WESTERN FORBS: BIOLOGY, ECOLOGY, AND USE IN RESTORATION

GOOSEBERRYLEAF GLOBEMALLOW

Sphaeralcea grossulariifolia (Hook. & Arn.) Rydb.

Malvaceae – Mallow family

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ORGANIZATION

NOMENCLATURE

Sphaeralcea grossulariifolia (Hook. & Arn.) Rydb., hereafter referred to as gooseberryleaf globemallow, belongs to the Malveae tribe of the Malvaceae or mallow family (Kearney 1935; La Duke 2016).

NRCS Plant Code. SPGR2 (USDA NRCS 2017).

Subtaxa. The Flora of North America (La Duke 2016) does not recognize any varieties or subspecies.

Synonyms. *Malvastrum coccineum* (Nuttall) A. Gray var. *grossulariifolium* (Hooker & Arnott) Torrey, *M. grossulariifolium* (Hooker & Arnott) A. Gray, *Sida grossulariifolia* Hooker & Arnott, *Sphaeralcea grossulariifolia* subsp. *pedata* (Torrey ex A. Gray) Kearney, *S. grossulariifolia* var. *pedata* (Torrey ex A. Gray) Kearney, *S. pedata* Torrey ex A. Gray (La Duke 2016).

Common Names. Gooseberryleaf globemallow, current-leaf globemallow (La Duke 2016).

Chromosome Number. Chromosome number is stable, 2n = 20, and plants are diploid (La Duke 2016).

Hybridization. Hybridization occurs within the *Sphaeralcea* genus. Gooseberryleaf globemallow hybridizes with scarlet globemallow (*S. coccinea*), small-leaf globemallow (*S. parvifolia*), and Munro's globemallow (*S. munroana*). The resulting intermediate hybrids make identification challenging (Welsh et al. 1987; Atwood and Welsh 2002).

DISTRIBUTION

Gooseberryleaf globemallow is native to North America and occurs primarily in the Intermountain region in the western states of Washington, Oregon, Idaho, Nevada, Utah, Arizona, and New

Mexico (La Duke 2016). It is also reported in northern California but may reach its maximum abundance in Utah (Kearney 1935). Plants are winter hardy, especially in regions with at least periodic snow cover. They are most abundant on open or disturbed sites receiving 8 to 12 inches (200-300 mm) of annual precipitation (Wasser 1982; Stevens et al. 1985).

Habitat and Plant Associations. Gooseberryleaf globemallow is common and widespread in salt, warm, and cool desert shrublands (Fig. 1). It also occurs in the openings of mountain brush communities, pinyon-juniper (*Pinus*-*Juniperus* spp.) woodlands, and ponderosa pine (*P. ponderosa*) forests (Blaisdell and Holmgren 1984; Welsh et al. 1987; Atwood and Welsh 2002; Stevens and Monsen 2004a). Common vegetation associates are shadscale (*Atriplex confertifolia*), big sagebrush (*Artemisia tridentata*), blackbrush (*Coleogyne ramosissima*), and rabbitbrush (*Chrysothamnus* or *Ericameria* spp.) (Flowers 1934; Fautin 1946; Plummer et al. 1968; Horton 1989; Donart 1994; Alzerreca-Angelo et al. 1998; Stevens and Monsen 2004a).

Figure 1. Gooseberryleaf globemallow growing on Milford Flat, Milford County, UT. Photo: S. Young, Utah State University.

Elevation. Gooseberryleaf globemallow occupies sites at elevations from 330 to 6,600 feet (100-2,000 m) across its range (La Duke 2016).

Soils. Plants are drought tolerant and grow on most soil textures, but are common on volcanic substrates. Sandy to clay loams are common habitats, but plants also occur on rocky, or gravelly soils and thin foothills soils (Wasser 1982; Belcher 1985; Pendery and Rumbaugh 1986; La Duke 2016).

Plants are most frequent on sites with basic soils (Kearney 1935; Horton 1989; Pendery and Rumbaugh 1993). Moderately saline soils are tolerated but sodic soils are not (Wasser 1982).

