

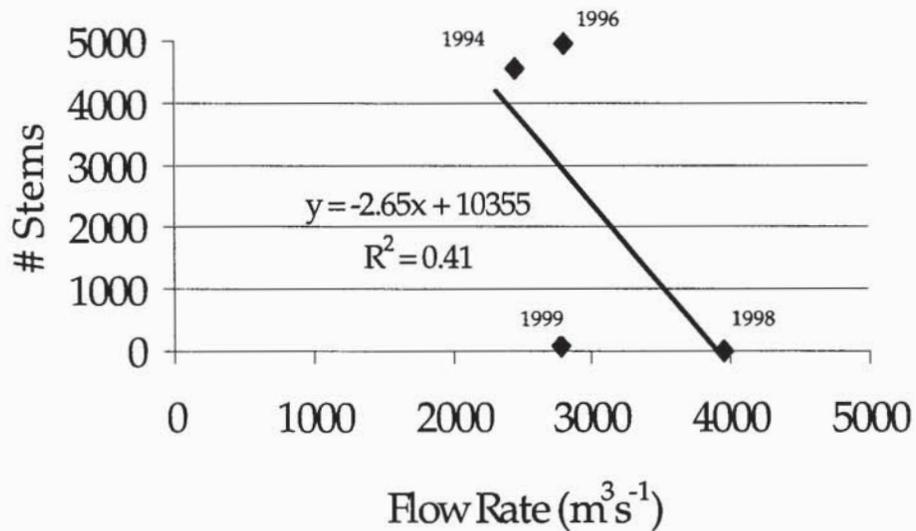


Figure 5. The inverse one-year lag relationship between the number of Columbia yellowcress stems on 100F beach and Columbia River flow. The number of stems is plotted against the average daily flow for the period July 1 – November 30 of the previous year. The regression is significant ($p < 0.05$).

Table 2. Columbia yellowcress stem count data collected from 1994 to 1999

Year	Subplot 1		Subplot 2		Subplot 3		Total/ Year		
	#Stems	%Freq	#Stems	%Freq	#Stems	%Freq	#Stems	%Freq	#Flrs
1994	1791	68	1568	53	1179	44	4538	55	0
1996	1733	58	2074	66	1158	45	4965	56	0
1997	Macroplot inundated throughout the year – no counts available								
1998	0	0.0	8	0.7	9	0.9	17	0.5	0
1999	0	0.0	10	0.6	84	3.7	94	1.4	0

%Freq = the total number of 1-dm² squares in each subplot containing Columbia yellowcress stems divided by the total number of squares (1000) multiplied by 100.

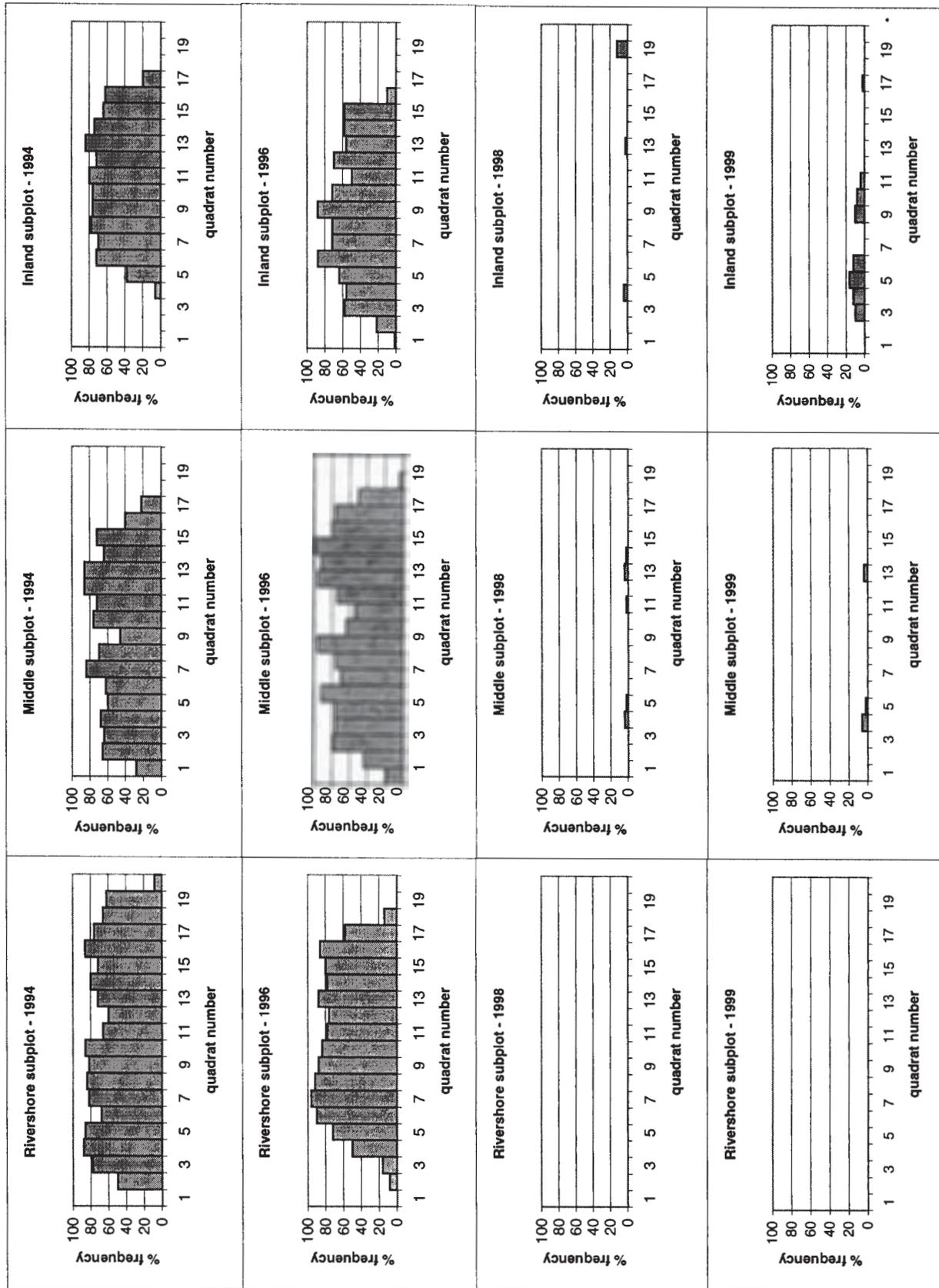


Figure 6. Percent frequency of Columbia yellowcress stem presence in three subplots on a beach area on the Hanford Reach from 1994 to 1999.

