On sites examined in the present study, there were usually fewer than 10 *Lepidium* plants. Many seedlings germinated on *Lepidium*-sites, as observed in 1992, but few survived the drying conditions of the following weeks in spring. Poor seedling emergence, therefore does not necessarily account for the low plant numbers observed, but seedling survival on slick spots might be predicated by successful taproot extension into the argillic horizon. The thin crusts dry out well before *Lepidium* plants mature, so to survive, plants must extract moisture from the deeper saline, sodic, natric zone. The few mature plants that were excavated had taproots to at least 20 cm below the soil surface or, on average, more that 15 cm below the upper boundary of the argillic and below the distinctively columnar argillic horizon. It seems likely that physical resistance of the crust soils and, or resistance at the interface of the surface crust and the argillic horizon stopped the taproots of a majority of *Lepidium* seedlings from growing to necessary depths. Critical survival characteristics of *Lepidium* on slick spots appear to be related to its taprooted morphology, its early germination and root elongation before the soil crusts dry out, and a tolerance of high osmotic pressures of available water in the saline, sodic argillic horizons.

There is little known about the water relationships of shrub interspaces and particularly slick spot types. Questions of water redistribution within, and evaporation from, similar soils will be addressed in a field study to be conducted in 1996 (Dr. Mark Seyfried, pers. comm.). The results will provide insights about the water availability to plants growing on and adjacent to these shrub interspaces and perhaps shed some light on why *Lepidium* is typically absent from shrub interspaces.

This study does not support the conclusion (Meyer and Quinney, 1993) that a particular tolerance for flooded-soil conditions allows *Lepidium* to grow on slick spot sites. Plant growth in saturated soils is reduced by the decreased availability of oxygen in the soil and by chemical toxicities produced under anaerobic conditions. The slick spot profiles do not indicate that anaerobic conditions occur during temporary ponding events. There is no gleying or high chroma mottling in the *Lepidium*-site profiles, although chemically reducing soil conditions might be expected if the soils were persistently saturated during the warm summer months (Howeler and Bouldin, 1971; Fisher and Stone, 1991). Apparently, summer ponding as a result of thunder showers is so transitory that it does not lead to anaerobic soil conditions.

Between January and March, 1992, the surface soil on slick spots and shrub interspaces (0 - 15 cm depth) was persistently wet. Precipitation on frozen soils and low permeability of the wet upper argillic horizon probably contributed to the high surface water contents. Although high soil moisture content limits oxygen availability, the oxygen consumption by plants and soil microbes was probably minimal at the low soil temperatures encountered (Hook, 1984). Once the soils thawed, high soil moisture contents did not persist and should be uncommon given the aridic moisture regime (Soil Survey Staff, 1992). Through the late winter season, surface soils on both site types dried at similar rates. *Lepidium* germinated in the unsaturated soil crusts and rosettes of biennial plants broke dormancy after the thaw when soil crusts were drying. Increasing soil salinity levels in the drying soils interfered with the method used for measuring soil water contents (time domain refractometry, TDR) and comparative results between site types are not available after significant drying had occurred on slick spot soils.

Earlier efforts to characterize slick spot soils (Sandoval and others, 1959; Lewis and White, 1964) were inspired by the low water permeability and poor growth observed on cultivated slick spot soils. The Chilcott-Sebree soil association was the focus of these studies and is significant here because it is mapped on the Tenmile Ridge near one *Lepidium* population included in this study (Collette, 1980). These studies found that slick spot soils are most highly correlated with high exchangeable sodium throughout the profile, montmorillonitic-type clays (expanding clay types) in upper horizons of the soil profile, and high amorphous silicates that probably contribute to lower water permeability of the slick spots.

An early radiotracer study of water movement in and around Sebree-soil sites (Lewis et al., 1959) demonstrated the slow permeability of slick spot soils and indirectly showed that subsurface water movement must move laterally from the slick spot edges to the slick spot subsoil. By such a pathway, salts from surrounding soil might have been concentrated in the slick spot subsoils. Salts also moved upwards from the subsoil, suggesting that a similar process might be maintaining the high salt conditions near the surface of *Lepidium* slick spots. Lateral and vertical movement of soil solution was not restricted on the associated non-slick spot soils (Chilcott series), thus accounting for the lack of salt accumulation layers in these profile.

