Developing biogeographically based population introduction protocols for at-risk Willamette Valley plant species:

Agrostis howellii (Howell's bentgrass)
Aster curtus (white-topped aster),
Aster vialis (wayside aster),
Delphinium leucophaeum (hot rock larkspur),
Delphinium pavonaceaum (peacock larkspur),
Erigeron decumbens var. *decumbens* (Willamette daisy),
Horkelia congesta ssp. *congesta* (shaggy horkelia),
Lomatium bradshawii (Bradshaw's desert parsley),
Lupinus sulphureus ssp. *kincaidii* (Kincaid's lupine),
Montia howellii (Howell's montia),
Sidalcea spp. (Willamette Valley checkermallows)

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Report format:

The following species are presented in alphabetical order: *Agrostis howellii* (Howell's bentgrass), *Aster curtus* (white-topped aster), *Aster vialis* (wayside aster), *Delphinium leucophaeum* (hot rock larkspur), *Delphinium pavonaceaum* (peacock larkspur), *Erigeron decumbens* var. *decumbens* (Willamette daisy), *Horkelia congesta* ssp. *congesta* (shaggy horkelia), *Lomatium bradshawii* (Bradshaw's desert parsley), *Lupinus sulphureus* ssp. *kincaidii* (Kincaid's lupine), *Montia howellii* (Howell's montia), *Sidalcea* sp. (Willamette Valley checkermallows). 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.

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Developing biogeographically based population introduction protocols for at-risk Willamette Valley plant species:

Lomatium bradshawii
(Bradshaw's desert parsley)

Lomatium bradshawii (Bradshaw's lomatium)

Conservation status

Although *Lomatium bradshawii* (Rose) Math. & Const. (Figure 25) was once found throughout the extensive native prairies of the Willamette Valley (Kagan 1980), this rare Willamette Valley species is now listed as endangered by both the U.S. Fish and Wildlife Service and the State of Oregon. It is on the Oregon Natural Heritage Information Center List 1 (threatened or endangered throughout its range), and has a Natural Heritage Network Rank of G2/S2 (imperiled throughout its range/imperiled in Oregon) (ORNHIC 2004a). In Washington, *L. bradshawii* is listed by the State as Endangered, though this status carries no legal mandate for protection on state or other public lands (Florence Caplow, Washington Natural Heritage Program, Olympia Washington, personal communication). The species also has also been assigned a rank of S1 (critically imperiled) by the Washington Natural Heritage Program (WNHP 2003). A Recovery Plan for *L. bradshawii* was finalized in 1993 (USFWS 1993). Loss and degradation of the low elevation, seasonally wet, prairie habitat which *L. bradshawii* needs is the biggest threat to the species at this time.

Figure 25. *Lomatium bradshawii* habit. (Photo by Steve Gisler.)

Range and habitat

For many years *Lomatium bradshawii* was considered a Willamette Valley endemic, its range limited to the area between Salem and Creswell, Oregon (Kagan 1980). However, in 1994 two populations of the species were discovered in Clark County, Washington (CPC 2004). The Oregon Natural Heritage Information Center (ORNHIC 2004b) currently lists 38 occurrences of *L. bradshawii* in three populations centers located in Benton, Lane, Linn, and Marion Counties, Oregon. Most of these populations are small, ranging from about 10 to 1,000 individuals, although the largest site contains approximately 30,000 plants. The Washington populations are larger, with one site estimated to have over 70,000 individuals; unfortunately, both of these populations occur on private land and are not protected (WNHP 2004).

According to Siddall and Chambers (1978), the species was first collected in Salem by Nelson in 1916. Bradshaw collected the type specimen a few years later, in 1921, in "low swales near the high school, Eugene, Oregon." Siddall and Chambers describe *L. bradshawii*'s habitat as undisturbed sites of native Willamette Valley grassland, with associated species including: *Carex* spp., *Deschampsia caespitosa*, *Eryngium petiolatum*, *Galium cymosum, Grindelia integrifolia*, *Hordeum brachyantherum*, *Juncus* spp., *Microseris laciniata*, *Perideridia* sp., and *Poa pratensis*. Kagan (1980) further elaborates by stating that the *Lomatium* occurs on and around the small mounds created by senescent *Deschampsia caespitosa* plants, and lists