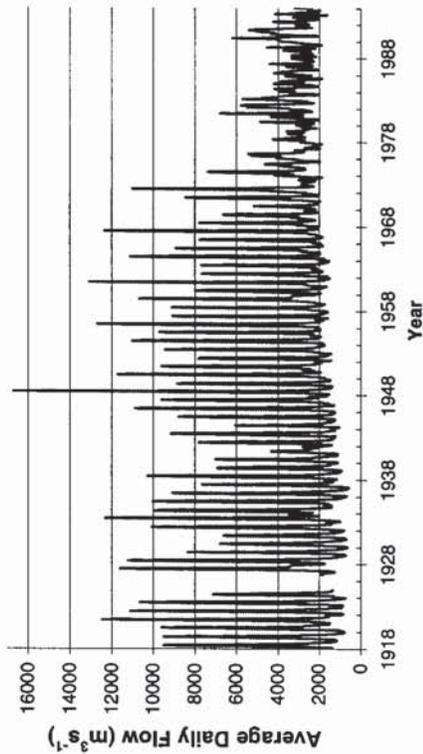
Table 3. Stem measurements (cm) of Columbia yellowcress stems over a 30-day period in the raceway experiment

Water Level	n*	Mean Change in Height ± SD	Range in Height Measurements	Mean Change in Foliar Spread ± SD	Range in Foliar Spread Measurements
Deep	19	0.786 ± 0.746 ^a	-2.5 to 4.8	-1.148 ± 0.232 ^a	-4.4 to 0.9
Medium	18	0.614 ± 0.276 ^a	-1.7 to 3.3	-0.633 ± 0.144 ^a	-2.4 to 0.9
Shallow	13	1.572 ± 0.939 ^{ab}	-4.7 to 3.1	-0.477 ± 0.304 ^a	-2.0 to 0.5
Control	12	3.210 ± 0.930 ^b	-2.6 to 10.7	2.337 ± 0.702 ^b	-0.6 to 6.1

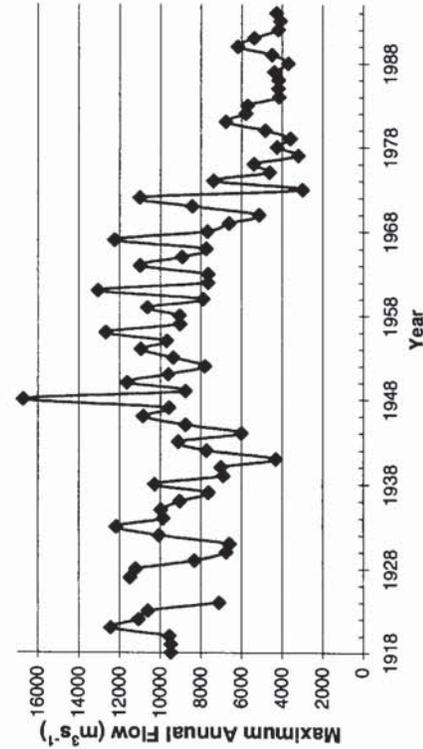
* *n* = the total number of stems measured at each water level

Values followed by the same letter are not significantly different $p < 0.05$.

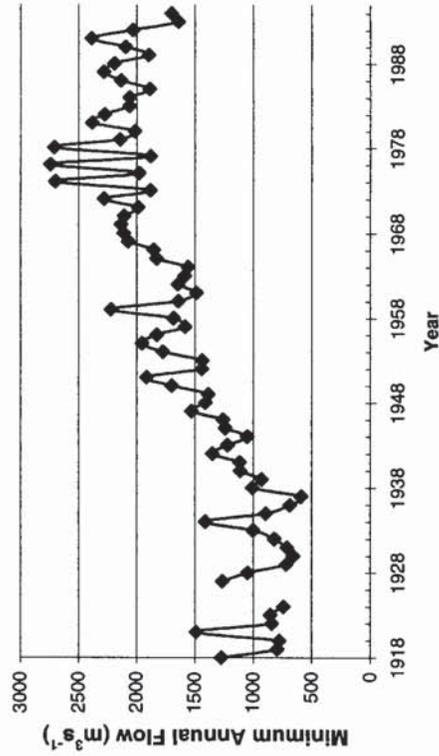
Monthly Average Daily Flow
October 1918 - September 1994



Annual Average Maximum Monthly Flow,
1918-1994



Annual Average Minimum Monthly Flow 1918-1994



Annual Flow Amplitude 1918-1994

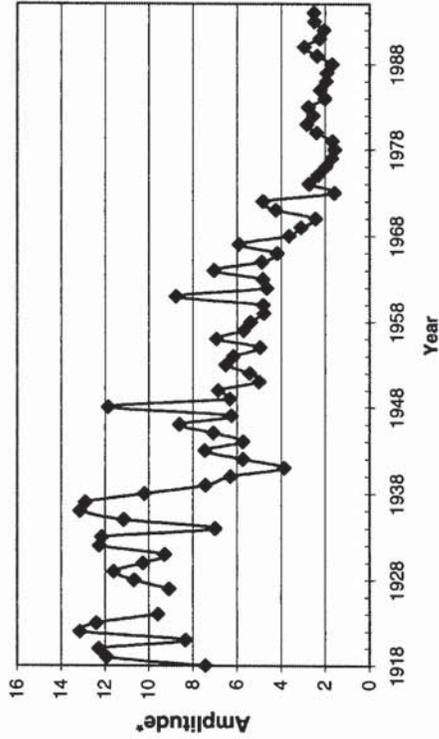


Figure 7. Columbia River flow rates at Vernita from October 1917 to September 1994 (from USGS 1999).