In a greenhouse study evaluating growth in field-collected soils, emergence and short-term survival were significantly greater ($P < 0.05$) in sandy loam than clay loam soils. Sandy loam soils were 69% sand, 13% clay, and 19% silt; clay loams were 35% sand, 30% clay, and 36% silt (Rawlins et al. 2009).

DESCRIPTION

Gooseberryleaf globemallow is a morphologically diverse perennial (Kearney 1935; Stevens and Monsen 2004a; Tilley et al. 2011; La Duke 2016). Many intermediate forms are possible where its distribution overlaps with scarlet, small-leaf, or Munro's globemallow with which it freely hybridizes (Welsh et al. 1987; Atwood and Welsh 2002; Tilley et al. 2011; Sriladda et al. 2012).

Plants produce a large, deep, branching taproot with several surface feeding roots (Kearney 1935; Wasser 1982; Mee et al. 2003; Holmgren et al. 2005; Tilley et al. 2011). Erect to somewhat spreading stems develop from the branching woody base (Welsh et al. 1987; Mee et al. 2003; Holmgren et al. 2005; Pavek et al. 2012). Stems are few to many in loose tufts and typically measure 24 to 39 inches (60-100 cm) tall, but taller and shorter forms also occur (Wasser 1982; La Duke 2016). Stems are up to 4 mm in diameter at the base (Kearney 1935) and range from hairless to densely covered with short, fine, white hairs and thus are green to gray-green or whitish (Welsh et al. 1987; Atwood and Welsh 2002; La Duke 2016). Density of hairs may decrease as stems age (Kearney 1935; Holmgren et al. 2005).

Leaves are arranged alternately and are typically triangular with 3 to 5 lobes that are divided nearly to the midvien (Welsh et al. 1987; Parkinson 2003; Holmgren et al. 2005; La Duke 2016). Five veins spread from the leaf base where they are most prominent (Kearney 1935). Leaves are often thin and 0.4 to 2 inches (1.3-5 cm) long, although lengths of 3.5 inches (9 cm) have been reported. Leaves are generally slightly longer than they are wide (Welsh et al. 1987; Mee et al. 2003; Holmgren et al. 2005; La Duke 2016) and often covered with gray stellate hairs. Teeth on the leaf margins are irregularly pointed to rounded (Kearney 1935; Wasser 1982; La Duke 2016).

Flowers are several per node and attached by short petioles along a narrow, elongate, interrupted thyrsoid panicle (Fig. 2) (Mee et al. 2003). Flowers are 8 to 20 mm wide with 5 red to red-orange or red-pink petals. Stamens are numerous and coalescent, forming a tube (staminal column). Anthers are yellow (Wasser 1982; Welsh et al. 1987; Atwood and Welsh 2002; Holmgren et al. 2005; Pavek et al. 2012; La Duke 2016). Fruits are densely pubescent schizocarps, each consisting of 10 to 12 one or two-seeded mericarps (carpels) arranged in a ring (Kearney 1935; Wasser 1982; Belcher 1985; La Duke 2016). Schizocarps measure 2.5 to 3.5 mm long and are slightly less wide (2-2.5 mm) (Figs. 3 and 4). Mericarps dehisce along the upper one-third to one half, which is papery and veiny, exposing the seeds. The lower portion is indehiscent (Holmgren et al. 2005; La Duke 2016). Seeds are gray to black, kidney shaped, hairless or covered with short, soft hairs, and contain little or no endosperm. Seeds often have the lacy fruit coat attached when the mericarps dehisce naturally (Fig. 4) (Belcher 1985).

Figure 2. Gooseberryleaf globemallow flowers. Photo: USDI BLM ID931 SOS.

The mericarp is the structure that is dispersed at reproductive maturity. This structure naturally dehises but unevenly over time. For the remainder of this chapter, the term seed will refer to both the mericarp and its one or two seeds.

Figure 3. Gooseberryleaf globemallow schizocarps (whole fruits), mericarps (segments of the schizocarps), and individual seeds (black). Photo: USDI BLM NM930 SOS.