Correlation of *Lepidium* Sites, Landscapes and Mapped Soils

With rare exceptions (disjunct populations in Owyhee and Bannock counties, Moseley, 1994), *Lepidium* populations are distributed on a band of low-elevation alluvial landforms and basalt plains that flank the northern and eastern shore of the lower Snake River (Figure 1). The geomorphic mapping units described were derived from general soil mapping units in the State Soil Geographic Data Base (Soil Conservation Service, 1991) for Idaho and the locations of the extant, historic and extirpated *Lepidium* populations were from another geographic data base (Conservation Data Center, 1995). According to this view, *Lepidium* occurs on four broad geomorphic areas. The most extensive and numerous populations occur on a large unit of basalt ridges and plains in the middle and southern end of the species range. A few populations occur on a lobe of dissected piedmont, adjacent to the basalt plains but formed from igneous mountains rising to the north of the lower Snake River plain. Other than the extensive population on Tenmile Ridge, the occurrences of *Lepidium* on the two remaining alluvial geomorphic units are relatively small populations. These units include (1) alluvial lake and river terraces and Bonneville flood deposits, and (2) higher alluvial deposits in the foothills.

Within these broad geomorphic areas, the actual *Lepidium* habitat is very limited and confined to small inclusions of natric-like soils within the extensive matrix of non-natric soils. Despite the very particular characteristic of *Lepidium*-slick spot sites, however, some general soil factors can describe the general soil matrix in which the species grows. *Lepidium* populations occur on regions of an aridic soil moisture regime. These soils are dry for most of the time that temperatures are suitable for plant growth. At the highest level of the Soil Taxonomy system, such soils are classified into the soil order of Aridisols. Furthermore, the *Lepidium* populations almost exclusively occur on landscapes of Aridisols that border with a xeric moisture regime (Soil Survey Staff, 1992). Xeric soils receive a greater proportion of moisture in the cool winter when potential evaporation is at a minimum and leaching potential is greatest. The implication for slick spots is that there is sufficient moisture to leach salts where soils are more permeable (shrub interspaces and shrub dune coppices), but not so much moisture to remove salts from the less permeable slick spot soils.

Elsewhere throughout the arid and semi-arid west, small natric slick spots are found on remnant Pleistocene surfaces, e.g., alluvial fans and steep hillslopes, within soil matrices of two Aridisol great groups, the Haplargids and the Durargids (Nettleton and Peterson, 1983). These belong to the suborder of Argids, which are Aridisols with diagnostic horizons of clay accumulation (argillic horizons). Haplargids are typical Argids that lack additional profile features and Durargids are Argids underlain by a silica subsurface horizon (duripan). The argillic horizons and duripans of these soils are thought to be relicts of soil formation processes during a wetter Pleistocene climate.

Recent (Holocene) additions of eolian salts, often by loess deposition, produced the natric character of soils now found on these same landscapes (Nettleton and Peterson, 1983). A drying climate, gradual shallow leaching of salts, directed subsurface or surface movement of soil solutions, sodium-induced changes in clay chemistry and structure, and surface soil erosion, contributed to the formation of natric soil inclusions. On the semi-arid Carrizo Plain of California, a very recent expansion of slick spots within the past 300 years is related to surface erosion and eolian salt deposition (Reid et al., 1993). Under the current climatic regime, the slick spot formation is not expected to be reversible.

The landforms on which *Lepidium papilliferum* are found are also remnant Pleistocene surfaces typical of the Great Basin landforms described. Accordingly, the most common soil great groups on *Lepidium*-habitat landscapes in Elmore and Ada Counties are Haplargids and Durargids (Appendix C). Nadurargids, which in addition to a duripan have a natric horizon, and Paleargids, which have particularly strongly developed clay and calcium carbonate accumulations, are also extensive on these older landscapes. Camborthids dominate the dissected terraces and plains associated with the Snake River where there are a few smaller *Lepidium* populations. The Aridisol suborder of Orthids lack the diagnostic argillic horizon of the Argids.