* Amplitude = Maximum Annual Flow divided by Minimum Annual Flow

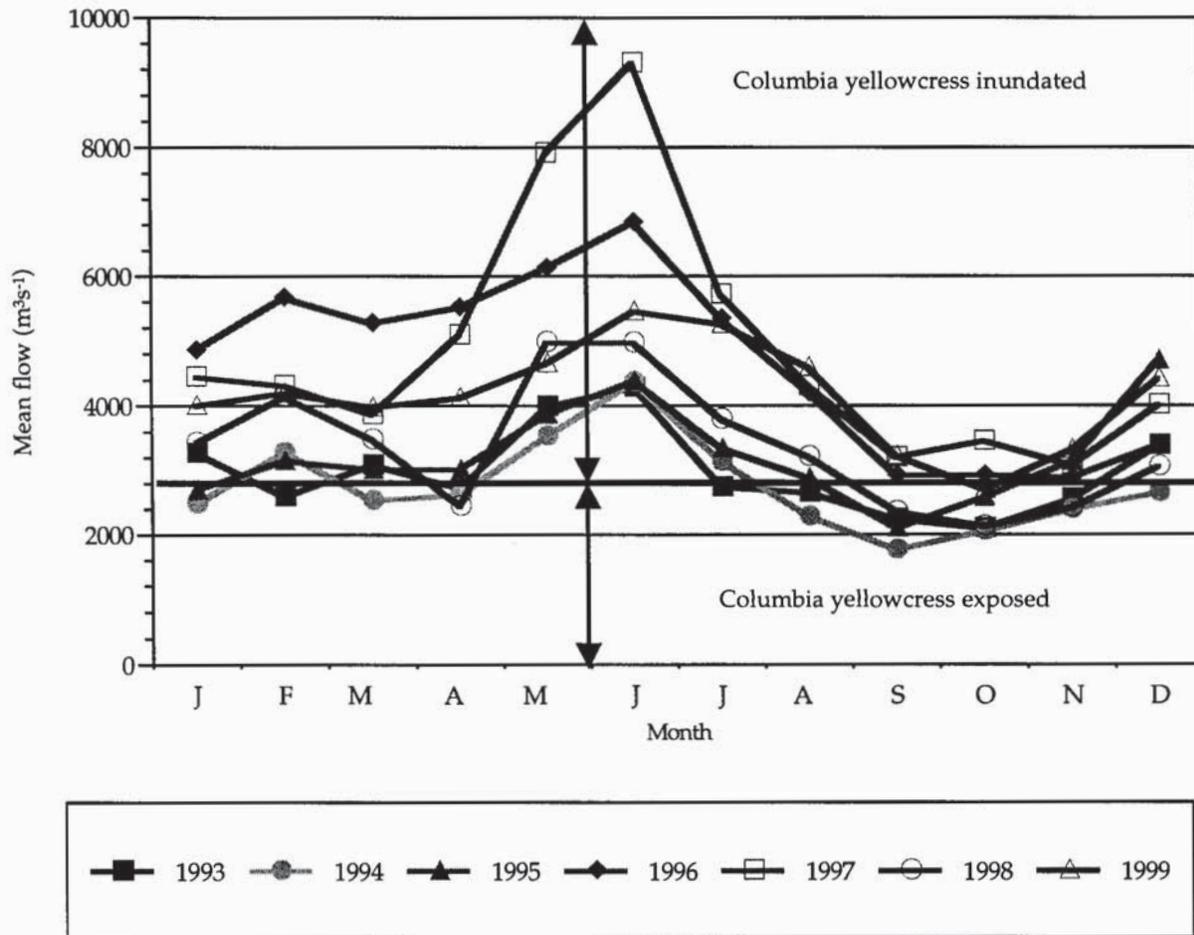


Figure 8. Average monthly flow rate of the Columbia River at Priest Rapids Dam 1993-1999 (modified from DART 1999).

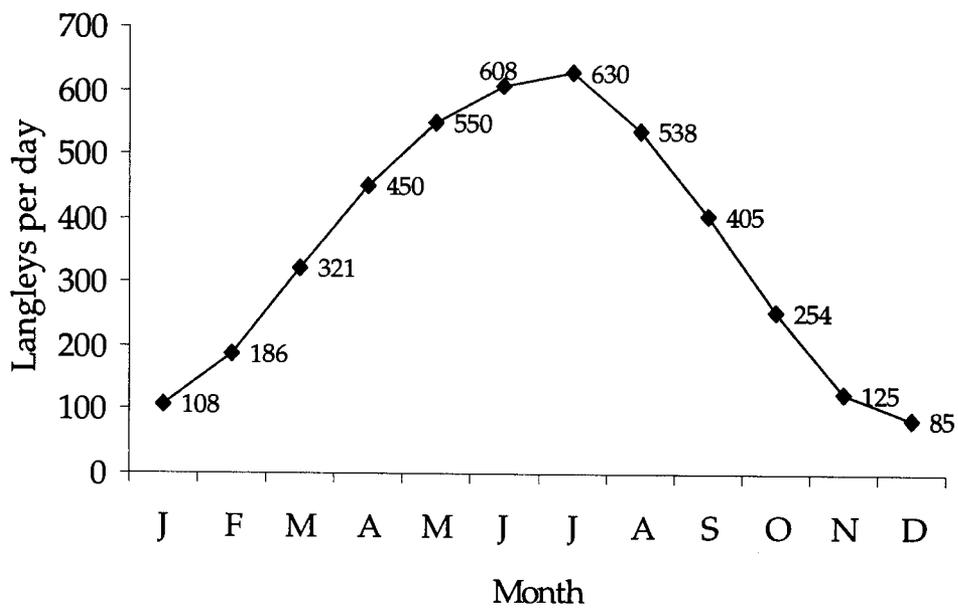


Figure 9. Average solar radiation values on the Hanford Site from 1953 to 1998 (from Hoitink *et al.* 1999).

CHAPTER THREE

A revitalization of the ecotype concept and its application to

Lesquerella tuplashensis

A revitalization of the ecotype concept

Word count: 4825

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Abstract

In a comparative study between a rare endemic, *Lesquerella tuplashensis*, and a closely-related common species, *L. douglasii*, questions were raised concerning the separation of the two species based on floral morphological characteristics alone. The 1995 monograph of *L. tuplashensis* by Rollins, Beck and Caplow in Rhodora describes morphological characteristics, specifically stipitate trichomes on the siliques and imbricated cauline leaves, to separate *L. tuplashensis* from *L. douglasii*. No differences in the trichomes or cauline leaves in individuals collected from populations of *L. douglasii* and from populations reported to be *L. tuplashensis* by Rollins *et al.* were detected. Time of flowering did not differ between the two populations. Differences in rooting substrates, topographic position, and associated plant species, however, do exist and could account for the phenotypic differences that have been reported. The findings of this study suggest *L. tuplashensis* is not a separate species, but an ecotype of *L. douglasii*. I take this opportunity to revitalize the concept of the ecotype and discuss its relevancy to *L. tuplashensis*.

Introduction

In 1994 a new species of *Lesquerella* (Brassicaceae) was discovered by botanists conducting a survey of the White Bluffs area located on the Hanford Reach in Franklin County in south central Washington state. Type specimens of the new discovery were sent to the Gray Herbarium at Harvard University (Cambridge, MA) for verification and it was described as a new species, *Lesquerella tuplashensis* Rollins, Beck, & Caplow, sp. nov. Prior to the new discovery, *L. douglasii* S. Watson was the only species of *Lesquerella* known from Washington state (Rollins, Beck, and Caplow 1995). Because *L. tuplashensis* occurs only in small, scattered patches in the White Bluffs area, it is considered a Species of Concern by the U. S. Fish and Wildlife Service, listed as State Endangered (Washington Natural Heritage Program 1997, Soll and Soper 1995), and a candidate for Federal listing under the Endangered Species Act.

As part of a comparative study between closely-related rare and common native plant species, characteristics of the rare *L. tuplashensis* were compared to those of *L. douglasii*. *Lesquerella douglasii* is a more widely distributed species that occurs in dryland habitats along the Columbia River and its major tributaries in eastern Washington, northeastern Oregon, southwestern Idaho and British Columbia (Hitchcock and Cronquist 1973). The purpose of this study was to determine if restricted habitat limits the distribution of *L. tuplashensis* to the White Bluffs area. A profile was developed for each species comparing distribution, habitat characteristics, phenology, associated plants, morphological

characteristics, and genetic variation. Although distribution and habitat characteristics differed, phenology and morphological characteristics of individual plants were not significantly different suggesting the populations thought to be *L. tuplashensis* are ecotypes of *L. douglasii*.

Methods

Distribution, habitat and community characteristics

Based on field surveys, *L. tuplashensis* appears to be restricted to a caliche layer along a narrow 17-km long strip (2 to 25 m wide) on the rim of the White Bluffs overlooking the Columbia River in western Franklin County in Washington state (Rollins, Beck and Caplow 1995). Because the population is not continuous, study sites were placed at the northernmost and southernmost points of the strip, with another site between those two extremes in areas with many plants. Study sites of *L. douglasii* were limited to those found on the Hanford Site (Figure 10) to insure populations were within the same macroclimatic region and to provide some protection from human disturbance and livestock grazing.

Permanent plots, one per site, were established with three sites per species. Species diversity, seedling, juvenile, and adult plant density, and canopy cover were measured using a modified-Whittaker nested sampling plot (Stohlgren *et al.* 1997). The modified-Whittaker plot was chosen for its efficiency in capturing species richness, usefulness in trend analysis of long-term monitoring, and because it minimizes many of the problems associated with the

original Whittaker design (see Stohlgren *et al.* 1995 for a complete description): The plot was 20 by 50 m (1000 m²), contains ten 0.5- by 1-m (0.5 m²) subplots arranged systematically inside and adjacent to the plot perimeter, two 2- by 5-m (10 m²) subplots in opposite corners, and a 5- by 20-m (100 m²) subplot in the center of the plot. Percent cover by species was recorded in the ten 0.5-m² subplots. Species presence was recorded in the 10-m² and 100-m² subplots and in the entire 1000-m² plot area. Species richness was determined by combining lists from the replicate plots and removing duplicate entries.