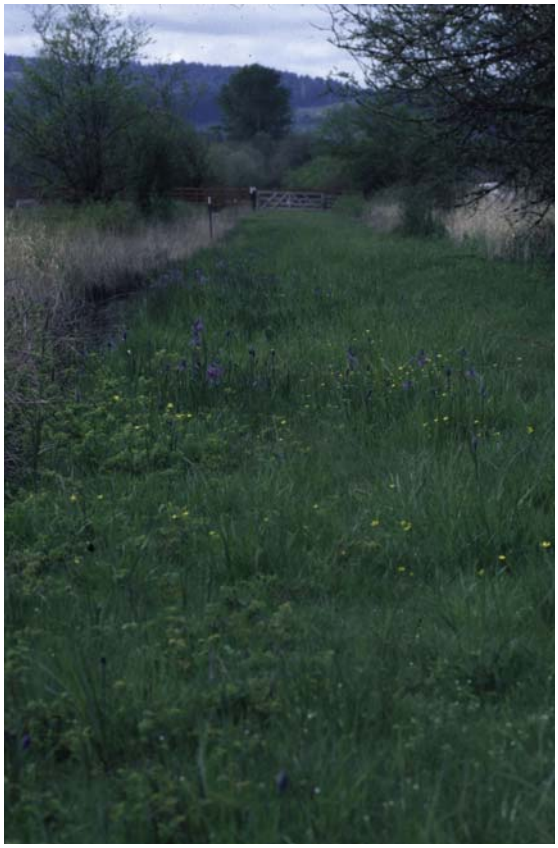

Figure 26. *Lomatium bradshawii* habitat (roadbed population at Finley NWR). (Photo by Steve Gisler.)

the following additional associates: *Carex aurea*, *C. lasiocarpa*, *C. lanuginose*, *C. obnupta*, *Danthonia californica*, *Juncus patens*, *J. acuminatus* and *Luzula campestris*. All of the populations studied by Kagan occur within 500 meters of the banks of creeks or small rivers, where soils largely consist of clay, and are shallow and poorly drained. These sites often have standing water until late spring or early summer. In populations near the Santiam River in Marion and Linn Counties, Kaye and Kirkland (1994) found that *L. bradshawii* plants occupy thin, seasonally saturated soils overlying basalt. (Habitat shown in Figure 26.)

Species description

Lomatium bradshawii is a low, erect perennial arising from a long slender taproot. Overall, the plant is glabrous and has leaves 4-12 inches long which are dissected into linear or filiform segments. *L. bradshawii* has small light yellow flowers that occur in umbels (umbellets are rarely larger than 1 cm across). Generally, only 2-5 flowers in each umbel are actually fertile. The fruit of this *Lomatium* is oblong, 1/4-1/2 inch long and glabrous with thickened, corky wings and inconspicuous dorsal ribs (Hitchcock 1961). The plant's blooming period peaks around the end of April and beginning of May, but flowers may be observed as early as the first week of April through the end of May (Kagan 1980).

Figure 27. Diagnostic bracts of *L. bradshawii*. (Photo by Steve Gisler.)

The species is distinguished from other species of *Lomatium* by its conspicuously ternately divided free involucel bracts (Figure 27). *L. utriculatum*'s range overlaps with

that of *L. bradshawii*, but its involucels are shallowly cleft and its fruit is thinly winged (WNHP 1999).

Seed production

Kaye et al. (2003) observed of unfilled seeds in mature fruits of *L. bradshawii*, but no data are available on the extent of this phenomenon. Kagan (1980) sampled seed production at six sites and found the mean number of fruits per plant to range from 7.2-18.5. He observed that seeds may be dispersed by wind or water, but they do not usually travel more than one meter from the parent plant. In another study, Kaye and Kirkland (1994a) state that the plant does not form a persistent seed bank, and average fruit production is 10.8 fruits per plant. While researching the effects of fire on *L. bradshawii*, Pendergrass et al. (1999) observed fruit production to vary in response to site, year, and burning regime, ranging between 0.3-18.0 fruits per plant.