Figure 4. Gooseberryleaf globemallow seeds (scale is cm). Photo: USDI BLM ID931 SOS.

Reproduction. Plants reach reproductive maturity by their second year (Wasser 1982), and flowering is episodic and extensive (Sharp et al. 1990; Kitchen 1994). Many researchers have reported reproductive explosions and subsequent disappearance of plants (Shreve and Hinckley 1937; Blaisdell and Holmgren 1984; Sharp et al. 1990; Kitchen 1994). Kitchen (1994) indicated that favorable germination conditions trigger explosive reproduction. Blaisdell and Holmgren (1984) indicated that favorable establishment conditions are required every 2 to 3 years for the species to persist on a site. Shreve and Hinckley (1937) noted that plants disappeared and reappeared during periodic visits to desert sites near Tucson, Arizona. While no research has specifically investigated the origin of plants in a year of extensive flowering, the appearance of many large, seemingly mature plants following a year of relative absence, suggests that boom populations may be a mixture of seed germination and sprouting from dormant plants (S. Young, Utah State University [USU]-retired, personal communication, February 2018).

While the episodic, boom and bust reproduction suggests gooseberryleaf globemallow is short-lived, a very small percentage of plants may be long-lived. On the Desert Experimental Range in southwestern Utah, West (1979) followed a seedling cohort and found a small number of plants lived for 33 years in the salt desert shrub community (West 1979).

Repeat photo monitoring suggests that the timing and amount of spring precipitation may be important for episodic explosions of flowering and reproduction. Photo monitoring was conducted over a 40-year time frame in a shadscale shrubland in the Raft River Valley of south-central Idaho. The largest gooseberryleaf globemallow floral display occurred in 1964 when spring precipitation was 3 times the average. However, plants were also present and flowered, albeit much less in years when spring precipitation was below average (Sharp et al. 1990).

Figure 5. Gooseberry globemallow flower boom on the Colorado Plateau. Photo: USDI BLM CP2 SOS.

Flowering and fruiting phenology. Gooseberryleaf globemallow flowers indeterminately. While flowers are typical in the spring or summer and generally most abundant from May through July (Stevens et al. 1985; La Duke 2016), flowering can continue into September or later (Shock et al. 2015; USDI BLM SOS 2017). Seed is typically mature in June, July, or August (Stevens et al. 1985).

Breeding system. Gooseberryleaf globemallow is strongly outcrossing and perhaps even self-sterile (Kearney 1935).

Pollination. Gooseberryleaf globemallow is insect-pollinated and especially attractive to bees (Pendery and Rumbaugh 1986; Ogle et al. 2011; Tepedino 2017). The globemallow bee (*Diadasia diminuta*) is a globemallow (*Sphaeralcea* spp.) specialist and an important pollinator for gooseberryleaf globemallow (Tepedino 2017). Other bees (*Apis*, *Agapostemon*, *Calliopsis*, *Halictus*, *Melissodes* spp.) and wasps (*Ammoplanus* spp.) are also important globemallow pollinators (Pendery and Rumbaugh 1986). At sites in Idaho, Nevada, Utah, and Wyoming, an average of 14.5 native bee visitors were observed for every 100 globemallow (gooseberryleaf and Munro's) plants examined (Cane and Love 2016).

ECOLOGY

Gooseberryleaf globemallow is frequently associated with disturbed sites, but it is also a common component of late seral shrubland and woodland vegetation (Stevens and Monsen 2004a; 2004b; Sharp et al. 1990).

Seed and Seedling Ecology. Partially dehiscent gooseberryleaf globemallow fruits are considered an adaptation to exploit a range of dispersal conditions and increase the chances of capitalizing on favorable germination conditions. Dehiscent portions of the mericarp release the seed as soon as they are mature, while the indehiscent portion holds seeds until they are dislodged or later natural dehiscence occurs after a period of weeks or months (Kearney 1935). Colonization of disturbed sites is primarily thought to be from germination of soil-stored seed (Plummer 1958; Wasser 1982; Ott et al. 2001).

