Developing biogeographically based population introduction protocols for at-risk plant species of the interior valleys of southwestern Oregon:

Fritillaria gentneri (Gentner's fritillary)
Limnanthes floccosa ssp. *bellingeriana* (Bellinger's meadowfoam)
Limnanthes floccosa ssp. *grandiflora* (big-flowered wooly meadowfoam)
Limnanthes floccosa ssp. *pumila* (dwarf wooly meadowfoam)
Limnanthes gracilis var. *gracilis* (slender meadowfoam)
Lomatium cookii (Cook's desert parsley)
Perideridia erythrorhiza (red-rooted yampah)
Plagiobothrys hirtus (rough popcorn flower)
Ranunculus austro-oreganus (southern Oregon buttercup)

Prepared by Rebecca Currin, Kelly Amsberry, and Robert J. Meinke
Native Plant Conservation Program, Oregon Department of Agriculture
for
U.S. Fish and Wildlife Service (Grant OR-EP-2, segment 14)

Acknowledgements:

We would like to thank the many people who contributed to the completion of this report. Thanks to Andy Robinson and Kathy Pendergrass (USFWS) for providing funding and encouragement (Grant no. OR-EP-2, segment 14). R.J. Meinke contributed to text completion and review, and Melissa Carr provided invaluable assistance in compiling data. Thanks also to the staff, interns and students who provided plant and habitat photos.

Contact Information:

Robert J. Meinke
Native Plant Conservation Program
Oregon Department of Agriculture
Dept. of Botany and Plant Pathology
Oregon State University
Corvallis, OR 97331
(541) 737-2317
meinker@science.oregonstate.edu

Kelly Amsberry
Native Plant Conservation Program
Oregon Department of Agriculture
Dept. of Botany and Plant Pathology
Oregon State University
Corvallis, OR 97331
(541) 737-4333
amsberrk@science.oregonstate.edu

Report format:

The following species are presented in alphabetical order: *Fritillaria gentneri* (Gentner's fritillary), *Limnanthes floccosa* ssp. *bellingeriana* (Bellinger's meadowfoam), *Limnanthes floccosa* ssp. *grandiflora* (big-flowered wooly meadowfoam), *Limnanthes floccosa* ssp. *pumila* (dwarf wooly meadowfoam), *Limnanthes gracilis* var. *gracilis* (slender meadowfoam), *Lomatium cookii* (Cook's desert parsley), *Perideridia erythrorhiza* (red-rooted yampah), *Plagiobothrys hirtus* (rough popcorn flower), and *Ranunculus austro-oreganus* (southern Oregon buttercup). Each species' section consists of segments covering Conservation Status, Range and Habitat, Species Description, Seed Production, Seed Germination, Vegetative Reproduction, Breeding System, Hybridization, Cultivation, Transplanting and Introduction Attempts, Population Monitoring, and Land Use Threats and other Limitations, followed by a final segment outlining a specific Population Introduction/Augmentation Strategy.

Literature citation:

Currin, R.E., K. Amsberry, and R.J. Meinke. 2004. Developing biogeographically based population introduction protocols for at-risk plant species of the interior valleys of southwestern Oregon. Report to US Fish and Wildlife Service, Portland, Oregon. Native Plant Conservation Program, Oregon Department of Agriculture, Salem, Oregon.

Developing biogeographically based population introduction protocols for at-risk plant species of the interior valleys of southwestern Oregon:

Southern Oregon Meadowfoams *(Limnanthes* spp.)

Limnanthes floccosa ssp. *pumila*. Photo by D. Detling – used with permission.

Four rare *Limnanthes* (meadowfoam) species:

***Limnanthes floccosa* ssp. *bellingeriana* (Bellinger's meadowfoam)**

***Limnanthes floccosa* ssp. *grandiflora* (big-flowered wooly meadowfoam)**

***Limnanthes floccosa* ssp. *pumila* (dwarf wooly meadowfoam)**

***Limnanthes gracilis* var. *gracilis* (slender meadowfoam)**

Conservation status

Limnanthes floccosa Howell, a member of the Limnanthaceae family, is a highly polymorphic vernal pool annual occurring throughout south-central Oregon and northeastern California (Arroyo 1973). Oregon is home to three rare subspecies of *Limnanthes*, as well as the endemic *Limnanthes gracilis* Howell var. *gracilis*. *Limnanthes floccosa* Howell ssp. *bellingeriana* (Peck) Arroyo (Figure 5) is found in Jackson and Klamath Counties, as well as in California. It is on Oregon Natural Heritage Information Center's (ORNHIC's) List 1, with a Natural Heritage Network Rank of G4T2/S2, indicating that this subspecies is considered imperiled throughout its range. *Limnanthes floccosa* ssp. *bellingeriana* is a federally listed Species of Concern, as well as being included in Oregon's Department of Agriculture's Candidate list. *Limnanthes floccosa* Howell ssp. *grandiflora* Arroyo (Figure 6) occurs only in Jackson County, Oregon, and is an ORNHIC List 1 species with a G4T1/S1ranking (critically imperiled throughout its range/critically

Figure 5. *Limnanthes floccosa* ssp. *bellingeriana*. Photo courtesy of CalPhotos. (http://elib.cs.berkeley.edu/cgi-bin/img_query?special=calflora&where-taxon=Limnanthes+floccosa+ssp.+bellingeriana&where-anno=1)

Figure 6. *Limnanthes floccosa* ssp. *grandiflora*. ©Mark Turner, reprinted with permission. (http://www.turnerphotographics.com)

Figure 7. *Limnanthes floccosa* ssp. *alba*, commercially grown for its seed oil. (Courtesy of http://flash.lakeheadu.ca/~whparker/bill01.jpg.)

imperiled in Oregon). It is listed as Endangered both at the federal and state level. *Limnanthes floccosa* Howell ssp. *pumila* (Howell) Arroyo is also endemic to Jackson County, and is considered critically imperiled throughout its range (G4T1/S1 ORNHIC ranking). *Limnanthes floccosa* ssp. *pumila* is listed also as a Species of Concern by the US Fish and Wildlife Service, and as Threatened in Oregon. Finally, ORNHIC considers *Limnanthes gracilis* Howell var. *gracilis*, which is found in Jackson, Douglas and Josephine Counties in Oregon, to be imperiled throughout its range (G3T2/S2). *Limnanthes gracilis* var. *gracilis* is not listed federally, although it is a candidate for listing in Oregon (ORNHIC 2004).

All members of the genus *Limnanthes* (meadowfoam) (Figure 7) are of particular interest to the general public due to the usefulness of the oil produced from their seeds. Unlike common seed oils, meadowfoam oil consists almost entirely of long-chain fatty acids, making it one of the most stable vegetable oils known to scientists. Research on meadowfoam seed oil began in the late 1950s, and today it has commercial potential as raw material for many products, including lubricants, cosmetics, waxes and polymers. Meadowfoam oil may provide one of the most feasible environmentally friendly replacements for whale oil (Oelke et al. 1990, Ehrensing et al. 1997).

