EXPERIMENTAL OUTPLANTING OF *PERIDERIDIA ERYTHRORHIZA* ("*KLAMATHENSE*") ON THE FREMONT-WINEMA NATIONAL FOREST

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Introduction

Some of the first collections of the rare endemic perennial *Perideridia erythrorhiza* (Apiaceae) were taken from the Odessa area in the early 20th century, on what is now the Fremont-Winema National Forest. This site, generally considered historically significant by Oregon botanists, is located near the northwest shore of Klamath Lake (Fig. 1), and comprises one of just a few populations cited for the species in the only comprehensive taxonomic review of the genus (Chuang and Constance, 1969). The species has always been categorized as rare, having been recorded from only a handful of scattered sites in Klamath, Jackson, Josephine, and Douglas counties. It is a Region 6 (Forest Service) Sensitive Species, and is listed as threatened with extinction throughout its range by the Oregon Natural Heritage Data Base. It is a candidate for listing by the state.

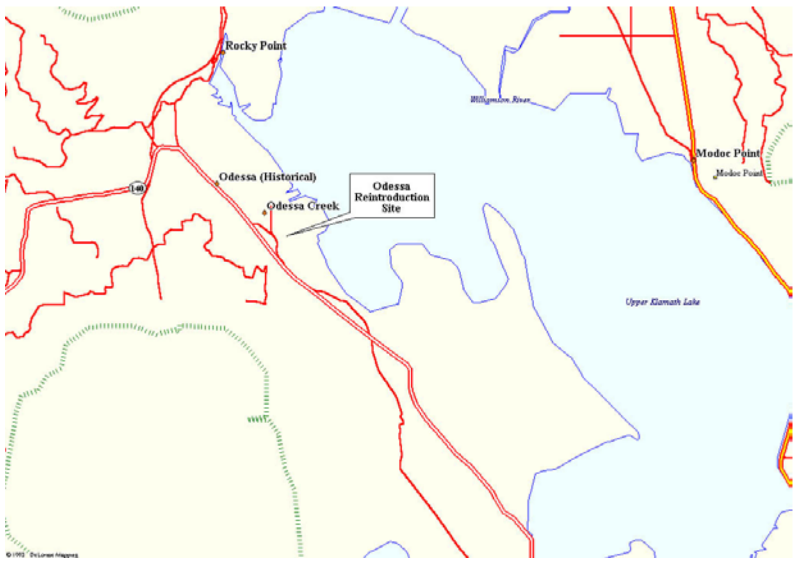


Figure 1. Location of the Odessa area near Klamath Lake and Oregon Highway 140 (T36S R6E S25 NE¼).

Recent studies (Meinke, 1998; Whittall et al., 2003) have confounded the conservation picture for the species, suggesting that plants occurring in seasonally moist meadows east of the Cascades crest differ significantly from those populating westside slopes and valleys, with the eastern plants potentially representing an undescribed species (tentatively referred to as *P.* "*klamathense*"). The new species would be endemic to western Klamath and eastern Jackson counties. Results from a recent phylogenetic study of *Perideridia* (Downie et al., 2004) using DNA *ITS* sequences are more equivocal. While not discounting the proposed species split, this work suggests that additional sampling may be necessary to better comprehend the taxonomic relationships among the populations of what is collectively known as *P. erythrorhiza*. It's worth noting, however, that ITS sequences can vary comparatively little between related populations that have evolved rapidly in response to dramatically different environments (as are typically seen on either side of the Cascades), and in such cases may not be good taxonomic indicators. In any case, whether the Klamath County populations constitute a new species is perhaps not so critical from a conservation viewpoint, since *P. erythrorhiza* (sensu lato) is suitably rare and threatened even with the east- and westside plants combined as a single taxon.

What remains of the suspected "Odessa site" was believed to occur on property managed by the Fremont-Winema National Forest, in the vicinity of a fenceline dividing national forest land from a private pasture (Fig. 2). Visits to the site in 2000 and 2001 revealed that plants of *P. erythrorhiza*, as well as numerous *P. oregana* and *P. gairdneri* individuals, were scattered over the immediate vicinity. The three species were essentially sympatric, though separating out (very locally) along a soil moisture gradient that is in part bisected by the fencing. Observations at the time suggested that *P. erythrorhiza* was very scarce, but appeared to have originally been more common on the private pasture side.

Figure 2. Private pasture to the right and Forest Service land to the left of the disputed fenceline (less than a year after realignment and just prior to *Perideridia* outplanting).

At some point prior to 2003, Forest Service staff discovered that the fenceline was incorrectly placed, favoring the private landowner by less than an acre or so. Although the discrepancy was not great, the private side of the fence was believed to include significantly better edaphic conditions (despite on-going cattle grazing) than the adjacent Forest Service property, which, although including many native species, appeared to have hydrologic features less suitable for *P. erythrorhiza*. The fence was subsequently removed and realigned, providing an opportunity to try and restore plants and habitat in the area repatriated to the Forest Service. During a prior study of *P. erythrorhiza*, Roberts (2003) used the Odessa area to establish test transplant plots, where she focused on developing a reintroduction protocol for the species. *Perideridia* plants are perennials that annually develop starch-rich, underground tubers (Fig. 3), which re-grow in the fall after plants flower and set seed (Roberts, 2003). These typically get progressively larger as plants age, and are easy to cultivate and ideal for use in transplant projects. Roberts (2003) convincingly demonstrated that greenhouse cultivation and outplanting of tubers was a practical recovery tool for *P. erythrorhiza*, and her general methods form the basis for much of this work.