Disturbance Ecology. Abundance of gooseberryleaf globemallow is often greater in open or recently disturbed than in undisturbed sites (Plummer 1958; Wasser 1982; Ott et al. 2001). Plants were either restricted to or had greater abundance on mechanically disturbed than undisturbed sites in Utah. Growth was "remarkable" by the 3rd year after cabling a Utah juniper-singleleaf pinyon (*J. osteosperma*-*P. monophylla*) woodland where it was inconspicuous before treatment and on undisturbed sites (Plummer 1958). In Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) and Utah juniper communities, established gooseberryleaf globemallow plants were relatively unaffected by chaining that followed post-fire aerial seeding (Ott et al. 2003).

Fire response. Gooseberryleaf globemallow is common on burned sites where its abundance is often greater than on unburned sites. Plants were absent from unburned sites but occurred on 2-, 6-, and 17-year old burned blackbrush-dominated sites in southwestern Utah. Cover was greatest on 6-year old burned plots (Callison et al. 1985). In west-central Utah, frequency was slightly greater on burned than unburned sites visited 1, 2, and 3 years after a summer wildfire that killed nearly all nonsprouting perennials in big sagebrush and Utah juniper vegetation (Ott et al. 2001). In central Arizona, production increased after fire in lovegrass (*Eragrostis* spp.)-dominated grasslands even when post-fire growing season precipitation was about 7 inches (180 mm) below normal. On north slopes, production was 9 lbs/acre (10 kg/ha) before the fire and 30 lbs/acre (34 kg/ha) in the first post-fire growing season. On south slopes, production was 10 lbs/acre (11 kg/ha) before and 18 lbs/acre (20 kg/ha) after the fire (Pase and Knipe 1977).

Land-use response. Land-use legacies may also affect abundance of gooseberryleaf globemallow (Morris et al. 2013). When abandoned old-fields (dryland farmed in the 1910s) were compared to uncultivated sagebrush vegetation in northwestern Utah in 2011, the biomass of gooseberryleaf globemallow was about half as much in the old fields. In a follow-up greenhouse study, survivorship was significantly ($P = 0.01$) less when gooseberryleaf globemallow seeds were grown in soil collected from the old field (73%) than from the non-cultivated (100%) site. Survivorship and growth differences could not be linked to soil nutrient differences, which suggested other abiotic factors may affect plant performance on old fields and non-cultivated sites (Morris et al. 2013).

Grazing response. Although described as grazing tolerant, abundance of gooseberryleaf globemallow was often less on sheep-grazed than ungrazed sites, regardless of the season of use. Close grazing or grazing after prolonged drought often resulted in plant injury or loss (Pendery and Rumbaugh 1986; Stevens and Monsen 2004a). When long-term (59 yrs) effects of winter and spring sheep grazing were compared in exclosures and grazed sites at Utah's Desert Experimental Range, frequency was lower on grazed than exclosure plots, but not significantly so (Kitchen and Hall 1996). In newly established pasture near Kimberly, Idaho, mortality of gooseberryleaf globemallow was greater in plots grazed by sheep in the fall (43%) than in ungrazed plots (24%). While mortality differences may have been exacerbated by a clipping treatment conducted in the first year of the study, mortality was also greater in grazed than ungrazed plots that were not clipped (Rumbaugh et al. 1993a). West (1979) found seedling establishment and persistence were less on winter sheep-grazed plots than on ungrazed plots in a salt desert shrubland at Utah's Desert Experiment Range (Table 1).

Table 1. Establishment and survival of 1935 seedling cohorts of gooseberryleaf globemallow with and without winter sheep grazing. Total number of seedlings surviving on plots (4 each, plot size: 5 X 20 ft) at the Desert Experimental Range in Millard County, UT (West 1979).