For germination trials, ripe seeds were collected by hand. Thirty seeds per species were placed in sterile petrie dishes on filter paper saturated with distilled water and grown in the dark at 25°C in a plant growth chamber. Percentage of seeds germinated was calculated.

Phenology and morphological characteristics

Twenty *Lesquerella* plants at each site were selected for measurement by using a random number generator in Excel 5.0 (Microsoft, Redmond, WA) to select plants from along the 140-m perimeter of the plot. These individuals were marked with metal tags and measured for plant height, canopy spread at widest point, and canopy spread at 90° from widest point. The number of inflorescences were counted and recorded. Life stage (i.e., seedling, juvenile, or flowering adult) was recorded for the marked individuals. Density of seedlings, juvenile, and adult *Lesquerella* plants per square meter in each plot was obtained by

counting all individual *Lesquerella* plants within a one meter strip inside the entire 140-m perimeter of the 20- by 50-m plot.

Morphological descriptions of each species were compiled from the published literature (Rollins, Beck and Caplow 1995; Hitchcock *et al.* 1994). To obtain data on the variability in leaf size and shape, two leaves from the basal rosettes of the 20 plants were collected (40 leaves at each of the six sites) on the same day. Leaves were measured for length and width to the nearest 0.5 mm and photographed to show the variation in leaf size and shape. To obtain data on fruit morphology, 20 inflorescences were collected from each of the six study sites on the same day. Exterior surfaces of the silique valves were examined under a dissecting scope for the presence or absence of stipitate trichomes.

Soil characteristics

I collected soil cores approximately 10 cm deep from as close to the base of individual plants as possible with a soil corer to form a composite soil sample from each site. Samples were oven dried at 40°C for 48 hours, sieved to 2 mm, and analyzed for organic matter (modified Walkley-Black method, Nelson and Sommers 1982), calcium and potassium (ammonium acetate method, Rhoades 1982), phosphorus (Olsen extraction method, Olsen and Sommers 1982), mineral nitrogen (calcium sulfate and potassium chloride methods, 1982), and soluble salts (leaching of the sample using distilled water in a 1:1 ratio, Rhoades 1982). Analysis was conducted at the Moses Lake Soil Test Lab in Moses Lake, Washington.

Statistical analyses

I used the statistical program SPSS (SPSS, Inc., Chicago, IL) to obtain descriptive statistics and run t-tests on the means to determine level-of-significant difference for canopy coverage, percent germination, average plant height, canopy spread, canopy spread at 90°, number of flowers leaf length, leaf width, leaf length to leaf width ratios, soil nutrient content, and pH values.

Results

Habitat and community characteristics

The *L. tuplashensis* habitat was different from that where populations of *L. douglasii* are found. The *L. tuplashensis* habitat consists of deep layers of sediments of the Ringold Formation and lacustrine deposits that occurred during the late Pliocene Epoch approximately 3-5 million years ago (Reidel *et al.* 1994). The faces of the White Bluffs are steep and range in altitude from about 100 m at river level to 290 m at the rim. The upper five meters of sediments are heavily calcified and silicified forming a fine-grain, cement-like caliche layer (Newcomb 1958). These sediments combined with the steep, south-facing slopes comprise a hostile environment for plants. The compacted soils interfere with rainfall infiltration and moisture that does infiltrate is not as readily available to plants because it is tightly held by the fine-textured particles.

Lesquerella douglasii populations occur on flat land composed of coarse alluvium associated with the Hanford formation deposited as recently as 12,000 years ago during periods of glacio-fluvial flooding (Bretz 1959). The Hanford

formation is a mix of flood gravels and slackwater sediments consisting of a heterogeneous mix of pebbles, gravels and boulders, sand, and laminated silt deposits (Reidel *et al.* 1994). Populations of *L. douglasii* occur above normal flood water levels. These coarse-textured soils permit infiltration of rainfall with virtually no loss from runoff. In addition, moisture is more readily available for uptake by plants because it is not as tightly held by the larger sized soil particles.

Fifty-four species were recorded from the six sites: 6 shrubs, 11 grasses, and 37 forbs (Table 4). Of these, only 8 were common to both habitats. Twenty one were found only on the bluffs and 25 were found only on the flat land. Percent cover varied widely between sites. In the *L. douglasii* sites, canopy cover ranged from 44% to 100%, whereas, the *L. tuplashensis* sites ranged from 16% to 59%. On average, the *L. douglasii* sites had twice as much cover as the *L. tuplashensis* sites. Individual plants were more widely spaced on the bluffs compared to those on the flat land.

The average percent germination was slightly higher for *L. douglasii* seeds (24% compared to 20% for *L. tuplashensis*), but did not differ statistically ($p < 0.05$).

Phenological and morphological characteristics

Individual plants of *Lesquerella douglasii* did not differ in average height or canopy spread from *L. tuplashensis* (Table 5). However, the average number of inflorescences per individual was significantly different ($p < 0.001$). Density of seedlings, juvenile, and adult *L. douglasii* plants were greater than twice that of

L. tuplashensis plants. Density in the *L. tuplashensis* plots declined in 1999 from 1998 (Figure 11).

From the monograph prepared by Rollins *et al.* (1995):

"In comparing *Lesquerella tuplashensis* with its related *L. douglasii*, we find that most features are similar. Basically, the cauline leaves of *L. tuplashensis* are imbricated and there is a range from linear to petiolate with a broad rounded blade, while those of *L. douglasii* are loosely arranged and narrowly linear. The basal leaves, especially those of the outer margin, of *L. tuplashensis* are more rounded and broader than those of *L. douglasii*. The most noticeable distinction between the two species is in the trichomes of the siliques. Trichomes on the exterior surfaces of the silique valves of *L. tuplashensis* have the radiate portion raised on a stipe-like stalk whereas the comparable trichomes of *L. douglasii* are sessile and the radiate portion is appressed to the valve surface. In general habit, the plants of *L. tuplashensis* are more compact and denser than those of *L. douglasii*".

The majority of cauline leaves on individual *Lesquerella* plants in all six plots were loosely arranged although some individuals had a mix of imbricated and loosely-arranged cauline leaves. Cauline leaves varied in shape from narrowly linear to linear. The basal leaves of *L. tuplashensis* were different from those of *L. douglasii* as described by Rollins *et al.* (1995). Leaves of *L. tuplashensis* were about the same length, but were wider and more lobed than those of *L. douglasii*. Leaf length to width ratios differed statistically ($p < 0.001$) between *L. douglasii*

and *L. tuplashensis* (Table 5, Figure 12). However, of the 672 silique valves examined, all had the radiate portion of the trichomes raised from the surface on stipe-like stalks. The stipes on *L. tuplashensis* tended to be longer. Radiate portions of the trichomes on the exterior surfaces of *L. douglasii* siliques were on shorter, but clearly evident stipes (Figure 13).

I observed a large amount of variation within and between the populations. I also observed distinct differences in the morphology of individual plants from one year to the next. In 1998, the plants on the White Bluffs (*L. tuplashensis*) were typically shorter and more foliar compacted than those on the flat land. In 1999, however, plants on the flat land were shorter and more compact than those on the White Bluffs.