Methods

The purpose of this project is to restore a population of *Perideridia erythrorhiza* at the so-called Odessa site, an historic locality noted in the original monograph for the genus. In

Figure 3. Second-year *Perideridia erythrorhiza* tubers ready for outplanting in late November, with winter roots and shoots emerging. Most tubers for a given plant are single in the first year, but by the second and later years they are often fascicled (i.e., developing as multiple, essentially independent units attached at the crown). Tuber clusters typically produce only a single apical shoot, although two shoots per group are occasionally seen.

2002, the Odessa population consisted of approximately 100 individuals near the edge of Forest Service property adjacent to private land (S. Malaby, pers. comm.). At least some of these are suspected to be leftovers from the outplanting project undertaken earlier by Roberts (2003), which means that naturally-occurring *P. erythrorhiza* plants at the site were extremely scarce. Thousands of *P. oregana* and hundreds of *P. gairdneri* plants were also present. The recent discovery of a boundary discrepancy has created an opportunity to expand the *P. erythrorhiza* population into a strip of suitable meadow habitat previously managed as private pasture. Generally speaking, Forest Service objectives were to (1) eliminate or reduce grazing to promote native species recovery in the reacquired former pasture, and (2) establish a viable presence of *P. erythrorhiza* at the site, consisting of at least 300-500 reproductive individuals.

To accomplish this restoration effort, the following tasks were undertaken:

1. ***Summer, 2002*****:** The proposed Odessa transplant site was examined in July to aid in the development of a site plan. Possible outplanting sites were identified, and examined to ensure that they did not already contain any *P. erythrorhiza* plants. About 4,000 wild seeds were then collected in August for use in the cultivation work. The seeds were

taken from a population (with about 800 to 1,000 plants) located less than a mile to the west, to minimize potential genetic dissimilarity between transplant stock and any remaining on-site remnants of the natural Odessa population. Approximately 70 wild plants were used as seed stock.

2. ***Late summer to early winter, 2002*:** Seeds were cleaned after collection, and then ca. 1,200 were placed (moist) in sterile petri dishes for 6-7 weeks at about 3°C (see Roberts, 2003). Remaining seeds were stored in dry paper bags at ambient temperatures. Vernalized seeds were then sown (in late September) into flats filled with standard potting mix, and watered daily. Greenhouses were artificially lit (~14 hour photoperiod) and warmed (ca. 20°C). Once emerged and established, seedlings were thinned until roughly 500 were left – these were then fertilized and grown until small tubers (about the size of a Spanish peanut – see Fig. 7) had formed and the plants had senesced, taking approximately 11-12 weeks. These first year tubers were harvested in late fall and stored dry, under mild refrigeration (4-6°C), for several weeks.

3. ***Winter to mid-summer, 2003*:** In early March, the small tubers were planted out in pots, and placed in warming conditions (18-20°C) to sprout. They were watered, fertilized, and allowed to grow and flower outside, after which they senesced in mid-summer. Once leaves and stems had withered, remaining second year tubers (ranging from 2-8 cm) were excavated. After discarding diseased or otherwise unhealthy tubers, the largest, highest quality that remained (presumably representing broad genetic stock) were segregated for outplanting work in the fall. These totaled about 140, and were stored in mostly dry, cool, dark conditions (in loose soil in flats).

4. ***Mid- to late summer, 2003*:** Another set of small tubers was also grown, using some of the reserved seed collected in 2002, and following the methods outlined in (2), above. Approximately 1,200 seeds were used, with ca. 400 small tubers harvested in October.

5. ***Fall, 2003*:** First- and second-year tubers, and the remaining reserved seeds from 2002, were outplanted at the reclaimed Odessa site on November 17, 2003. The site plan, including the re-introduction design and a long-term monitoring protocol, was discussed with the Forest Service at the time the tubers were transplanted. The overall plot layout and planting scheme is outlined and illustrated in Figs. 4-8. Prior to planting, 26 individual plots (each one meter-squared in size) were weeded and tilled to loosen soil, and the NE corner of each was staked (Figs. 4 and 5). The locations of outplanted tubers and seeds within the plots were also marked. (The wooden corner stakes have been left in place, but planting markers were removed in 2005.) Tubers were placed in cooler conditions (about 4-5°C) in October to harden them off prior to planting. The cold stimulated roots and early shoots of large tubers to initiate slow growth (Fig. 3), a winter response previously observed in excavated wild plants. Accordingly, the tubers were planted carefully to avoid damage to tender roots and shoots. Seeds were not vernalized before sowing into planted rows (Fig. 8).