As with many rare and endangered plants, the loss and deterioration of habitat poses the largest threat to these *Limnanthes* species' survival. *Limnanthes floccosa* subspecies are vernal pool inhabitants, specially adapted to take advantage of the seasonal availability of water. Unfortunately, much of their original habitat has been permanently altered by agricultural, residential, commercial and industrial development. At this time, there are only 20 populations of *Limnanthes floccosa* spp. *grandiflora* (9 of which have not been observed in over 20 years), 39 Oregon populations of *Limnanthes floccosa* ssp. *bellingeriana*, 3 populations of *Limnanthes floccosa* spp. *pumila* and 76 populations of *Limnanthes gracilis* var. *gracilis* (over 20% of which have not been seen for over 20 years) (ORNHIC 2004b).

Range and habitat

Limnanthes species are spring-flowering annuals which reside in seasonal wetlands along the Pacific Coast of North America (Mason 1952). *Limnanthes* tend to grow in colonies in moist habitats such as vernal pools, or along ephemeral streams and wet meadows (McNeill and Jain 1983); however, there is some variation in the microhabitat of the four taxa discussed in this chapter.

Limnanthes floccosa* ssp. *grandiflora: *Limnanthes floccosa* ssp. *grandiflora* occurs at the edge of vernal pools at elevations of about 375-400 m, primarily in the Agate Desert region north of Medford Oregon in Jackson County (Figure 8). Although the historic range of this plant may have encompassed over 130 km^2, the current range is much

Figure 8. Agate Desert vernal pool habitat. © Mark Turner, reprinted with permission. (http://www.turnerphotographics.com)

smaller. The Agate Desert is characterized by shallow, Agate-Winlow complex soils, a relative lack of trees, sparse prairie vegetation and mound-swale topography. The rocky or clay soils have an underlying impervious layer, which traps water during the rains,

creating the vernal pools. These pools vary from 1 to 30 meters across, with a maximum depth of about 30 cm (USFWS 2002a). This subspecies may generally be found near the wetter, inner edges of the pools, as opposed to the drier outer fringes which harbor the sympatric subspecies *floccosa* (Meinke 1982). Associated species include *Baeria chrysostoma, Deschampsia danthonioides*, *Draba verna*, *Hordeum murinum*, *Juncus uncialis*, *Lomatium cookii*, *Lupinus micranthus*, *Myosurus minimum*, *Navarettia leucocephala*, *Plagiobothrys nothofulvus*, *P. bracteatus*, *Taeniatherum caput-medusae*, and *Trifolium depauperatum* (Meinke 1982, ORNHIC 2004b).

Two of the *Limnanthes floccosa* ssp. *grandiflora* sites occur entirely or partially within the Agate Desert Preserve, owned by The Nature Conservancy (TNC). An additional two sites reside on State land, primarily in the Ken Denman Wildlife Area. Portions of three sites are on lands owned by the City of Medford, within an area designated as the Whetstone Industrial Park. Portions of two sites are located in highway or powerline rights-of-way. The remaining sites occur on private land (ORNHIC 2004b) (Figure 9).

Limnanthes floccosa ssp. bellingeriana: There are 39 occurrences of *Limnanthes floccosa* ssp. *bellingeriana* listed in the Oregon Natural Heritage Information Center database (ORNHIC 2004b), but the Center for Plant Conservation only cites 14 known populations of this subspecies in Oregon (CPC 2004) (Figure 10). There are 5 populations of *L. floccosa* ssp. *bellingeriana* in California, in Shasta County, but these populations are not recognized as distinct from *L. floccosa* ssp. *flosccosa* in California (Hickman 1993). Population sizes range from 15 – 10,000 individuals, but many of the populations have less than 200 individuals (ORNHIC 2004b). *Limnanthes floccosa* ssp. *bellingeriana* is found at a higher elevation than some of the other subspecies; elevations in Oregon range from 1100-1200 m (3600-3900 feet). California populations of the subspecies are found at lower altitudes, however, with elevations ranging from 290-1100 m (950-3600 feet) (CPC 2004). This *Limnanthes* subspecies grows in these high elevation vernal pools located in shallow soiled rocky meadows in spots that are at least partially shaded in the spring. Associated species include *Bromus mollis*, *Ceanothus cuneatus*, *Danthonia californica*, *Eleocharis paulstris*, *Erodium cicutarium*, *Juncus*

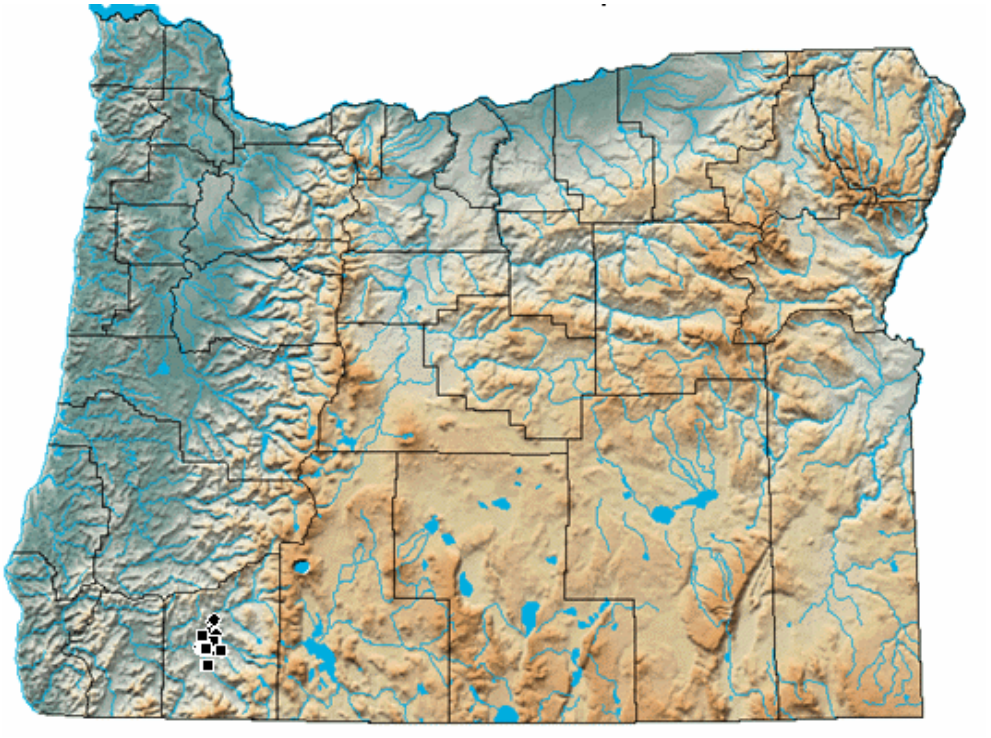

Figure 9. Distribution of *L. floccosa* ssp. *grandiflora*. Map courtesy of Oregon Flora Project.