Soil characteristics

Soil chemistry was variable between sites in the same habitat, however, sample means for the six sites did not differ significantly in nutrient content or pH values. Except for calcium and potassium, nutrient content at all sites was low (Table 6). *Lesquerella douglasii* sites tended to have slightly more nitrogen and organic matter and slightly lower potassium, soluble salts, and pH values. There was virtually no organic matter at any of the sites. The average calcium content at the *L. tuplashensis* sites was about twice the average amount measured in the *L. douglasii* sites.

Discussion

An ideal system of taxonomic identification is based on good diagnostic characters. Because variation in any character is not constant, it is important to assess the potential range of variation in a particular characteristic (Cook 1991). Comparative studies on variation in the parts of an individual plant, between large numbers of individuals in a single population, between different populations, and between related species are necessary to evaluate the taxonomic significance of a single characteristic (Bell 1967; Rollins and Shaw 1973).

Seven specimens of *L. tuplashensis* are on file in the Gray Herbarium at Harvard University, including the type specimen. One specimen, collected by Brandege and Tweedy for the Northern Transcontinental Railroad in 1883 from the White Bluffs area, has been labeled as six different species as 1) *Vesicaria montana* Gray, 2) *V. occidentalis* Wats. (identified by Watson), 3) *V. douglasii* Wats. (annotated by C. V. Piper), 4) *Lesquerella kingii* Wats. (rejected by Watson), 5) *L. douglasii* Wats. (identified by Rollins and Shaw in 1970), and 6) *L. tuplashensis* Rollins, Beck, and Caplow by Rollins in 1999.

Vesicaria is the former name for some species of *Lesquerella* and *Physaria*. Species within *Lesquerella* and *Physaria* were once considered under the Old World genera *Alyssum* and *Vesicaria* (Rollins and Shaw 1973). Taxonomists have debated the specific characters separating the four genera since the late 1800s. Watson (1888) stated succinctly that characters of species within

Lesquerella were unique and quite distinct from Old World species in *Vesicaria* and took the liberty of separating all species within the genus in North America into *Lesquerella*. Recent studies of North American species within *Physaria* suggest they should also be united into *Lesquerella* (O'Kane personal communication). The controversy over the systematic placement of species in the four genera likely stems from the large amount of morphological and habitat variability characteristic of Brassicaceae.

For example, *L. douglasii* is widely distributed and is commonly found in sagebrush deserts as well as adjacent ponderosa pine forests (Hitchcock and Cronquist 1973). The environmental factors affecting populations of *L. douglasii* in sagebrush deserts are different from those affecting *L. douglasii* populations near ponderosa pine forests. The phenotype of *L. douglasii* has a normal range of variation, or norm of reaction, that is dependent upon local environmental conditions and, as noted by Niklas (1997), "remarkably different-looking phenotypes can be produced by the same genotype depending on local conditions."

The habitat differences could account for the morphological differences and the more compact habit observed in individuals of *Lesquerella* on the White Bluffs. According to Daubenmire (1959), "since differentiation into ecotypes results from the discriminating selection offered by unlike habitats, it follows that in general the wider the ecological range of the species the more numerous are its ecotypes." Therefore, I would expect to observe differences in the

morphology of individual *L. douglasii* plants simply because the habitats are different. Furthermore, I would expect to find numerous ecotypes of *L. douglasii* because it occurs over a wide range of habitats.

The Ecotype

Göte Turesson (1922) coined the term "ecotype" as an "ecological unit to cover the product arising as a result of the genotypical response of an ecospecies to a particular habitat." Turesson recognized variation in morphological characters were the result of the reaction of the plant's genotype to external conditions (termed reactiontype or phenotype). This was proven in an experiment by Clausen, Keck, and Hiesey (1940) where genetically-identical divisions of *Potentilla glandulosa* grown in different environments displayed markedly different phenotypes. To describe the extent of variation within a species quantitatively, it is essential to assess the ability of the individual organism to alter its morphology in response to environmental conditions (Schlichting 1986). Turesson's statement in 1922 is as significant today as it was then: "we have nothing like a reliable picture of the significance of the ecological factors in the differentiation process of the organism."

It may be impossible to determine the extent of phenotypic variation and its causes in *L. douglasii*, or any other widespread species. Stebbins (1950) stated "the pattern of variation which exists in any widespread species is so complex and multidimensional that it cannot be analyzed in its entirety." He emphasized that in any sexually reproducing, cross-fertilized species, no two individuals or

populations are exactly alike and that variation within species is random, while variation in other characteristics follows regular geographic patterns. There is no reason to suspect individuals of *L. douglasii* growing on flat land near the river are reproductively isolated from those on the White Bluffs. I have observed bees and other flying insects visiting both areas that are separated by less than a kilometer in some cases.

I attempted to count chromosomes on fixed and stained root tips of young seedlings without success. Like Rollins and Shaw (1973), I had hoped that chromosome counts on individuals in different populations would provide some definitive evidence for taxonomic identification. They found that polyploidy exists within species and between closely related species in *Lesquerella* and that diploids and polyploids can and do exist in the same population. However, if the chromosome count on *L. tuplashensis* differed from the diploid numbers they found in *L. douglasii*, it would provide enough evidence to warrant further investigation into the separation of the two species based on genetic isolation (Windham personal communication). There is currently no evidence to suggest that a barrier to genetic interchange exists between these populations. Furthermore, the highly variable morphological characters presently used to separate them taxonomically do not differ enough to justify defining them as separate species.

Grady and Quattro (1999) favor the recognition of evolutionarily distinct taxa based on suites of independent characters that co-vary and not on any one

character, thus avoiding the taxonomic confusion and controversy over what constitutes a good character for taxon-level descriptions. This approach, termed character concordance, also reduces the risk of delineating nonevolutionary units as species. Such an approach is especially important in plants because the phenotype will vary depending on environmental conditions (the ecotype). The ecotype concept proposed by Turesson in 1922 is a concept worth revitalizing in light of efforts to document biodiversity.

Conclusion

Morphological comparisons between *L. douglasii* and *L. tuplashensis* indicate *L. tuplashensis* is an ecotype of *L. douglasii* due to differences in habitat. No differences in the trichomes or cauline leaves in individuals collected from populations of *L. douglasii* and from populations reported to be *L. tuplashensis* by Rollins *et al.* (1995) were detected. The basal leaves of *L. tuplashensis* were different than those of *L. douglasii* as described by Rollins *et al.* (1995). Leaves of *L. tuplashensis* were about the same length, but were wider and more lobed than those of *L. douglasii*. Leaf length to width ratios were statistically different between *L. douglasii* and *L. tuplashensis*. Time of flowering did not differ between the two populations. Differences in rooting substrates, topographic position, and associated plant species, however, did exist and could account for the phenotypic differences that were observed. Individuals will vary in phenotype in different environments, the basic premise behind the ecotype concept.