Seed germination

Gasser (1990) performed a series of germination trials for rare Apiaceae species, including *L. bradshawii*. Using one-year-old and thirteen-year-old seed stored at the Berry Botanic Garden (BBG), Gasser cold stratified seeds for either 8 or 16 weeks, followed by germination at either a constant temperature of 68°F (20°C) or alternating temperatures of 50°F/68°F(10°C/20°C). One hundred percent germination was attained by one-year-old seeds stratified for 16 weeks, followed by a constant germination temperature of 68°F (20°C). High germination rates were also achieved for both seed ages with both the 8 and 16 week cold stratification followed by the alternating temperature regime (70-90%).

Kaye and Kuykendall (2001) investigated this cold stratification requirement further by pre-chilling *L. bradshawii* seeds for 0, 2, 4, 6, and 8 weeks at 4°C, then germinating the seeds under two alternating temperature regimes: 59°F/77°F (15°C/25°C) and 68°F/86°F (20°C/30°C). Germination percentages were the highest (50-70%) for seeds which were

cold stratified for 8 weeks, followed by lower alternating temperature regime (15°C/25°C).

The most recent *Lomatium bradshawii* seed germination attempts were performed by Lynda Boyer (Heritage Seedlings Inc., Salem, Oregon, personal communication), who reported nearly 100 percent germination by mixing seeds with pre-moistened vermiculite inside sealed plastic bags and cold stratifying the mixture at 1°C for 11 weeks. This seed/vermiculite mixture was then sown into soil-filled flats, lightly covered with a "light dusting of soil," with germination typically occurring within seven days of sowing.

Vegetative reproduction

Kaye and Kirkland (1994a) state that *L. bradshawii* is taprooted, and is not capable of vegetative reproduction.

Breeding system

Kagan (1980) found that 90% of *Lomatium* flowers are exclusively male, with hermaphroditic flowers occurring mainly on the outer umbellets of the second umbel of a plant, so fruit set is somewhat limited. Bagging experiments show that the species is completely self compatible, and suggest that plants were capable of seed production through selfing in the absence of pollinators. There was no evidence of apomixis among emasculated flowers. As in other species of *Lomatium*, flowers of *L. bradshawii* are protogynous, with the styles exerted while the stamens and the petals are still recurved inward, as in the bud. Despite extensive observations, Kagan observed very few insects near the plants. The primary insect visitors were small gnats, and these did not appear to transport any pollen. At Willow Creek a few Andrenidae bees were observed, and appeared to carry pollen, but they were infrequent. Kagan speculates that some between-umbel pollination could occur through wind dispersal of pollen. He also comments that higher fruit set among plants more distant from their nearest neighbors may indicate some inbreeding depression.

Seemingly in contrast to Kagan (1980), Kaye and Kirkland (1994a) showed through a pollinator exclusion experiment that insects are required for fruit production. Autogamy is prevented because protogyny completely separates sexual phases of flowers within an inflorescence. As such, outcrossing rates are very high within populations. Their research confirms Kagan's findings that the first umbel is all male, and that the second umbel produces some hermaphroditic flowers among the outer umbellets. Unlike Kagan, Kaye and Kirkland observed a large diversity of insect visitors, including at least 38 species of bees, flies, wasps, beetles, and others. Twenty-six of these species (primarily bees and syrphid flies) exhibited *Lomatium* pollen on their bodies. (Figure 28 shows an additional pollinator observed at Finley NWR.)

Figure 28. Pollinator (*Halictus* sp.) visiting *Lomatium bradshawii*. (Photo by Steve Gisler.)

Jackson (1996) observed 21 species of pollinator at the Fisher Butte population near Eugene. The most frequent pollinators included a large syrphid fly (*Heliophilus fasciatus*) (44 percent of visits), two species of *Andrena* (14.8 percent of visits), smaller syrphid flies (11.1 percent) and a dung fly (*Scatophaga stercoraria*) (7.4 percent). Mean

seed dispersal distance was 22.46 cm. Based upon density calculations and pollen carryover estimates, neighborhood size (the number of interbreeding individuals) was estimated using three different models from 17-95 individuals (40 m^2 to 227 m^2).