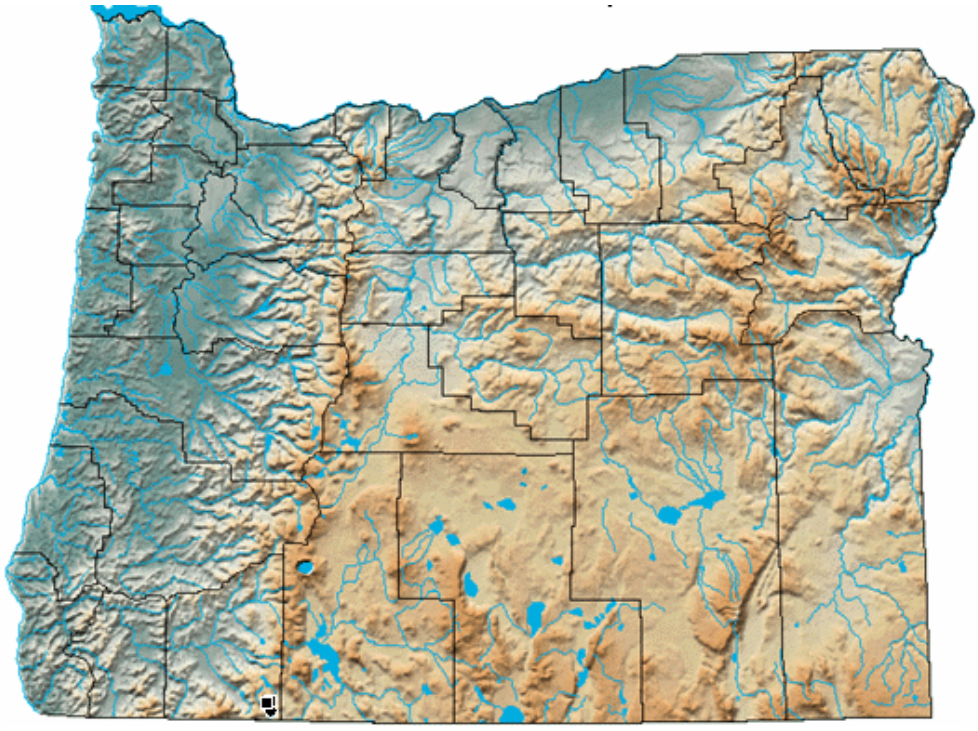

Figure 10. Distribution of *L. floccosa* ssp. *bellingeriana*. Map courtesy of Oregon Flora Project.

ensifolius, *Juncus tenuis*, *Mimulus guttatus*, *Montia linearis*, *Navarretia intertexta*, *Poa bulbosa*, *Polygonum polygaloides*, *Plagiobothrys* sp. *Pinus ponderosa, Ranunculus occidentalis* (Meinke 1982, ORNHIC 2004b).

Limnanthes floccosa* ssp. *pumila: *Limnanthes floccosa* ssp. *pumila* is known in only two ancient basalt lava flows forming Upper and Lower Table Rocks, respectively, in Jackson County (Figures 11, 12). This area is designated as the Table Rocks Area of Critical Environmental Concern, and managed by the Bureau of Land Management's Medford District. *Limnanthes floccosa* ssp. *grandiflora* and *L. floccosa* ssp. *floccosa* occur immediately below the rock formations, but *L. floccosa* ssp. *pumila* has never been found at lower elevations (below 600 m) (Arroyo 1973). *L. floccosa* ssp. *pumila* grows along the edges of deep vernal pools. Although there are only three known populations of this subspecies, each one numbers in the thousands, and appears to be vigorous (ORNHIC 2004b). Species associated with this habitat include *Alopecuris geniculatus*, *Ceanothus cuneatus, Deschampsia danthoniodes*, *Lupinus bicolor*, *Mimulus guttatus*, *Nemophila pedunculata*, *Plagiobothrys cognatus*, *P. figuratus*, *Plectritus congesta*, *Poa bulbosa*, *Quercus garryana*, *Saxifraga californica* and *Vulpia myuros* (ORNHIC 2004b).

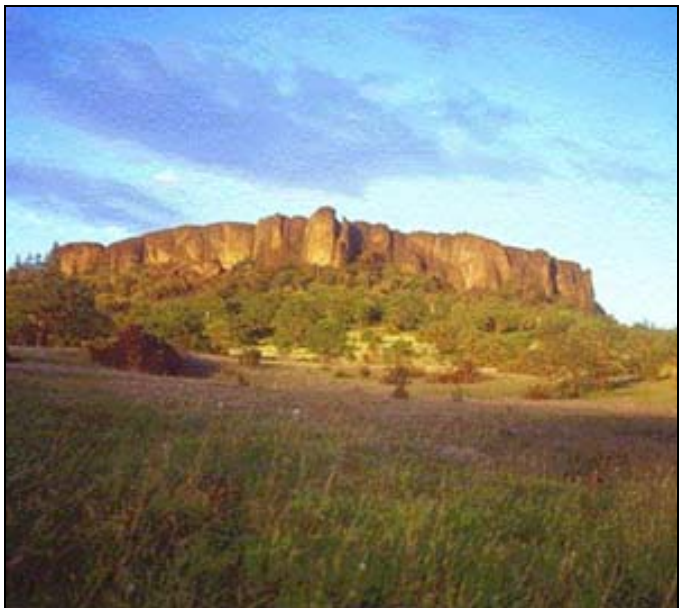

Figure 11. Table Rock. *Limnanthes floccosa* ssp. *pumila* is found on the top of this unique rock formation. Photo courtesy of the Medford District BLM website. (http://www.or.blm.gov/medford/images/table/intro_4.jpg)