Typically, slick spots are too small to be delineated on Soil Survey maps. The natric soil areas are rarely large enough, common enough, or of significant importance to the associated land uses (e.g. irrigated cropland) to be mapped. The Chilcott-Sebree soil association, however, is one exception where a natric soil (Sebree) is recognized in association with a non-natric series (Collette, 1980). Appendix D lists several other soil series found within the range of *Lepidium* populations that occur in near proximity to natric soil types or are mapped natric soils. Searches for new *Lepidium* populations or potential habitat might best focus inventories on those remnant Pleistocene land surfaces where the listed series are mapped. The Ada County soil survey (Collette, 1980) does not identify any inclusion of natric soils on the lacustrine foothills (Appendices A and C), however. This may well be an omission of information and not a true indication that natric soils are absent. At least two soil series, Lankbush (a Haplargid) and Payette (an Argixeroll, similar to the Haplargid), are similar to other non-natric soils that occur with slick spot inclusions or natric-soil neighbors.

A question remaining to be answered is whether slick spots, not bearing *Lepidium*, provide the same or similar edaphic environments as the *Lepidium*-slick spots. If they do, then there is considerable available habitat for *Lepidium* that is not being used. This study suggests that there is a very strong correlation between slick spot features (panlike often gravelly surface, lack of shrubs, perennial grasses and forbs, a microbiotic crust, a very thin vesicular crust, and a shallow, dense argillic horizon) and saline and natric soil chemistry. Other accounts suggest the same relationship (Sandoval and others, 1959; Lewis and White, 1964), bringing up the perplexing question of why *Lepidium* is not growing on a greater proportion of slick spot sites, even within habitat where the plant is present.

Conclusions

Lepidium papilliferum grows on natric soil microsites, called slick spots, that occur on remnant Pleistocene surfaces within its main geographical range on the western Snake River Plain of

Idaho. These surfaces are on alluvial landforms associated with historic lakeshores and river terraces, stable piedmont and associated alluvial fans, basalt plains, and on historically dissected alluvial deposits. The habitat does not occur on active or recent (holocene) floodplains or alluvial fans, or on recently eroded slopes, and it does not occur above the lowest slopes of the foothills.

Lepidium microsites are small natric-soil inclusions that occur within a matrix of non-natric soils. Distinctive visual cues distinguish the *Lepidium*-sites from surrounding shrub interspaces. Very similar surface features also describe a large category of sites in the range of *Lepidium* on which the species is not growing. This suggests that there is considerable unused habitat for the species within its geographic range.

The restriction of *Lepidium papilliferum* to slick spot microsites and the absence of all perennial plant species from those sites, suggests that soil edaphic factors determine this species' distribution on the landscape. Distinctive features of the microsites are very thin vesicular crusts, a natric horizon just below the soil surface, and increasingly saline and sodic conditions with depth. Its taprooted morphology, early germination, root elongation into the argillic horizon before soil crusts dry out, and an apparent tolerance of high osmotic pressures of available water in the saline, sodic subsurface horizons, enable *Lepidium* to grow on the crusted slick spot soils.

Soils that occur on *Lepidium* habitat belong to the soil taxonomic suborder of Argids which includes soils with an aridic moisture regime (order Aridisol) and a diagnostic argillic horizon. Nearly all *Lepidium* habitat borders with the xerollic moisture regime. Typical Argids (great group Haplargid) and Argids underlain by a duripan (great group Durargid) are the predominant soil great groups found on older Great Basin landscapes where small natric slick spots are found. This is also true for *Lepidium* habitat. Holocene loess deposits on the western Snake River Plain probably account for the salt inputs needed for the formation of natric soils.

Several soil series found on *Lepidium* habitat were identified as either being natric or occurring near to natric soil series. Inventories to identify potential *Lepidium* habitat might focus on landscapes where these particular soil series have been mapped in current soil surveys.

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