Using AFLP markers to study the genetic diversity of *Lomatium bradshawii*, Gitzendanner (1998) found high levels of genetic diversity in most of the plant's populations. He does not consider inbreeding depression to be a threat to this species, and feels that, as long as population sizes do not decrease, the long-term genetic stability of the plant looks good.

Hybridization

Siddall and Chambers (1978) site Mathias and Constance as experts on the genus; these researchers state that *Lomatium bradshawii* has no close or compatible relatives in its range and habitat, suggesting that interspecific hybridization is not likely for this species. To date, no research has been conducted regarding potential hybridization between *L. bradshawii* and other *Lomatium* species. None of the literature reviewed mentions hybridization as a possibility or concern.

Cultivation

Kaye et al. (2003) successfully propagated *Lomatium bradshawii* plants by potting germinated seeds (see "Seed germination" section above) in Oregon State University greenhouse soil mix consisting of one part peat, one part loam and two parts pumice. Seedlings were grown in cohorts in a heated greenhouse (20°C-25°C), where they were watered twice weekly and fertilized with 20:20:20 fertilizer once a week. Survival rates were high (73%-99%), and most seedling mortality occurred at the early seedling stage. Survival in the short term was not affected by pot size.

The most recent attempts to cultivate *Lomatium bradshawii* were reported by L. Boyer (personal communication). As described in the "Seed germination" section above, seeds were mixed with pre-moistened vermiculite and cold stratified (at 1°C) inside sealed

plastic bags for 11 weeks. This seed/vermiculite mixture was then sown into flats filled with a planting medium consisting of bark, compost, peat, perlite, and Philip's pre-mix (crabmeal, 3 kinds of lime, micronutrients, Actino-iron, and a wetting agent). Following establishment in flats, seedlings were transplanted into 5 inch x 2 3/8 inch pots. Boyer reported very high (nearly 100 percent) establishment and survival rates, and noted that after 60 days, "*Lomatium bradshawii* does not produce many leaves but the root is well established by this time."

Transplanting and introduction attempts

According to Kaye et al. (2003), direct seeding of *Lomatium bradshawii* is highly effective, with recruitment at one location ranging from 17 to 38% for undisturbed and bare soil plots, respectively (5 plots per treatment with 60 seeds per plot). At the second study site, seedling emergence ranged from 19-30% and was not affected by soil amendments (compost, fertilizer, mycorrhizal inoculae, and mycorrhizal inoculae mixed with compost). Several years prior to this study, Clark et al. (2001) attempted direct seeding in burned and unburned plots, located in a study grid at Danebo Wetland, Eugene, Oregon. 180 seeds were used, but there was no germination, regardless of burned or unburned treatments.

Greenhouse-cultivated *Lomatium bradshawii* plants (grown from seed) were transplanted to research plots in both the fall and spring of 2000 (Kaye et al. 2003). Seeds were collected in late June or July of 1999, and potted (in 5" or 9" pots) in mid-December of the same year. Half of the plants were outplanted in March of 2000. The rest remained in the greenhouse throughout the summer, where they were watered daily and fertilized with liquid fertilizer monthly. The fall transplants were outplanted in late October of 2000. All transplants were given 1-2 teaspoons of 17-17-17 slow release fertilizer at the time of outplanting. Two years later, approximately 40 and 75 percent of the transplants had survived at the two sites, respectively, although as of 2002 very few of the survivors were reproductive. Survival of *L bradshawii* transplants appeared to be greater for unfertilized transplants and transplants planted in the autumn. The effect of fertilizer was

not seen in the first year, but became significant in the second and third years of monitoring.

Population monitoring

Pendergrass et al. (1999) monitored three sites to determine the impacts of burning on *Lomatium bradshawii* population trends at Bureau of Land Management and Army Corps of Engineers properties. The density and abundance of reproductive plants increased in the presence of fire (burned either twice or three times) between 1988 and 1997, corroborating other evidence that fire improves population growth rate and chances for survival (Caswell and Kaye 2001). Monitoring also showed the effects of fire to be temporary, dissipating after 1 to 3 years.