6. ***Summer, 2004 and 2005*:** Plots were re-visited at peak flowering and also peak fruiting during the 2004 growing season, and then once during mid-season in 2005 (this was in late July, when the population was about 70% in fruit). Survival rates and estimates of recruitment and reproduction were recorded during these visits.

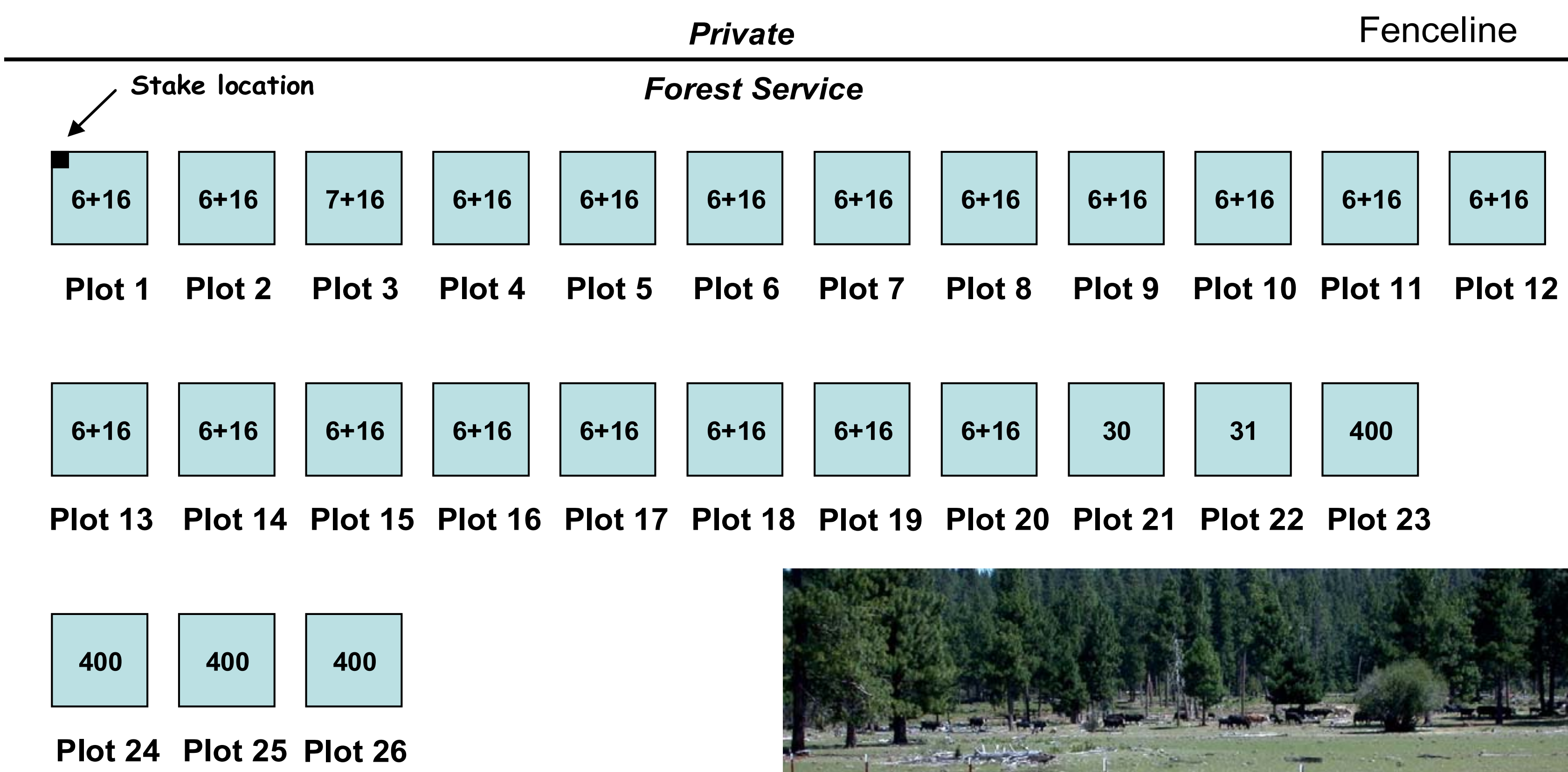


Fig. 4. Layout of *P. erythrorhiza* transplant plots. Fenceline runs more or less N to S. Plots are situated parallel to fence (arrows at right show corner stakes for Plots 16-18). Stakes were placed at upper left (NE) corner when facing fence. Plots 1-20 each had 6 large tubers planted (7 in Plot 3) plus 16 small tubers. Plots 21 and 22 had 30 and 31 small tubers only. Plots 23-26 were each planted with 400 seeds (4 rows of 100) for a total of 1,600 seeds. The number of tubers outplanted were 121 large (mean=5.6 cm) and 381 small tubers, for a total of 502.

Figures 5-8. *Clockwise from upper left*: **5.** Plot being prepped for outplanting. **6**. Large (second-year tubers) planted and ready to be covered. **7.** Examples of small (first year) tubers, with tiny winter shoots. **8.** Furrows used for sowing seeds and planting small tubers.