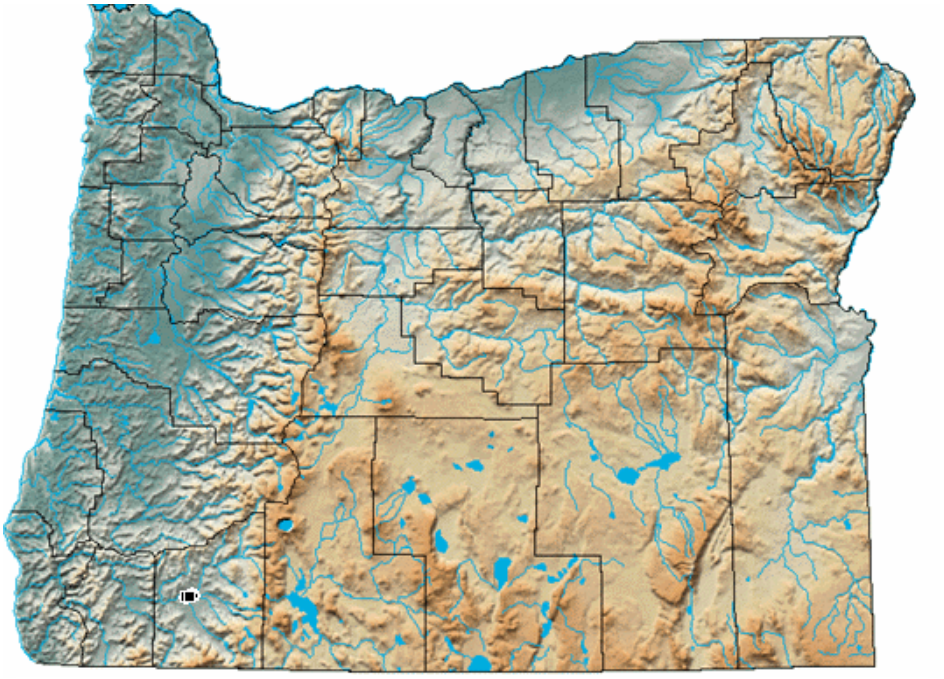

Figure 12. Distribution of *Limnanthes floccosa* ssp. *pumila*. Map courtesy of the Oregon Flora Project.

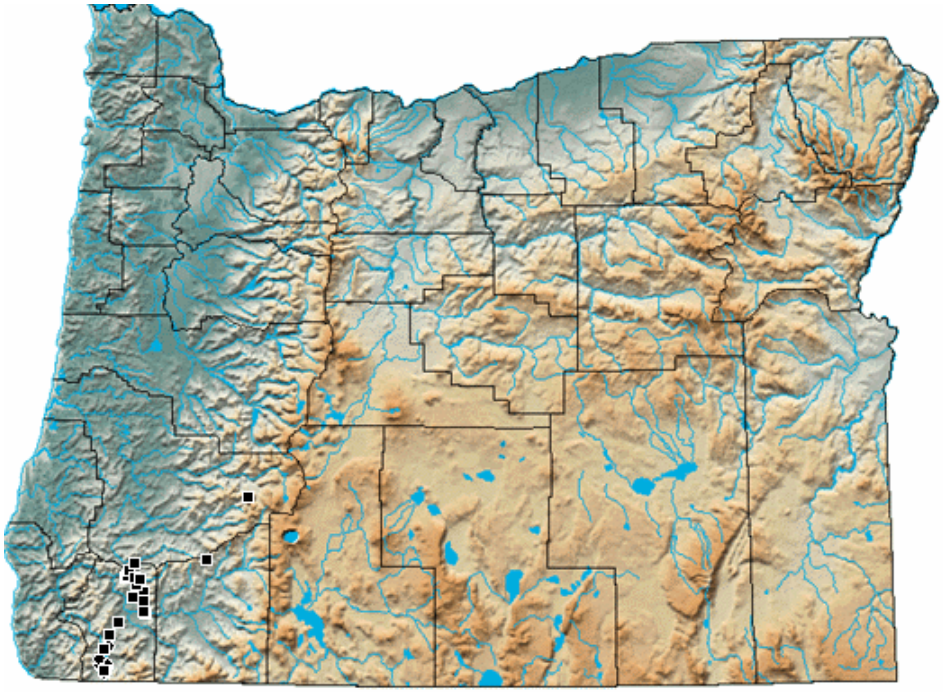

Figure 13. Distribution of *Limanthes gracilis* var. *gracilis*. Map courtesy of the Oregon Flora Project.

Limnanthes gracilis* var. *gracilis: This variety is restricted primarily to the Rogue River Valley of Josephine and Jackson counties, with some collections made in Douglas County (Meinke 1982). The Oregon Natural Heritage Information Center lists 78 occurences of *Limnanthes gracilis* var. *gracilis*. Forty-four of these are on Bureau of Land Management land, in either the Medford District (43) or the Roseburg District (1). One of the populations is located in the Siskiyou National Forest, and 3 sites are on Oregon Department of Transportation land, with the rest of the populations occurring on private land (Figure 13). *Limnanthes gracilis* var. *gracilis* prefers rocky slopes or basins on several different types of substrates, the most common being serpentine soil. As with other *Limnanthes*, the habitat tends to be moist to wet in the early spring. This plant's elevation range is quite wide, with populations reported anywhere from 150-1700 meters, although most sites are found at elevations of 300-600 meters. Associated species include *Achillea millefolium, Bromus hordeaces, Bromus tectorum, Calochortus tolmiei, Calochortus uniflorus, Camassia quamash, Ceanothus cuneatus, Dichelostemma capitata, Galium aparine, Lomatium utriculata, Mimulus guttatus, Pinus jeffreyi, Plectritis congesta, Poa secunda, Psuedotsuga menziesii, Ranunculus occidentalis, Saxifraga nuttallii* and *Trifolium tridentata* (ORNHIC 2004b).

Description of species

Although all *Limnanthes* taxa are small, white-flowered annuals, species and subspecies are distinguishable by size and shape of leaves, petals and other floral parts, sepal and petal pubescences, and nutlet morphology (McNeill and Jain 1983). For example, *Limnanthes floccosa* can be distinguished from other *Limnanthes* by the woolly calyx pubescence (Meinke 1982).

Limnanthes floccosa ssp. *grandiflora* is a small annual which grow only 5-15 cm tall, usually with a branched base. The leaves are relatively long (4 cm) and slender, and divided into 5-9 segments, with the lower segments subdivided into three segments. Flowers have five white to yellowish petals which are 7.5-9 mm in length. *Limnanthes floccosa* ssp. *grandiflora* can be distinguished from other similar species by the two rows

of hairs on the claws of the petals and the sparse pubescence of the stems and leaves (Arroyo 1973).

Limnanthes floccosa ssp. *bellingeriana* is less showy, growing 8-15 cm high with small, self-pollinating white flowers which often do not open completely (CPC 2004). Its leaves are pinnately divided into 5-7 segments, with the entire leaf 2-5 cm long. The calyx lobes are sparsely pilose to glabrous, and filaments are 2-3 cm long (Peck 1961). *Limnanthes floccosa* ssp. *bellingeriana* may be distinguished from other *Limnanthes* in the area by the combination of glabrous herbage and flowers and basally united styles (Meinke 1982). Although *Limnanthes floccosa* ssp. *bellingeriana* and *Limnanthes floccosa* ssp. *floccosa* are able to cross and produce fertile offspring, differences in pollen morphology, flower shape and wooliness, and absence of intermediates (indicating interbreeding barriers) between the two taxa suggest that they are two separate species (Southworth and Seavers 1997).

Limnanthes floccosa spp. *pumila* grows 5-10 cm tall, with simple to occassionally branching stems. Leaves are pinnately divided into 5-9 linear lanceolate divisions, with the lower segments 3-4 cm long and sometimes three lobed. Petals are 6-8 mm long, about equaling the sepals in length, oblong, obtuse, and not emarginate at the apex (Abrams 1951). This subspecies of *Limnanthes* differs from other subspecies of L. floccosa by its combination of glabrous herbage and pilose petals (Arroyo 1973).