Kaye and Kirkland (1994b) established permanent monitoring plots at 3 sites: Buford Park in Eugene, Finley National Wildlife Refuge (NWR) and Jackson-Frazier Wetland in Corvallis. Plots varied in shape to accommodate the distribution of plants. Plants were divided into one of seven size categories. All plants were mapped, numbered, and herbivory was recorded. First-year data showed population structures at Buford and Finley skewed towards non-reproductive plants, with only 31% and 33% of the populations reproductive, respectively. At Jackson-Frazier, 52% of the plants were reproductive. Seedlings occurred at low frequencies in all three sites, and populations were generally skewed towards smaller non-flowering plants. Plant density ranged from 1.05-28 plants per meter.

Monitoring by Drew (2000) at Oak Creek showed that grazing may increase emergence of new plants, while having no detectible effect on plant survival. Drew speculates that this pattern is possibly due to corresponding reductions in herbivory by small mammals (small mammal densities were lower in grazed plots).

Additional monitoring results are summarized by Robinson (1998). Annual monitoring has taken place at Willow Creek since 1993, showing a general downward trend in

population size from 1993-1998. Monitoring conducted from 1982-1993 at Finley NWR indicate a substantial increase in population numbers, from 41 plants to over 1700.

Conservation agreements for the two Washington populations were finalized in 1995 and 1998 (CPC 2004). As part of these agreements, both of these populations have been monitored since 1997; however, no data have been published regarding the results of this monitoring.

Land use threats and other limitations

The historical and continuing loss and degradation of Willamette Valley prairie habitat is a pressing concern for *Lomatium bradshawii*. Agricultural, commercial and residential development has almost completely eliminated the native grasslands of this area; currently less than one percent of the Willamette Valley prairie remains intact (CPC 2004). Pesticides, encroachment of woody and invasive species, herbivory and grazing are also threats to remaining *L. bradshawii* populations.

Development: The majority of Oregon's *Lomatium bradshawii* populations are located within a ten mile (16 km) radius of Eugene. The continued expansion of this city is a potential threat to the future of these sites. Even when the sites themselves are protected, the resultant changes in hydrology caused by surrounding development can alter the species' habitat (Meinke 1982, USFWS 1988, WNHP 1999, CPC 2004). Siddall and Chambers (1978) state that the majority of sites from which herbarium specimens have been collected are within areas of Salem or Eugene which are now developed for housing and agriculture.

Pesticides: Many *L. bradshawii* populations occur near roadways and other areas which are sprayed with pesticides. There is concern that these pesticides will kill the pollinators necessary for plant reproduction. Because *L. bradshawii* does not form a seed bank, any loss of pollinators (and subsequent lack of successful reproduction) could have an immediate effect on population numbers (Kaye and Kirkland 1994a).

Woody/Invasive Species: The final rule (USFWS 1988) states that one of the most significant threats to *L. bradshawii* is encroachment of its habitat by woody vegetation. Historically, Willamette valley prairies were periodically burned, either by wildfires or by fires set by Native Americans (Johannessen et al. 1971). Since European settlers arrived, fire suppression has allowed shrubs and trees to invade grassland habitat (USFWS 1988, Kaye 1993). To prevent habitat loss through successional vegetation changes, manual control of woody plants such as *Fraxinus latifolia* and *Rosa pisocarpa* has occurred as part of the conservation agreement for one of the Washington populations (CPC 2004).

Herbivory/Grazing: At a *Lomatium bradshawii* meeting, Robinson (1998) indicated that "vole herbivory at some sites is a major threat to local species viability." Studies of the effects of cattle grazing on *L. bradshawii* populations show mixed results. Grazing in the springtime, when *L. bradshawii* plants are growing and reproducing, can negatively impact the plants by biomass removal, trampling and soil disturbance (CPC 2004). However, late-season livestock grazing, after fruit maturation, led to an increase in emergence of new plants, and the density of plants with multiple umbels, although it did not alter survival rates or population structure (Drew 2000). Drew speculated that the increase in seedlings may be due to small disturbances in the soil, a reduction of shading by nearby plants, and reduced herbivory by small mammals.