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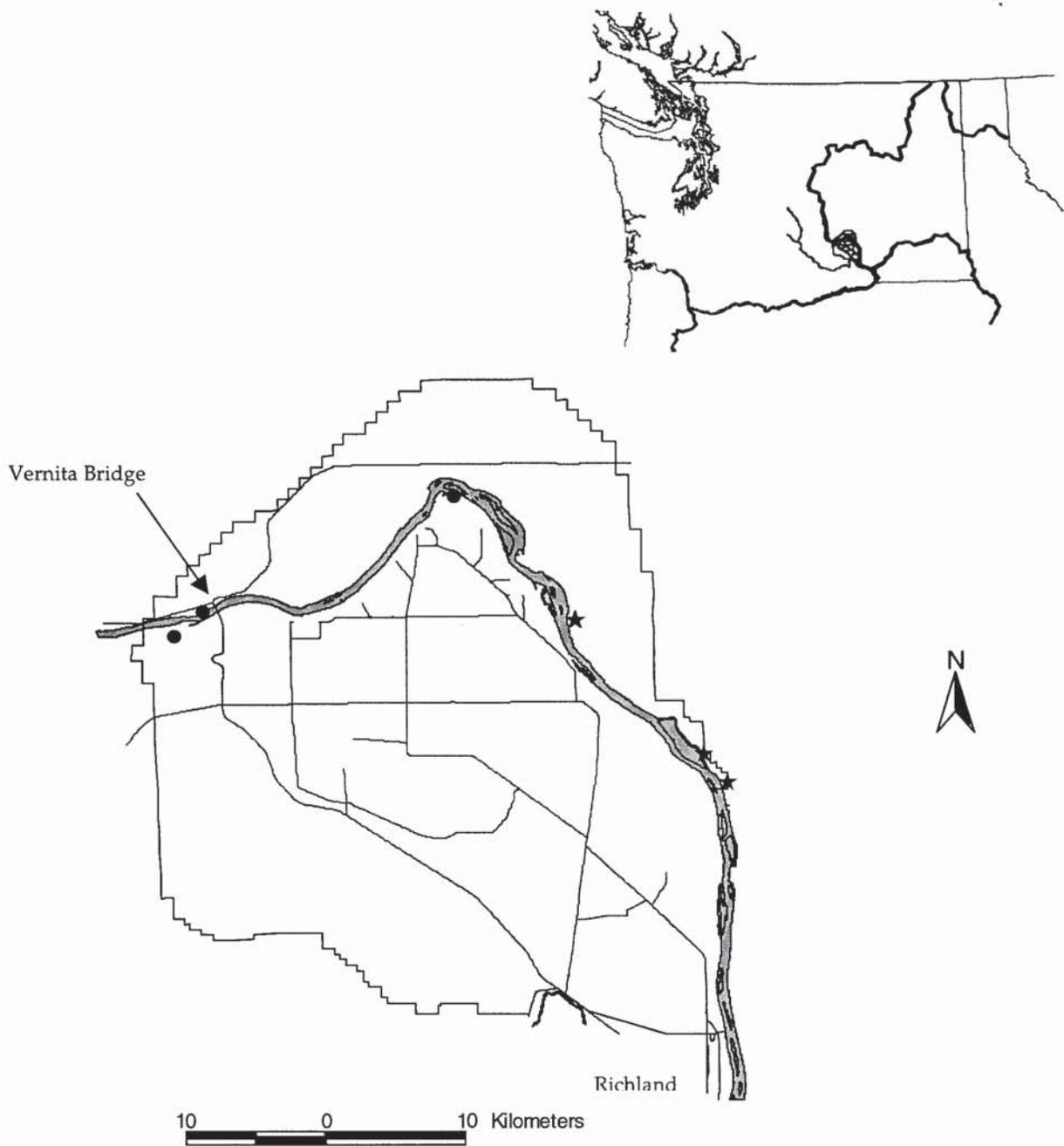


Figure 10. Location of *Lesquerella douglasii* (circles) and *L. tuplashensis* (stars) study sites on the U. S. Department of Energy's Hanford Site in south central Washington.

Table 4. Canopy cover by species of vascular plants in study plots in *L. douglasii* and *L. tuplashensis* habitats in south central Washington 1998

Type	Species	<i>L. douglasii</i>				<i>L. tuplashensis</i>			
		1	Plot		Avg.	1	Plot		Avg.
			2	3			2	3	
Shrubs	<i>Artemisia tridentata</i>	0.3			0.1		3.8		1.3
	<i>Atriplex canescens</i>				0.0			1.1	0.4
	<i>Grayia spinosa</i>				0.0			1.2	0.4
	<i>Chrysothamnus nauseosus</i>		0.1		0.0				0.0
	<i>Eriogonum microthecum</i>				0.0		0.3	0.3	0.2
	<i>Salvia dorii</i>				0.0	2.6			0.9
	Total shrub cover	0.3	0.1	0	0.1	2.6	4.1	2.6	3.1
Grasses	* <i>Agropyron cristatum</i>			7.5	2.5				0.0
	<i>Agropyron dasytachyum</i>	8.0			2.7				0.0
	* <i>Bromus tectorum</i>	10.4	1.7	19.5	10.5	52.3	0.3	10.0	20.9
	<i>Oryzopsis hymenoides</i>	3.5			1.2		0.2		0.1
	* <i>Poa bulbosa</i>	5.1	4.2	0.4	3.2				0.0
	<i>Poa secunda</i>	1.6	16.2	0.1	6.0		5.7	0.7	2.1
	<i>Pseudoroegneria spicata</i>				0.0		1.1		0.4
	<i>Sitanion hystrix</i>	1.8			0.6				0.0
	<i>Sporobolus cryptandrus</i>	2.4	4.1	1.3	2.6				0.0
	Unknown grass	5.8			1.9				0.0
	<i>Vulpia octoflora</i>	0.5	0.5		0.3				0.0
	Total grass cover	39.1	26.7	28.8	31.5	52.3	7.3	10.7	23.4

Type	Species	<i>L. douglasii</i>				<i>L. tuplashensis</i>			
		<u>Plot</u>			Avg.	<u>Plot</u>			Avg.
		1	2	3		1	2	3	
Forbs	<i>Achillea millefolium</i>	0.1			0.0				0.0
	<i>Allium robinsonii</i>		0.1		0.0				0.0
	<i>Amsinckia retrorsa</i>				0.0	0.6			0.2
	<i>Amsinckia tessellata</i>				0.0		0.8		0.3
	<i>Artemisia dracunculus</i>	0.2			0.1				0.0
	<i>Astragalus caricinus</i>				0.0		0.9		0.3
	<i>Astragalus purshii</i>	0.2			0.1				0.0
	<i>Astragalus succumbens</i>		0.2		0.1		1.0		0.3
	<i>Camelina microcarpa</i>				0.0	1.9		0.5	0.8
	<i>Camissonia pygmaea</i>				0.0			0.3	0.1
	<i>Carex spp.</i>		0.1		0.0				0.0
	* <i>Centaurea diffusa</i>		9.2	11.6	6.9				0.0
	<i>Chaenactis douglasii</i>				0.0	0.1		0.1	0.1
	* <i>Cirsium spp.</i>	0.3			0.1				0.0
	<i>Cryptantha pterocarya</i>				0.0			0.4	0.1
	<i>Cryptantha spiculifera</i>				0.0		1.2		0.4
	<i>Descurainia pinnata</i>	0.3	0.1		0.1	0.1			0.03
	<i>Draba verna</i>	2.5	3.8	14	6.8				0.0
	<i>Epilobium paniculatum</i>	0.2	0.2		0.1	0.1			0.03
	* <i>Erodium cicutarium</i>		1.5		0.5				0.0
	<i>Erigeron poliospermus</i>	1.3			0.4				0.0
	<i>Gilia sinuata</i>				0.0	0.4			0.1
	<i>Helianthus cusickii</i>				0.0		0.1		0.03