Results and Discussion

Tuber outplanting. Tuber dormancy is not known for *P. erythrorhiza*, so it was assumed any tubers that did not develop inflorescences (or at least form basal leaves) during the summer following transplanting had died. Table 1. and Fig. 9 summarize the survivorship results for the 502 large and small tubers outplanted in the fall of 2003. Figs. 10 and 11 provide individual plot data through the summer of 2005. Sampling in June, 2004 showed that large tubers which were cultivated an extra year before outplanting clearly had a survival advantage over smaller tubers that had been grown for just a single season – about 55% of the large tubers returned as flowering plants in 2004, while only 13% of the small tubers appeared to have survived. By the second sampling visit (in August, 2004), about 50% of the original large tubers were still alive and all had produced seed (seed data summaries are provided later). Only 6 (less than 2%) of the plants that developed from small tubers were still evident and producing seed. The total number of plants making an appearance in 2004 was 117 (or about a 23% return), based on the June sample data. In 2005, it was no longer possible to tell for certain if plants in the plots originated from large or small tubers, so the combined total per plot was recorded. The number of *P. erythrorhiza* plants observed in 2005 within the 22 tuber plots was 146, or 29% of the original 502, implying that some level of recruitment had taken place.

Table 1. Survivorship of large (second year) and small (first year) tubers outplanted at the Odessa site in November, 2003. A total of 502 tubers were originally outplanted

	2nd year tubers	1st year tubers	Tubers combined
Nov-03	121	381	502
Jun-04	66	51	117
Aug-04	61	6	67
Jul-05			146

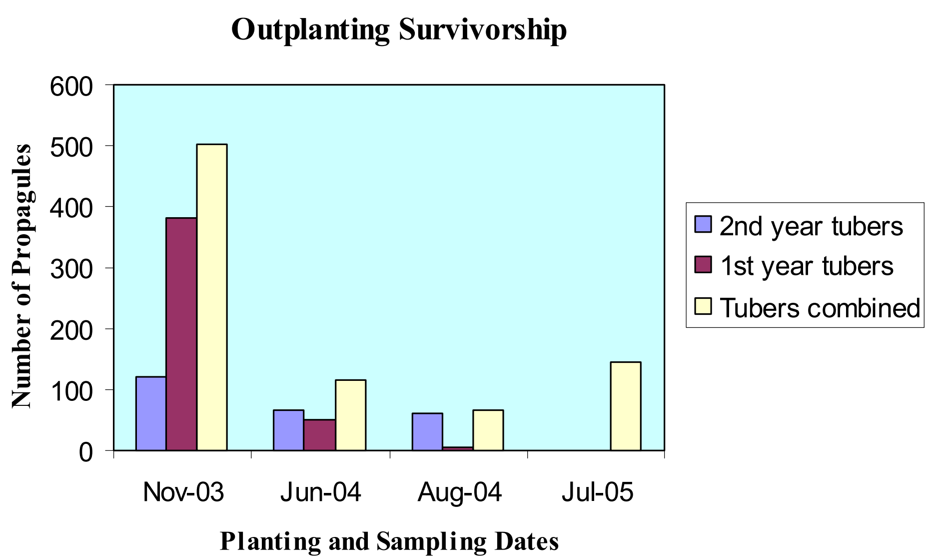
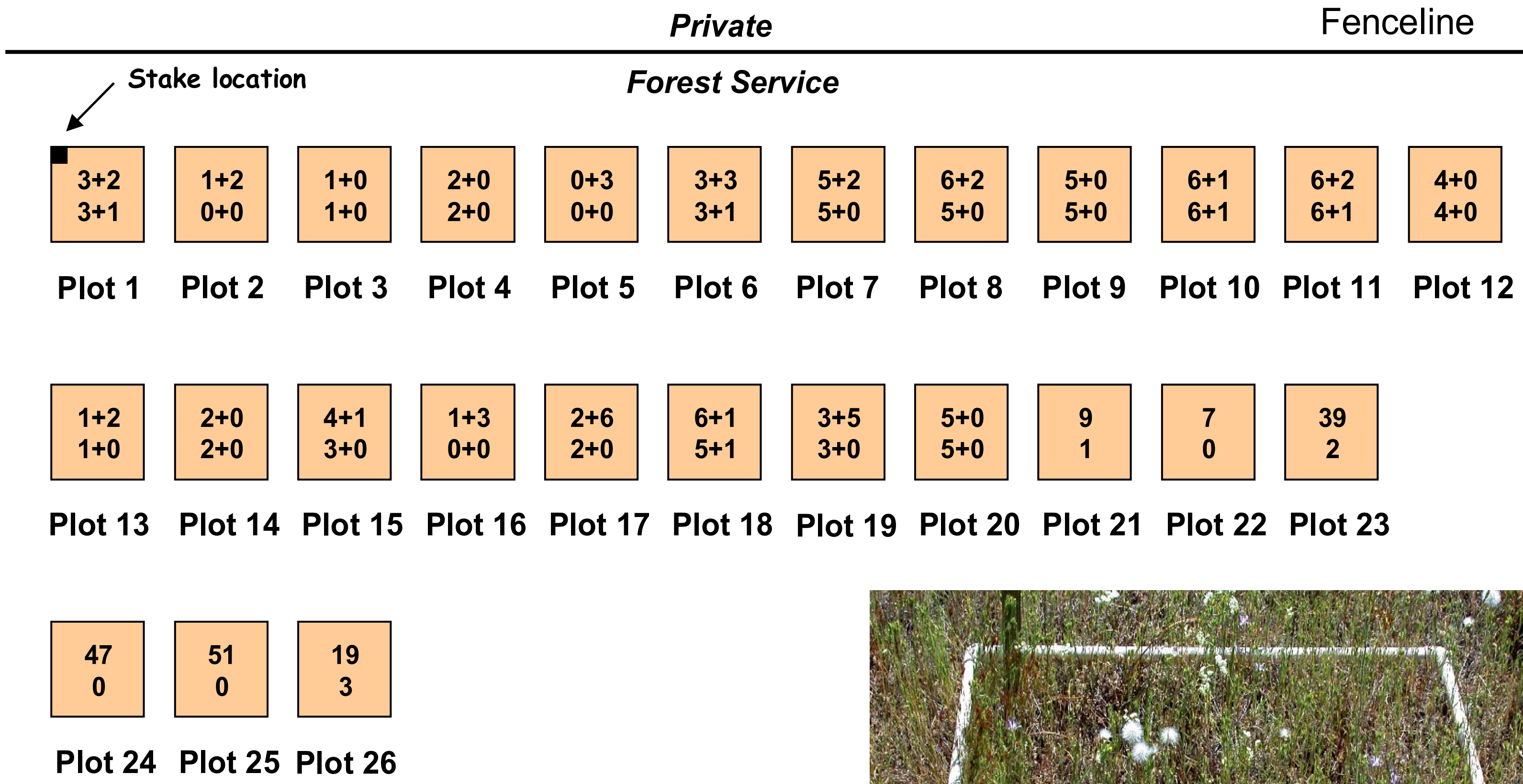