Limnanthes gracilis var. *gracilis* flowers and herbage are also fairly glabrous throughout, but the overall stature of the plant is larger than that of the other three *Limnanthes* discussed above. Its slender stems can grow from 7-30 cm tall, and its pinnately compound leaves, divided into 5-9 segments, are 3-8 cm long. The leaflets may be either entire or three lobed. Flower petals are 8-14 mm long and white (although they may turn pink or lilac in age), with a few scattered hairs on the veins and 2 rows of hairs at the base. The stamens are 2-4 mm long, the anthers are 1 mm long and the pistil ranges from 2-4 mm long, with the style split 1/3 to 1/2 its length. The distal part of petals are not

recurving (Mason 1952). *Limnanthes gracilis* var. *gracilis* may be distinguished from other *Limnanthes* found in the area by its glabrous calyx which is subjacent to the corolla.

Seed production

Limnanthes plants are adapted to grow, flower and set seed during the short time that water is available in the spring (USFWS 2002a). Each flower is able to produce 1-5 nutlets. Arroyo (1973) found that both *Limnanthes floccosa* ssp. *grandiflora* and *L. floccosa* ssp. *pumila* produce 3-5 nutlets per flower, while *L. floccosa* ssp. *bellingeriana* produces only 1-2 (occassionally 3) nutlets per flower. The lower seed production of *L. floccosa* ssp. *bellingeriana* is not unexpected, since this subspecies is completely autogamous, while the other two subspecies are able to both self and cross pollinate. No information is available on the number of nutlets produced per flower of *Limnanthes gracilis* var. *gracilis*. However, Jahns et al. (1997) looked at the seed production of *Limnanthes alba*, and found that, depending on the number of pollinator visits, plants produced an average of 1.6-3.3 seeds per flower. *Limnanthes alba* plants have 1-10 stems, with 1-12 flowers per stem. Therefore, each plant can produce 1-120 flowers and up to 400 seeds, although typically plants will have significantly lower numbers of seeds. *Limnanthes alba* is generally a larger plant (up to 30 cm tall) than *L. floccosa* subspecies (Hickman 1993), so it is reasonable to assume that the per plant seed production of the taxa of interest would be less than that of *L. alba*.

Seed germination

Toy and Willingham (1966) conducted a germination study involving 10 species and varieties of *Limnanthes*. Although the study did not include the four rare *Limnanthes* found in Oregon, seeds of the closely related *L. floccosa* ssp. *floccosa* and *L. gracilis* var. *parishii* were germinated as part of the study. Overall, the optimum seed germination temperatures for the 10 species and varieties of *Limnanthes* ranged from 40-60° F (4.4-15.6° C), with *L. floccosa* ssp. *floccosa*'s peak germination (99.3%) occurring at 50° F (10° C) and *L. gracilis* var. *parishii*'s highest germination rates (83.7%) occurring at 40° F (4.4° C). Peak germination occurred within 4-11 days. Germination rates of seeds

placed on wet filter paper in Petri dishes and started at room temperatures (70-80° F/21-26.7° C), and subsequently moved to a chamber with lower germination temperatures were about half that of the seeds started at the lower temperatures. Seeds left at room temperatures only had a 3% germination rate.

Toy and Willingham (1967) also studied the secondary dormancy of 10 accessions of *Limnanthes* seeds by moistening them and placing them in an 80° F (26.7° C) cabinet for up to 14 days, then transferring the seeds to 40, 50 or 60° F (4.4, 10 or 15.6° C) temperatures for germination. In two accessions, 85% of the seeds became dormant after 2 days at 80° F. In six accessions, 80% of the seeds were dormant after 14 days at 80° F and little or no dormancy was induced in the remaining two accessions. After 16 months, 50% of the ungerminated seeds were dried under room conditions for 2.5 months, then moistened and placed under their optimum germination temperatures (see Toy and Willingham 1966). Up to 78% of these seeds germinated, compared with almost none of the seeds which were maintained continuously under germination conditions (no drying period). The authors speculated that *Limnanthes* seed behavior was adapted to prevent early germination (like most vernal pool plant species, *Limnanthes* seeds typically germinate in the fall, after the rains begin) in the case of an early rain storm followed by another dry period in the late summer or early fall.

Ehrensing et al. (1997) conducted seed germination tests by sowing *Limnanthes alba* seeds in outdoor research plots at Oregon State University (OSU) and found similar results; seed-zone soil temperatures needed to be less than 60° F for good germination. In this study, seedbeds were tilled, smoothed and firmed so that no large soil clods remained and maximum seed-soil contact was achieved. Seeds planted in warmer soils frequently developed secondary seed dormancy, leading to lower germination rates. Seeds planted in the first two weeks of October had the highest germination rates. Because meadowfoam seedlings are not competitive, narrow row spacings and high planting concentrations were recommended. In the study, rows were spaced 6-8 inches apart, and seeds were planted with a standard grain drill at a depth of 1/4-3/4 inches. Highest seed yields were obtained when only limited amounts of nitrogen fertilizers were

used – too much fertilizer resulted in increased weed growth. No meadowfoam response was observed after applications of phosphorus, potassium, sulfur or micronutrients; however, it is important to note that this study took place in a cultivated field environment, for the purpose of growing a crop, rather than in the plant's typical vernal pool habitat.

Finally, Cole (1974) studied the impact of light on the germination of *Limnanthes alba* seeds. The study found that optimum germination occurred at 9-13° C (48-55° F), and that light was not a requirement for germination of *L. alba* seeds. The maximum germination rate (35%) was observed at an alternating temperature of 10° C (50° F) for 16 hours and 15° C (59° F) for 8 hours in continuous dark conditions.

Vegetative reproduction

All of these *Limnathes* subspecies and varieties are annuals, and do not appear capable of vegetative reproduction. Reproduction occurs solely by seeds.

Breeding system

Limnanthes flowers in the spring, beginning in March and continuing through May, although there is variation in flowering time between subspecies and varieties. *Limnanthes floccosa* ssp. *grandiflora* blooms in April and May (Meinke 1982), and is partially autogamous (self-pollinating), although outcrossing may occur as well. This subspecies can exhibit protrandry, with the anthers often dehiscing up to a day before the stigma is receptive. *Limnanthes floccosa* ssp. *bellingeriana* also blooms in April and May, and is fully autogamous; the flowers are small and often don't open completely, making pollination less likely. *Limnanthes floccosa* ssp. *pumila* blooms earlier in spring (March – April) and is partially autogamous (Arroyo 1973). *Limnanthes gracilis* var. *gracilis* blooms from March – May (Meinke 1982); however, there is no published information available on this variety's breeding system.

No pollination studies have been done with these four rare meadowfoams. The *L. floccosa* subspecies are all at least partially autogamous, making pollinators less critical for the survival of populations of these plants. Little is known about the insect pollinators of those subspecies which are able to outcross; however, the commercially grown *L. alba* requires insect pollination, and studies show that honey bees are the primary pollinators of this species (Jahn et al. 1997).