Type	Species	<i>L. douglasii</i>				<i>L. tuplashensis</i>			
		1	Plot		Avg.	1	Plot		Avg.
			2	3			2	3	
Forbs	<i>*Holosteum umbellatum</i>	3.1	0.1	42.5	15.2	0.4	0.2	0.2	
	<i>*Lactuca serriola</i>				0.0		0.1	0.03	
	<i>Lesquerella douglasii</i>	2.9	1.2	0.5	1.5			0.0	
	<i>Lesquerella tuplashensis</i>				0.0	0.5	1.2	0.6	
	<i>Lomatium canbyi</i>			1.3	0.4			0.0	
	<i>Lomatium grayi</i>		0.7		0.2			0.0	
	<i>Marsilea vestita</i>			1.0	0.3			0.0	
	<i>Mentzelia laevicaulis</i>				0.0	0.1		0.03	
	<i>Microsteris gracilis</i>		0.5		0.2			0.0	
	<i>*Salsola iberica</i>				0.0	0.1	0.6	0.2	
	<i>*Sisymbrium altissimum</i>				0.0		0.1	0.03	
	<i>Sphaeralcea munroana</i>	0.5			0.2			0.0	
	<i>Thelypodium lacinatedum</i>				0.0	0.1	0.7	0.3	
	<i>*Tragopogon dubius</i>	0.1		0.1	0.1			0.0	
Total forb coverage		11.7	17.7	71.0	33.5	3.8	5.1	3.6	4.2
Total canopy coverage		51	44	100	65	59	16	17	31
Number of species in 0.5 m ² quadrats		22	18	12	17	10	13	16	13
Number of species in each plot		29	21	24	25	21	29	29	26

* Non-native species

Table 5. Average plant height, canopy spread, canopy spread at 90°, number of inflorescences, leaf length, leaf width, and the ratio of leaf length to leaf width of individuals in *L. douglasii* and *L. tuplashensis* populations in south central Washington 1998

	<i>L. douglasii</i>				<i>L. tuplashensis</i>			
	1	2	3	$\bar{X}\pm\text{SE}$	1	2	3	$\bar{X}\pm\text{SE}$
Height (cm)	13	16	10	13±0.7	13	11	14	13±0.6
Canopy spread (cm)	12	20	14	15±1.3	20	12	21	18±1.1
Canopy spread at 90° (cm)	8	14	8	10±1.1	16	11	17	15±1.0
#Inflorescences	6	4	5	5±0.5	33	8	24	23±3
Leaf length (cm)	2.6	3.2	2.9	2.9±0.1	3.3	2.4	2.9	2.9±0.1
Leaf width (cm)	0.7	0.8	0.8	0.8±0.0	1.5	1.0	1.2	1.2±0.0
Leaf length/leaf width	3.7	4.0	3.6	3.7±0.1	2.2	2.4	2.4	2.4±0.1

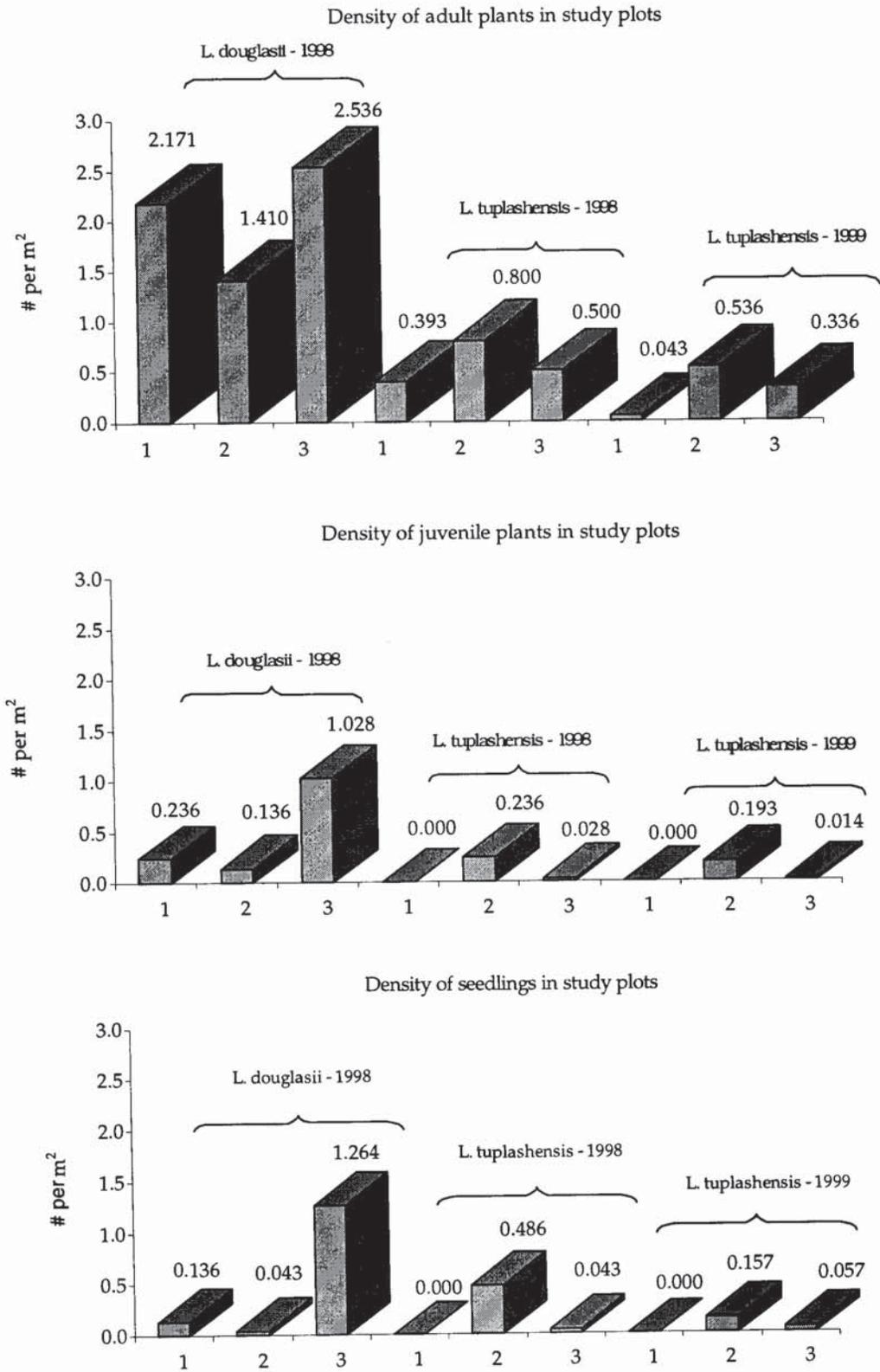


Figure 11. Density (#/m²) of seedlings, juvenile, and adult plants in *Lesquerella* study plots.

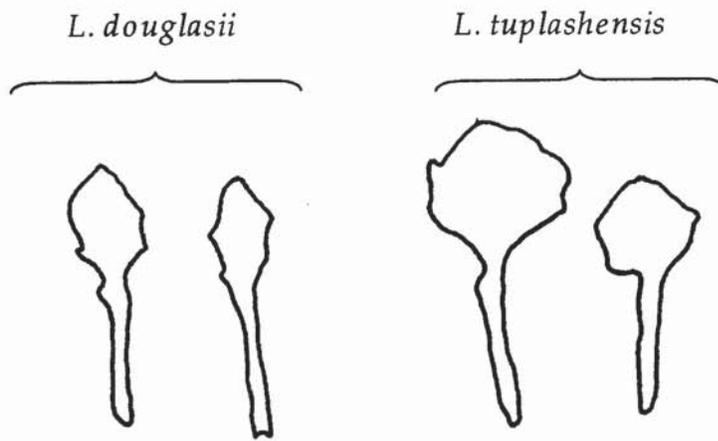


Figure 12. Outlines of leaves of *L. douglasii* and *L. tuplashensis* showing typical sizes and shapes.