Figure 9. Fate after two growing seasons of large and small tubers outplanted at the Odessa site in November 2003. The "Number of Propagules" (Y axis) is equivalent to *reproductive survivors* for the 2004 and 2005 dates.



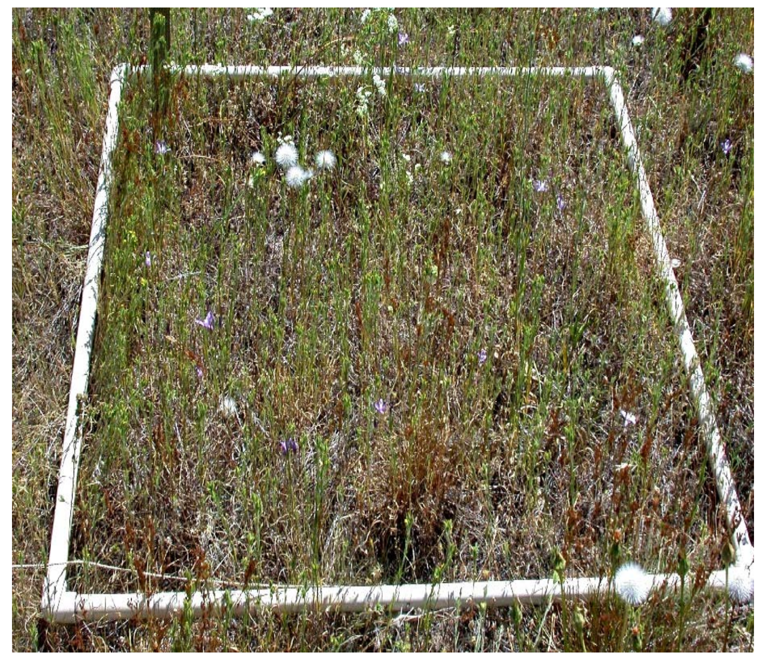


Fig. 10. Survivorship in the 2004 growing season. Plots were sampled in late June and early August using a 1-m^2 plot frame. For Plots 1-20, the top numbers in each plot box indicate how many large (i.e., second year) plus how many small (first year) tubers grew adult plants in 2004. The bottom numbers indicate how many large and small tuber plants had developed seed by the August visit (so for Plot 1, of the original 6 large tubers that were planted in 2003, 3 had produced flowering plants in June, 2004 and 2 of the 16 small tubers had developed plants – 3 large-tubered plants lived to produce seed in August, while only 1 of the 2 small-tubered plants produced seed.) Few plants were produced from small tubers or seed in Plots 21-26.