Hybridization

Some *Limnanthes* species are able to interbreed, producing partially fertile inter-specific hybrids. Crosses producing hybrids have been successfully conducted between *L. alba* and subspecies and varieties of *L. gracilis* and *L. floccosa*. However, these crosses have been done by researchers in order to develop improved cultivars of *L. alba* to be used for commercial growth (Knapp and Crane 1999). *Limnanthes alba* does not naturally occur in Oregon, so hybridization involving this species is not possible in the wild (although there has been some concern that naturalized *L. alba* populations along roadsides could potentially impact native *Limnanthes*). There is no indication that any of Oregon's four rare meadowfoams are hybridizing with other sympatric *Limnanthes.* Even in sites where *L. floccosa* subspecies occur sympatrically, the subspecies are spatially separated by differences in microhabitat. For example, *Limnanthes floccosa* ssp. *grandiflora* and *L. floccosa* ssp. *floccosa* occur immediately below the rock formations which hold *L. floccosa* ssp. *pumila*, but the latter has never been found at lower elevations (Arroyo 1973), and *L. floccosa* ssp. *grandiflora* is found closer to the inner areas of the vernal pools, whereas *L. floccosa* ssp. *floccosa* resides at the outer edges (Meinke 1982). None of the literature reviewed mentions hybridization as a concern.

Cultivation

There has been no published research on the cultivation of any of the four rare Oregon *Limnanthes*. The commercially cultivated *Limnanthes alba* is easily grown from seed, and research has not focused on cultivating the plant for transplanting efforts. However,

projects focused on establishing new populations of rare *Limnanthes* could potentially include outplanting plugs the first year in order to ensure seed production.

Any efforts to cultivate rare *Limnanthes* should take into account the life history of the genus. *Limnanthes* is a winter annual with seeds that typically germinate in the fall after the rains begin. Plants overwinter as rosettes, then bolt and bloom in the spring. As specific information on cultivation of Limnanthes is not available, methods for cultivation of other rare vernal pool plants such as *Lomatium cookii* and *Plagiobothrys hirtus* could provide initial information to be used in developing a cultivation protocol. Germinated seeds (see "Seed germination" section above) could be planted in 4" plastic pots filled with peat/bark/potting mix, then overwintered on open unheated greenhouse benches, watered daily, and fertilized 1-2 times a month with 20-20-20 soluble fertilizer (Amsberry and Meinke 1998, Kaye et al. 2003).

Transplanting and introduction attempts

Once again, there is no documentation of any transplanting/introduction of these four *Limnanthes*; however, considerable work has been done with the commercially grown *Limnanthes alba*. Oelke et al. (1990) summarize available information about growing this plant for maximum seed production, and recommend that plant densities of 3-4 plants per square foot are optimal. Seeds should be planted in the first two weeks of October, or after the ground temperature is less than 60° F (15.6° C), in order to prevent secondary dormancy in the seeds. *Limnanthes alba* requires good seed-soil contact for uniform germination, and the ground is tilled before planting. In the case of rare *Limnanthes* in vernal pool habitat, however, the habitat disturbance caused by soil cultivation is not recommended. When commercially planting *Limnanthes alba,* seeds are usually drilled 1/4-3/4 deep in rows space 3-7 inches apart; this method produces better results than broadcast seeding. Fertilization is not necessary, and often has the adverse effect of increasing weed competition.

Population monitoring

The Nature Conservancy (TNC) monitored the Agate Desert Preserve populations of *Limnanthes floccosa* ssp. *grandiflora* after a prescribed burn and wildfire in the area. *L. floccosa ssp. grandiflora* appeared to be positively impacted by fire. The population recovered during the second year after the fires, with plants appearing in great abundance, but the number of replicates per treatment was too small to determine a statistical significance of fire on *Limnanthes* density (Borgias 1993). Aside from this study, there is no record of monitoring projects involving *Limnanthes*.

Land use threats and other limitations

Limnanthes floccosa* ssp. *grandiflora: Because *L. floccosa* ssp. *grandiflora* is federally listed, there is more information available about threats to this subspecies than there is for the other taxa. Destruction of specialized habitat, industrial and residential development, agricultural conversion, grazing and competition with non-native plants have all impacted this subspecies. In the Agate Desert, where two of the *L. floccosa* ssp. *grandiflora* populations occur, the previously widespread vernal pools favored by this plant are now virtually eliminated. One survey estimated that, between 1998 and 2002, the remaining vernal pool system in the Agate Desert decreased by almost 50%, going from 54 to 28 hectares (Brock 1987, USFWS 2002a). Being located on public land does not protect *L. floccosa* ssp. *floccosa* plants. The two populations in the Ken Denman Wildlife Refuge have been negatively impacted by the management practices on this State-owned refuge. The area is devoted to wildfowl production, and much of the land has been covered with log deck debris, plowed in strips, and planted with non-native wildlife food plants (Brock 1987). Much of the City of Medford's Whetstone industrial park, where portions of three populations still remain, has been leveled and compacted, destroying any vernal pools.

Jackson County's rapid human population increase (from 1990-2000, the population increased 23.8%) has put further pressure on the *Limnanthes* populations in the area. Two sites where *L. floccosa* ssp. *grandiflora* was collected in 1969 have been recently destroyed – one by construction of a mill and another by construction of a large industrial

plant. Many other sites have been degraded by road and commercial construction, and residential development. Another site became the location for the City of Medford's new sewer plant, and the previously large area of *Limnanthes* habitat was reduced to two small pools.

The only *Limnanthes floccosa* ssp. *grandiflora* habitat currently protected and managed for rare species is located on the Agate Desert Preserve, managed by The Nature Conservancy (TNC). However, the Agate Desert Preserve may soon be surrounded by commercial and industrial developed land, which could disrupt the hydrologic processes of the Preserve. A road was built along one edge of Preserve in 1988; the accompanying drainage ditch caused several of the vernal pools in the adjoining Preserve to be drained, destroying the habitat (USFWS 2002a).

Recent Agate Desert Preserve research conducted by TNC showed an increase in *L. floccosa* ssp. *grandiflora* populations in areas where livestock grazing was excluded. Cattle grazing stopped in the Preserve in 1987; over the next fifteen years the meadowfoam populations went from 480 to over 60,000 individuals. Spring grazing of cattle impacted the populations by trampling and herbivory. Light late summer to early fall grazing (before the rains cause seed germination) may have less of an impact, since plants are not yet growing, and the reduction of non-native competitors may benefit the meadowfoam (Borgias 1993, USFWS 2002a).