Population introduction/augmentation strategy

Based upon the biogeographical data compiled and described above for *Lomatium bradshawii*, 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 this rare species. Although many *L. bradshawii* populations face imminent threats, and native prairie habitat has been reduced to a small fraction of its former abundance, there are still several extant *L. bradshawii* populations that occur on public or otherwise secure landholdings. The largest known site in Oregon and another smaller site occur on private plant that has been leased to The Nature Conservancy (TNC). Three of the Oregon populations are on land designated as a

"Wetlands Special Study Area" (CPC 2004). As such, pending interagency cooperation and funding availability, there should be sites available for collection of seeds for use in off-site cultivation projects, and open locations should also be available for population augmentation and introduction purposes.

The biology and life history of *Lomatium bradshawii* likewise pose no unavoidable hurdles to successful implementation of population introduction and augmentation projects. Although the relatively low seed production of *L. bradshawii* poses a potential limitation to the number of seeds that can be collected and used in a single year for off-site cultivation projects, this complication can be overcome, if necessary, by using sustainable seed collecting practices over multiple years prior to project implementation. Seed germination was fairly high for seed that had been stored for up to 13 years at the Berry Botanic Garden. *Lomatium bradshawii* has been successfully cultivated in the greenhouse, and the species exhibits no unique propagation or soil symbiont requirements. Once adequate seed supplies are available, there are no apparent cultivation-related obstacles to implementation of introduction projects.

Based upon the information provided in this manual, the following procedures are recommended for *Lomatium bradshawii* population introductions:

1. Select population introdution/augmentation target sites. Several factors should be considered when selecting target sites for *Lomatium bradshawii* population introduction and augmentation projects. First, target sites should contain suitable prairie habitat. Although habitat descriptions have been provided in this manual, it is extremely helpful to visit extant populations and see the habitat in which the plant grows. Such visits should give a better idea of the types of microsites occupied by *L. bradshawii* individuals within their larger native grassland habitat context.

   Given the lack of long-term protection of *L. bradshawii* 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. Because grazing can have a negative impact on *L. bradshawii* populations, it is important to ensure that grazing, if allowed, is carefully monitored and scheduled for late in the season, after *L. bradshawii* fruits have matured and seed dispersal is complete.

2. Collect *Lomatium bradshawii* seeds for off-site cultivation of introduction stock. Introduction efforts involving *L. bradshawii* indicate that both direct sowing of seed and transplanting plugs are successful ways to introduce new propagules into a site. Normally, if recruitment from directly-sown seed is high, this is the best way to introduce new plants – the cost is often lower and the genetic diversity of the new population is higher. However, since there have been mixed results with the two seeding experiments conducted so far, initial introduction efforts should include both direct seed sowing and transplants. Source material for off-site cultivation should be collected from the extant population(s) located nearest to the introduction target sites to maximize conveyance of potential local adaptations. When collecting seed, an effort should be made to collect seeds from as large a sample of genetically variable individuals as possible, in an effort to elevate seed production, fitness and adaptive genetic variability within the introduced population.

3. Cultivate *Lomatium bradshawii*. *Lomatium bradshawii* has been successfully cultivated from seed. Previous studies suggest that seeds should be cold stratified for at least eight weeks, followed by an alternating 10°/20°C (50°F/68°F) temperature treatment. Once seeds have germinated, they can be potted in 5" pots, watered daily and fertilized monthly.

4. Introduce cultivated plugs and seeds into the target site(s). *Lomatium bradshawii* propagules will probably be most likely to establish if planted in the late fall, after the arrival of the fall rains. Seed plots should have the vegetation cleared before

sowing, and no fertilizer should be used with plug transplants. Although few studies have focused on the impacts of population size on *L. bradshawii*'s ability to attract pollinators and produce viable seed and robust progeny, small populations tend to be more vulnerable to extinction through 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 *L. bradshawii* populations should be monitored annually to evaluate project success. These evaluations should take place in the late spring or early summer, when fruits are mature and it is possible to assess reproductive success. Monitoring should, at least in the first several years, consist of demographic monitoring of individuals in order to yield data on the survival and performance of individual plants over time.

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