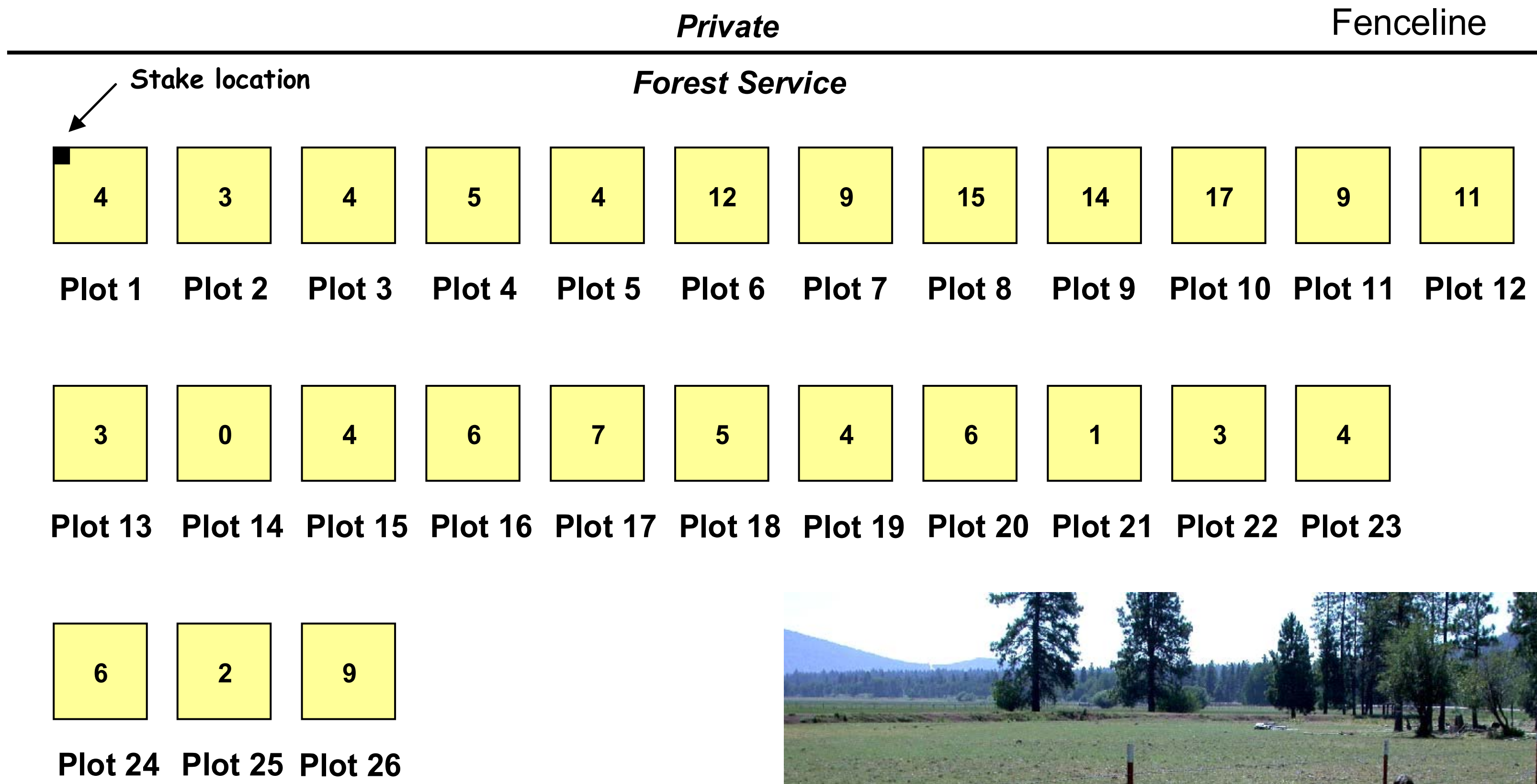


Fig. 11. Survivorship in the 2005 growing season. Plots were measured in late July, 2005, when plants were about 70% in fruit (no attempt was made to distinguish between plants originating from small and large tubers). As in 2004, there appeared to be a trend for more plants to survive on the right hand side of the plot array (when facing the fence) than the left, suggesting that soil moisture or possibly competition may be differentially affecting survival across the plots. And in some plots, more *P. erythrorhiza* plants appeared in 2005 than in 2003 or 2004 (see Plots 9 & 10, left), implying that some form of recruitment is occurring in the population.

Survivorship from seed. Nearly 10% of the 1,600 seeds sown in Plots 23-26 produced seedlings that were observable in late June, 2004 (Fig. 10). Most of these had died or senesced by early August, though this was not unexpected. But by July of 2005, only 21 plants were present and flowering in the seed sowing plots, a 1.3% return (Fig. 11). These results are more or less comparable to previous studies (ODA, 2001; Roberts, 2003). The 1.3% rate was considerably lower than the combined 2005 results for tuber plots (29%) in this study, though it was not possible to compare the efficiency of seeds with large and small tubers individually in 2005. Previous work (ODA, 2001) has suggested that sowing or planting seed, which can be relatively easily gathered if ample plants are accessible, is generally a more efficacious means of creating new populations than going to the trouble of cultivating numerous small tubers. Larger (second year) tubers are the surest choice for immediate success, and straight away develop plants that provide a good seed yield (see below). This is also the best approach if available seed for sowing is at a premium, often the case with rare and endangered species.