In the Agate Desert area, none of the remaining hydrologically intact vernal pool habitat has escaped the invasion of exotic weeds. Recent evidence indicates that non-native annual grasses, particularly medusahead (*Taeniatherum caput-medusae*), are a greater problem than previously believed. Unlike the area's original native perennial bunchgrasses, annual grasses die back each year, creating a buildup of thatch that can interfere with the germination of the native vernal pool occupants' seeds (USFWS 2002b). In some cases, like the Ken Denman Wildlife Reserve, these non-native grasses have been purposefully planted for livestock grazing and other reasons (Brock 1987). In one small TNC study, germination and seedling survivorship of rare plants (including

Limnanthes floccosa ssp. *grandiflora*) were increased on plots that were raked, as compared to untreated plots (D. Borgias, personal communication 1998 in USFWS 2002a).

***Limnanthes floccosa* ssp. *bellingeriana*:** The fact that the rocky shallow soils where *L. floccosa* ssp. *bellingeriana* is found are poorly suited to farming has probably prevented the complete eradication of this subspecies. However, residential construction, urban development and the building and maintenance of roads (herbicide spraying and mowing) are still major threats to the viability of this subspecies (CPC 2004).

Limnanthes floccosa* ssp. *pumila: Because *L. floccosa* ssp. *pumila* habitat is rocky and at a higher elevation than other *Limnanthes* (this subspecies is known in only at the BLM's Table Rocks Area of Critical Environmental Concern in Jackson County), it is less susceptible to some of the issues threatening the other taxa. However, the fact there are only 3 populations of this plant in one small area makes this subspecies vulnerable to extinction caused by a stochastic event. Other potential threats include off-road vehicle use and grazing (Meinke 1982).

Limnanthes gracilis* var. *gracilis: In addition to the factors that threaten habitat loss for all of the rare *Limnanthes*, serpentine strip mining for nickel is a potential threat to *L. gracilis* var. *gracilis* populations (Meinke 1982).

Finally, all of these rare *Limnanthes* are potentially threatened by the interest of collectors, since some members of the genus can cross with the commercially grown *Limanthes alba*, and researchers are looking for ways to improve the meadowfoam crops (CPC 2004). About 40% of *the L. floccosa* ssp. *grandiflora* sites are less than 2 ha in size, within easy access of the road and lacking any fencing which might prevent access and collection (USFWS 2002a).

Population introduction/augmentation strategy

Based on the biogeographical data compiled and described above for *Limnanthes floccosa* ssp. *bellingeriana*, *L. floccosa* ssp. *grandiflora*, *L. floccosa* ssp. *pumila* and *Limnanthes gracilis* var. *gracilis*, there do not appear to be any insurmountable ecological, life history, anthropogenic, or administrative obstacles to the successful implementation of population introduction and augmentation projects for these rare subspecies and varieties. Although many meadowfoam populations face serious threats to their ongoing survival, and vernal pool habitat has been reduced to a small fraction of its original presence, there are some extant rare *Limnanthes* populations occurring on public relatively secure landholdings in Oregon. As such, pending interagency cooperation and funding availability, there are several good sites available for collection of seeds for use in off-site cultivation and seed transplant projects, and open locations should also be available for population augmentation and introduction purposes.

These *Limnanthes* taxa should be able to produce fairly large amounts of seeds, which show high levels of germination as long as temperatures are kept below 60° F (15.6° C). Although no cultivation trials have been performed, there is no reason to expect *Limnanthes* seedlings to exhibit any specialized growth or symbiont requirements, and greenhouse cultivation should be possible. *Limnanthes alba* has been very successfully grown from seeds sown in the fall, and this also appears to be the best method for introduction of new populations of the rare *Limnanthes*, as well. Introducing seed has the additional benefit of increasing genetic diversity in the new population, which is especially important in a new environment (Guerrant 1996). Ideally, genetically diverse introduction stock should be used whenever possible to elevate seed production and reproductive fitness, and also potentially improve the odds of overall introduction success by maximizing the amount of adaptive genetic variability in the populations.

Based upon the information already provided in this manual, the following procedures are recommended for *Limnanthes floccosa* ssp. *bellingeriana, L. floccosa* ssp. *grandiflora, L. floccosa* ssp. *pumila* and *L. gracilis* var. *gracilis* population introductions:

1. Select population introdution/augmentation target sites. Several factors should be considered when selecting target sites for *Limnanthes* population introduction and augmentation projects. First, target sites should contain suitable vernal pool or ephemeral stream habitat, keeping in mind the microhabitat variation found between subspecies and varieties of this genus. *L. floccosa* ssp. *grandiflora* is found at elevations of 375-400 m, in the Agate Desert region's mound-swale topography. *Limnanthes floccosa* ssp. *bellingeriana* is found in partially shaded vernal pools located in rocky meadows at 1100-1200 m. *Limnanthes floccosa* ssp. *pumila* is also located at higher elevations, on the tops of Upper and Lower Table Rocks. *Limnanthes gracilis* var. *gracilis* habitat has the most variation in elevation, but most populations are found in vernal pools at 300-600 m elevation. Although habitat descriptions have been provided in this manual, it is extremely helpful to visit extant populations and actually see the habitat in which the plant grows. Such visits should give a better idea of the types of microsites occupied by *Limnanthes* individuals within their larger vernal pool habitat context.

   Given the lack of long-term protection of rare *Limnanthes* on private lands, inventories for suitable sites should focus on publicly owned or otherwise secure lands. Selection and use of sites should be coordinated with public landowners or agencies to ensure administrative protection and management of populations following introductions. Initial field observations indicate that grazing has a negative impact on *Limnanthes* populations, so it would also be important to ensure that no grazing is allowed to occur on the proposed target sites.

2. Collect *Limnanthes* seeds for off-site cultivation and sowing. Although transplanting efforts should probably consist primarily of seed sowing, it might be beneficial to introduce some cultivated plugs, as well, in order to insure rapid reproduction capacity. Source material for off-site cultivation and seed sowing should be collected from the extant population(s) located nearest to the introduction target sites to maximize conveyance of potential local adaptations. To maximize seed production, fitness and adaptive genetic variability within the

introduced population, an effort should be made to collect seed from as large a sample of genetically variable individuals within this population as possible.

3. Cultivate *Limnanthes*. Other vernal pool plants have been successfully cultivated from seed, their limiting factor being the lack of habitat rather than difficulty in reproduction and establishment in an appropriate environment. *Limnanthes* should be cultivated by germinating seeds at 40-50°F, then planting germinated seeds in 4" plastic pots filled with peat/bark/potting mix, watering daily, and fertilizing 1-2 times a month with 20-20-20 soluble fertilizer.

4. Introduce cultivated plugs/seeds into the target site(s). *Limnanthes* seed introductions should be performed after the arrival of fall rains, in early October, so that soils are moist at the time of planting and plugs have ample opportunity for root system development. *Limnanthes* plugs should be transplanted in early spring, when the growth season is beginning. Although there has been little research to date on the impacts of population size on the ability of *Limnanthes* to attract pollinators and produce viable seed and robust progeny, in general small populations tend to be more vulnerable to such factors as stochastic events and inbreeding depression. Therefore, it is recommended that introduced populations consist of many individuals planted in large clusters.