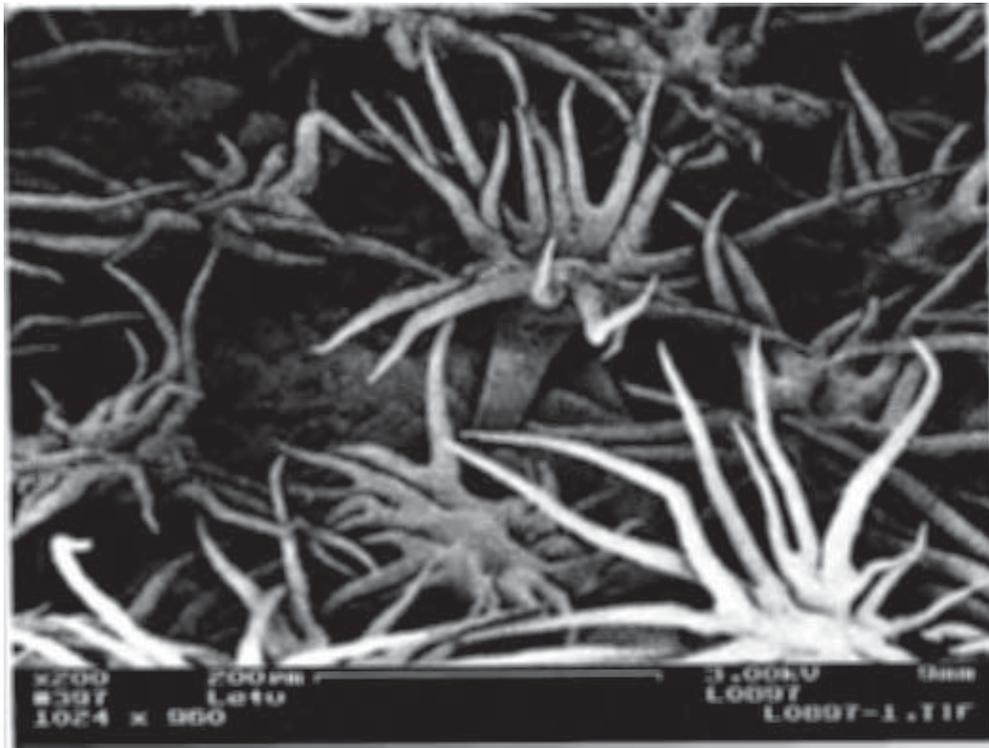


Figure 13. Scanning electron micrographs of stipitate trichomes on siliques of *L. tuplashensis* (top) and *L. douglasii*.

Table 6. Comparison of soil chemistry values between *Lesquerella douglasii* and *L. tuplashensis* habitat

	<i>L. douglasii</i>				<i>L. tuplashensis</i>			
	1	2	3	$\bar{X} \pm SE$	1	2	3	$\bar{X} \pm SE$
NO ₃ (ppm)	4.0	3.0	9.0	5.3 ± 1.9	5.0	2.0	3.0	3.3 ± 0.9
NO ₄ (ppm)	1.6	2.6	4.0	2.7 ± 0.7	3.7	0.9	1.9	2.2 ± 0.8
K (ppm)	350	160	260	260 ± 55	530	110	210	290 ± 127
Ca (meq/ 100g)	26.5	6.5	7.5	13.5 ± 6.5	39.5	19.9	27.5	29.0 ± 5.7
pH	7.7	7.3	7.1	7.4 ± 0.2	7.7	7.9	7.9	7.8 ± 0.1
Soluble salts	0.50	0.40	0.50	0.50 ± 0.0	0.90	0.30	0.50	0.60 ± 0.3
(mhos/ cm)								
%Organic matter	1.2	0.40	0.50	0.70 ± 0.2	0.70	0.30	0.70	0.60 ± 0.1

CHAPTER FOUR

SUMMARY

The purpose of this study was to address the question of rarity and the factors that affect the relative abundance of rare and common native plants. Initially, I chose to do a comparative study because I felt the comparisons would clarify the characteristics typically associated with rare plants which would lead to a better understanding of why one species was rare and another closely-related species was common. The intent of the project was to quantify community and habitat characteristics associated with both the rare and common species and establish long-term monitoring plots to track population trends over many years to determine the status of both the rare and common species. I chose to conduct my research on the Hanford Site because of the large number of rare plant populations it supports. Because it is protected, the Hanford Site is an ideal setting to conduct long-term monitoring of both rare and common plant species.

Rorippa columbiae populations occur on the shorelines of the Columbia River and in scattered patches in Washington, Oregon and northern California. Stuckey (1972) was unable to find any specimens in areas where Suksdorf had previously collected specimens in his surveys in 1890. The loss of populations was attributed to the construction of several hydroelectric dams along the mainstem of the Columbia River. In 1982, *R. columbiae* was listed as Endangered in Washington state by the Washington Natural Heritage Program (1994) and as a candidate for federal listing under the

Endangered Species Act (Federal Register 1982). *Rorippa columbiae* is currently listed as Threatened by the Washington Natural Heritage Program (1997). Originally, I planned to compare *R. columbiae* to the only other perennial *Rorippa* known in this area, *R. sinuata*, a fairly common species similar in appearance that typically occurs in wet lowlands in Washington, Oregon, east to Illinois and south to Arizona and Texas (Hitchcock *et al.* 1994). However, I failed in my attempts to locate any local populations of *R. sinuata*. In effect, the common species is more rare than the rare one, at least in south central Washington. Focusing efforts solely on *R. columbiae*, my hypothesis was that the fluctuating water levels and continuous inundation on the Hanford Reach of the Columbia River (where the largest known populations occur) was reducing their growth and flower production.

Due to operation of a series of hydroelectric dams on the Columbia River after 1938, water levels fluctuate daily in response to electrical power demands rather than to natural seasonal flow patterns. I found that the number of stems counted in a field population was inversely correlated with the average annual flow rate of the Columbia River. When river flows remained high, the number of stems was low. A one-year lag in the effect of flows shows a strong inverse correlation in the relationship. The lag effect is due to the fact that high flows in the previous year or season result in even further reduction in the number of stems. In addition to monitoring a field population, an experiment was conducted to determine the effects of water levels on growth and flower production of Columbia yellowcress plants. Results of the experimental

manipulations paralleled observed effects of water level fluctuations in the field. Water inundation resulted in reduced growth and failure of the plants to flower.

In the second comparative study between a rare endemic plant, *Lesquerella tuplashensis*, and a closely-related common species, *L. douglasii*, questions concerning the separation of the two species based on floral morphological characteristics alone became apparent as my study progressed. The monograph of *L. tuplashensis* by Rollins *et al.* (1995) describes morphological characteristics, specifically stipitate trichomes on siliques and imbricated cauline leaves, to separate *L. tuplashensis* from *L. douglasii*. I did not find differences in the trichomes or cauline leaves in individuals collected from populations of *L. douglasii* and from populations reported to be *L. tuplashensis* by Rollins *et al.* (1995) were detected. Time of flowering did not differ between the two populations. Differences in rooting substrates, topographic position, and associated plant species, however, do exist and could account for the phenotypic differences that have been observed. On the basis of the results of my study, I concluded that *L. tuplashensis* is not a separate species, but an ecotype of *L. douglasii*.

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