Seed production by transplants. Seed production from the 2003 transplants is graphically summarized in Fig. 12. Very few plants originating from small tubers survived to reproduce, and their reproductive contribution to the population was negligible. Seed-bearing plants from large tubers were much more numerous. Plants were overall less fecund in 2004,

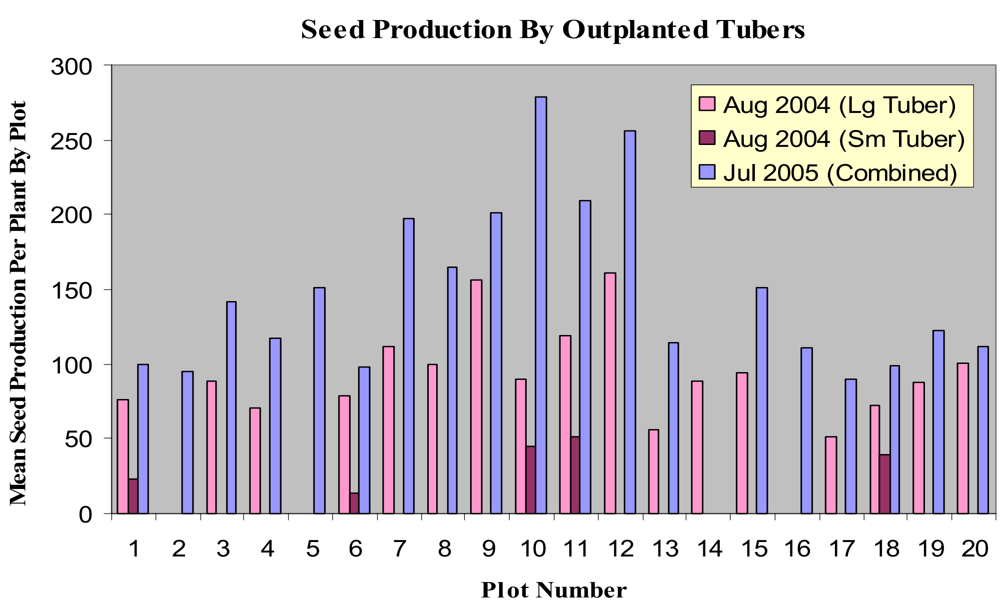


Figure 12. Seed yield (averaged by plot – see Figs. 10 and 11) for *P. erythrorhiza* plants from tubers outplanted in 2003. Seed yield per plant increased substantially in 2005 as the population matured.

presumably at least partly due to their younger age. Once established for a second season, they produced considerably more seed. Individual plants in 2004 produced an average of 94 seeds, while those from 2005 matured 148 each. This number takes into account modest impacts from pre-dispersal predations, which were perpetrated by an unidentified larva, probably a moth species (Fig. 13). The mean number of seeds produced per plant was lower in both years than those previously reported in Meinke (1998), though in that case reproductive levels were being reported from naturally-occurring plants, versus the recently transplanted individuals assessed here. In 2004, an estimated 5,750 seeds were produced by transplants in the Odessa site plots, with that number increasing to 21,600 in 2005. As the population ages, future sampling may reveal average seed yields approaching those of the natural populations previously described in Meinke (1998) and Roberts (2003).

Figure 13. Lepidopteran larvae observed on *P. erythrorhiza* and other yampah species at the Odessa site. An estimated 5-15% of a plant's seed crop could be lost to this predator if it attacked flowers before seeds were set.

Survivorship patterns. It is interesting to note that, despite the relatively small space covered by the plot array, the distribution of plants that survived to flower and set seed is not random. Fig. 10 clearly shows that tubers planted in the front row of the array (closest to the fence) had a greater likelihood of surviving than those placed elsewhere. And those planted on the right-hand side of the front row were particularly apt to do well. Fig. 11 reveals that this trend continued into 2005. The photo in Fig. 11 shows tight clumps of plants associated with Plots 9 and 10. Plants not only were more likely to return the following year in these front row plots, but they also produced higher numbers of seed per plant (Fig. 12). Perhaps not coincidentally, the plots with the highest yields in terms of plant numbers and seed set per plant occurred most squarely within the reclaimed strip of habitat that had been private pasture prior to the fenceline realignment. An environmental gradient (moisture, competition, soil features) presumably runs through the plot array that favors the species on one end.

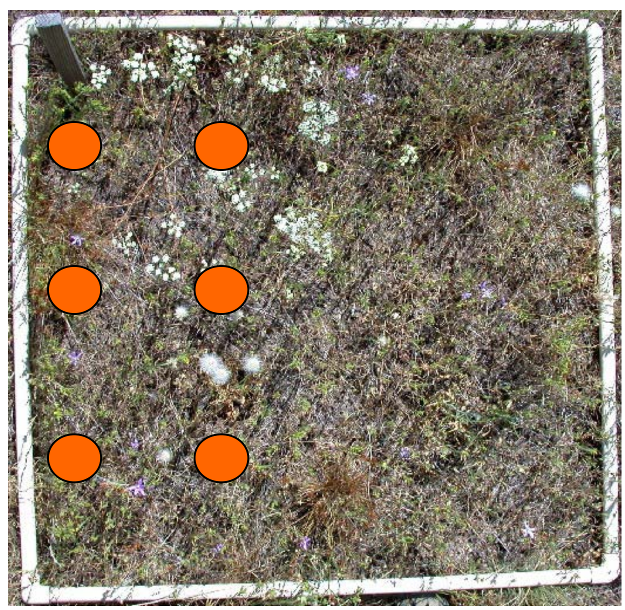


Figure 14. Plot 9 as of July, 2005. The circles indicate where the original 6 large tubers were planted in 2003.