5. Monitor introduced populations. Introduced *Limnanthes* populations should be monitored annually to evaluate project success. These evaluations should take place in the late spring, when plants are flowering and setting fruit, and more easily identified. Because *Limnanthes* is an annual, and not known to spread vegetatively, there should be little difficulty in distinguishing introduced individuals, even when they grow closely together. Individuals could be monitored through basic census techniques, or more intensive monitoring could be used to track survival and reproductive performance of individual plants over time.

Literature Cited

Abrams, L. 1951. Illustrated Flora of the Pacific States (vols 1-3). Stanford University Press, Stanford, CA. As cited in Meinke 1982.

Amsberry, K., and R.J. Meinke. 1998. *Plagiobothrys hirtus* reintroduction project. Unpublished progress report prepared for the U.S. Fish and Wildlife Service, Portland, Oregon. Oregon Department of Agriculture, Salem, Oregon.

Arroyo, M.T.K. 1973. A taximetric study of infraspecific variation in autogamous *Limnanthes floccosa* (Limnanthaceae). Brittania 25:177-191.

Borgias, D.D. 1983. Fire effects on the Rogue Valley mounded prairie on the Agate Desert, Jackson County, Oregon. Unpublished report for The Nature Conservancy, Portland, Oregon.

Brock, R. 1987. The ecology of *Lomatium cookii*, an endangered species of the Rogue Valley, Oregon. Unpublished report for The Nature Conservancy, Portland, Oregon. As reported in Kagan, J. 1994. Habitat Management Plan for *Lomatium cookii* (Cook's desert-parsley) in the Illinois Valley, Josephine County, OR. Unpublished report prepared for the Oregon Natural Heritage Program (now Oregon Natural Heritage Information Center), Portland, Oregon.

Cole, D.F. 1974. Effect of light and temperature on germination of two accessions of *Limnanthes alba* seed. Economic Botany 28:155-159.

CPC (Center for Plant Conservation). 2004. CPC National Collection Plant Profile, *Limnanthes floccosa* ssp. *bellingeriana*. Accessible at http://ridgwaydb.mobot.org/cpcweb/CPC_ViewProfile.asp?CPCNum=2556. (Accessed September 8, 2004.)

Ehrensing, D.T., G.D. Jolliff, J.M. Crane and R.S. Karow. 1997. Growing meadowfoam in the Willamette Valley. Oregon State University Extension Service publication EM 8567. Corvallis, Oregon.

Guerrant, E.O., Jr. 1996. Designing populations: demographic, genetic, and horticultural dimensions. In D.A. Falk, C.I. Millar, and M. Olwell, editors. Restoring Diversity. Island Press, Washington, DC.

Hickman, J.C. 1993. The Jepson manual: Higher plants of California. University of California Press, Berkeley.

Jahns, T.R., D.M. Burgett and G.D. Jolliff. 1997. Pollination and seed set in meadowfoam. Oregon State University Extension Service publication EM 8666. Corvallis, Oregon.

Jain, S.K. 1978. Local dispersal of *Limnanthes* nutlets: an experiment with artificial vernal pools. Canadian Journal of Botany 56: 1995-1997.

Kaye, T.N. J. Cramer, and A. Brandt. 2003. Seeding and transplanting rare Willamette Valley prairie plants for population restoration. Unpublished third year progress report prepared for The Bureau of Land Management (Eugene District) and the City of Eugene. Institute for Applied Ecology, Corvallis, Oregon.

Knapp, S. J. and J. M. Crane. 1999. Breeding advances and germplasm resources in meadowfoam: A novel very long chain oilseed. In J. Janick, editor. Perspectives on new crops and new uses. ASHS Press, Alexandria, VA.

Mason, C.T. 1952. A systematic study of *Limnanthes* R. Br. University of Calif Publications in Botany 25:455-512.

McNeill, C.I. and S.K. Jain. 1983. Genetic differentiation studies and phylogenetic inference in the plant genus *Limnanthes* (section Inflexae). Theoretical and Applied Genetics 66:257-269.

Meinke, R.J. 1982. Threatened and endangered vascular plants of Oregon: An illustrated guide. Unpublished report for the U.S. Fish and Wildlife Service, Region 1, Portland, Oregon. Oregon Department of Agriculture, Salem, Oregon.

Oelke, E.A., E.S. Oplinger, C.V. Hanson and K.A. Kelling. 1990. Grain Crops Production and Management A University of Wisconsin Short Course: Meadowfoam. http://corn.agronomy.wisc.edu/FISC/Alternatives/Meadowfoam.htm. Accessed 11/14/2002.

ORHNIC (Oregon Natural Heritage Information Center). 2004a. Rare, threatened and endangered plants of Oregon. Oregon Natural Heritage Information Center, Portland, Oregon.

ORNHIC (Oregon Natural Heritage Information Center). 2004b. Oregon Natural Heritage Information Center Database. Portland, Oregon.

Peck, M.E. 1961. A manual of the higher plants of Oregon, 2nd ed. Binfords and Mort, Portland.

Southworth, D. and J. Seevers. 1997. Taxonomic status of *Limnanthes floccosa* subspecies *bellingeriana*. In Kaye, T.N., A. Liston, R.M. Love, D.L. Luoma, and M.V. Wilson, editors. Conservation and Management of Native Flora. Native Plant Society of Oregon, Corvallis, Oregon.

Toy, S.J. and B.C. Willingham. 1967. Some studies on secondary dormancy in *Limnanthes* seed. Economic Botany 21:363-366.

Toy, S.J. and B.C. Willingham. 1966. Effect of temperature on seed germination of ten species and varieties of *Limnanthes*. Economic Botany 20:71-75.

USFWS (U.S. Fish and Wildlife Service). 2002a. Endangered and threatened wildlife and plants; determination of endangered status for *Lomatium cookii* (Cook's Lomatium) and *Limnanthes floccosa* ssp. g*randiflora* (Large-Flowered Wooly Meadowfoam) from Southern Oregon. Federal Register 67:68003-68015. November 7. Available at http://www.epa.gov/fedrgstr/EPA-SPECIES/2002/November/Day-07/e28237.htm. (Accessed August 27, 2004.)

USFWS (U.S. Fish and Wildlife Service). 2002b. Endangered and threatened wildlife and plants; reopening of comment period on the proposed endangered status of two plants, *Lomatium cookii* (Cook's Lomatium) and *Limnanthes floccosa* ssp. *grandiflora* (Large-Flowered Wooly Meadowfoam). Federal Register 67:1712-1713. January 14. (Available at http://www.epa.gov/fedrgstr/EPA-SPECIES/2002/January/Day-14/e812.htm. (Accessed August 31, 2003.)

USFWS (U.S. Fish and Wildlife Service). 1996. Endangered and threatened species; notice of reclassification of 96 candidate taxa. Federal Register 61:7457-7461. February 28.