Recruitment. The fact that the 2005 data reveal an overall increase of *P. erythrorhiza* plants in transplant plots (versus 2004) suggests that the created population is already recruiting new members. Plot 9 (Fig. 14) contained 17 individual flowering plants (easier to count if you're actually there) in late June, 2005, a sizeable increase over the eight plants present in 2004. The curious thing is that they don't really match up to the spots where the 6 large bulbs were outplanted in 2003 (approximated by the orange dots). So did the bulbs move, or did the new plants come up from seed just recently dispersed in 2004? Or both? The seed option seems unlikely, since those that we did sow were not very successful – but then they were planted back away from the fenceline, while this particular plot occurs along the fence where plants in general had greater success (Figs. 10 and 11). Even though several of these plants were smaller than average for the species, in our experience we felt it unlikely they would have flowered from seed in a single year (we'd never seen that in the greenhouse). And then the chance they were from the 16 small tubers we planted in this plot also seems slim, since they were planted on the other half of the plot – how would they have all moved to the upper left?

Another option is that some *P. erythrorhiza* plants managed to hang on in the pasture area near the fence, and once released from grazing pressure were able to send up an inflorescence. This seems like a possibility when you look at the dramatic response of native species along the fenceline in 2005 (Fig. 15) – where did all these yampahs come from? This could also help explain the smaller average size of the plants we sampled in our plots – if they had been languishing for years in a bad grazing environment, maybe it's not surprising they could only muster a meagre reproductive effort their first year out. But how many plants could really hang on this way? Fig. 15 shows the current alignment of the fence, with the private side looking essentially as it has every year since at least 1999, and perhaps for much longer. It's a pretty harsh environment, and few native plants manage to flower and set fruit there, especially the more palatable ones like *Perideridia*. So could a geophyte species that needs to send up leaves and stalks each spring (to provide photosynthates for the new tubers that must be produced each fall) survive indefinitely under these conditions? Maybe, but then why were the *P. erythrorhiza* plants we observed at Odessa in 2005 primarily distributed within or near the transplant plots (especially

Figure 15. The Odessa site fenceline (looking north) in late July, 2005. The private pasture (right) was severly grazed and cattle were present. No *Perideridia* plants (of any species) were observed flowering or fruiting on the right of the fence. The Forest Service land (left) has been recovering since grazing was recently reduced/excluded. *Perideridia oregana* (red circle in the background corner) has rebounded, as has the habitat for transplanted *P. erythrorhiza* plants (foreground near the fence).

along the fenceline)? If they were in fact holdovers from the recently released private pasture, then it seems reasonable that the pattern should have been more random.

Similar enigmatic trends held (more or less) for most plots (i.e., plants were scattered in areas where tubers weren't originally planted, more plants were present in 2005 than were there in 2004, etc.). Since we have no obvious explanation, we'll try and go with the most plausible. Probably some or most of the plants in any given plot are the result of the tubers outplanted in 2003. There usually were at least a few impressively robust plants, and we can assume these are returnees from the original large tubers (Fig. 6). But since, in at least some plots, more plants were present than were visible in 2004, some form of population expansion is clearly taking place. Since many *P. erythrorhiza* plants were on the small side in 2005, and a number were very small, some of the plants appearing that year may have resulted from the 2004 seed crop. We know that thousands of seed were dispersed in 2004, and although we have not seen cultivated plants grow from seed to flowering in a single spring/summer cycle, maybe this does happen in nature. Greenhouse-grown plants receive a lot of care (i.e., fertilizer, watering, rich soil, etc.), while plants in nature generally lead less pampered lives. Such a difference in growing conditions may lead to dissimilar reproductive responses, with some individuals bolting early and then reproducing quickly under stress, something many herbaceous perennials are known to do in nature. And then finally, depending on the grazing regime on the adjacent property over the years, some of the newly observed plants from 2005 may have indeed come in as cow pasture refugees. More information on the grazing angle is clearly needed.

In any case, our goal of establishing a Klamath yampah population that has a chance to become self-sustaining appears to have been met. And what's more, our data tend to support the original notion that the fenceline habitat was worth reacquiring as an aid towards the recovery of *P. erythrorhiza*. It would be ideal to resample the site in 2006 (and later years) to see how the population progresses (which plants and plots do best, how much seed is produced, if the plants migrate away from the plots, is supplemental augmentation needed, etc.), since all too often we set up created populations and then quit surveying them before we have any real chance to measure their response. The fact that this project seems at least reasonably successful is probably not much of a surprise, since a few *P. erythrorhiza* plants already occurred in the immediate vicinity, and the species was known to exist in the area in greater numbers in the past. It is always much more challenging to create a viable population in an entirely new site, where we typically base site selection on very little hard data and a lot of intuition. Perhaps studies like this will help provide at least some of the data necessary to be more successful at population creation, should that ever become a necessity for *P. erythrorhiza*.

Acknowledgements

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