Year	1935 establishment yr	1936	1937	1958	1968
Grazed	51	36	28	5	4
Ungrazed	189	111	91	6	5

Ingested seed may be dispersed by livestock (Whitacre and Call 2006). In a controlled study, about 50% of the seeds fed to heifers were recovered within the first 3 days of ingestion. Seed recovery was greatest 1 day after ingestion (28%), and increased time in the gut decreased seed germinability. Germination was significantly greater (17.7%) after 1 day than after 2 days (8.7%) or 3 days (10.4%) in the gut ($P \leq 0.05$). Germination of control seed was 40% (Whitacre and Call 2006).

Wildlife and Livestock Uses. Gooseberryleaf globemallow is utilized by a variety of wildlife and livestock (Ogle et al. 2011). Plants are green early in the spring (mid- or late March) and can remain green through late September or October (Horton 1989; Monsen and Stevens 2004), especially with seasonal storms (Ogle et al. 2012). Deer (*Odocoileus* spp.), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), and bighorn sheep (*Ovis canadensis*) feed on the forage and birds and rabbits feed on the seed. Globemallow species are also considered a preferred greater sage-grouse (*Centrocercus urophasianus*) food (Dumroese et al. 2016). If rabbit (Leporidae) populations are high, establishment of globemallow from seed is challenging (Pendery and Rumbaugh 1986).

Plants are considered most palatable to pronghorn when flowering (Pendery and Rumbaugh 1986). On the Desert Experimental Range in western Utah, globemallows (gooseberryleaf was most common) were preferred by pronghorn (Beale and Smith 1970). Globemallow use was high in spring (March-May), wet summers (June-August), and wet falls (September-November). In an uncharacteristically wet June and July, globemallow made up 34% of pronghorn diets. The considerable drought tolerance of globemallows provided green forage in most summers (Beale and Smith 1970).

Utilization of gooseberryleaf globemallow by domestic sheep was high on spring- and winter-grazed sites in Idaho and Utah. Average utilization was 80% in the fall and winter after 10 years of evaluations on winter sheep range in west-central

Utah (Hutchings and Stewart 1953). Average sheep consumption was 70% in the spring and 63% in the fall after 2 years in newly transplanted pastures of crested wheatgrass (*Agropyron cristatum*), alfalfa (*Medicago sativa*), and gooseberryleaf globemallow near Kimberly, Idaho (Rumbaugh et al. 1993a).

Nutritional value. Gooseberryleaf globemallow meets the dietary requirements of sheep and cattle (Pendery and Rumbaugh 1993). In studies of spring nutrition, in vitro digestibility averaged 70% and crude protein averaged 20% (Welch 2004). Forage characteristics of gooseberry globemallow in new pastures near Kimberly, Idaho (Table 2), met the nutritive requirements for sheep and medium-sized, yearling heifers (Rumbaugh et al. 1993b).

Table 2. Nutritional content (fall and spring concentrations averaged) of gooseberryleaf globemallow plants growing near Kimberly, Idaho (Rumbaugh et al. 1993b).

Measurement	Microminerals (µg/g)				
Element	Cu	Fe	Mn	Na	Zn
Leaves	14	1560	62	160	41
Stems	15	390	22	320	33

Measurement	Macrominerals mg/g				
Element	Ca	Mg	N	P	K
Leaves	24	5.4	38	3.9	18
Stems	14	4.5	23	2.3	20

Ethnobotany. Medicinal value of gooseberryleaf globemallow may be limited. The Hopi used it to ease consitipation and treat broken bones. Parts of the plant were also mixed with clay in Hopi pottery (Moerman 2003).

Horticulture. Gooseberryleaf globemallow is grown and sold as an attractive, xeric, and pollinator-friendly landscape plant in the Intermountain West (Mee et al. 2003; UW Ext. 2018). Its ready establishment from planted seedlings, rapid growth, showy flowers, and long flowering periods make it a landscape favorite (Meyer et al. 2009; UW Ext. 2018). Flowers give off a pleasing scent that, although not strong, resembles a mix between orange blossom and cotton candy (Meyer et al. 2009).

REVEGETATION USE

Many gooseberryleaf globemallow growth characteristics make it useful in restoration of disturbed or degraded rangelands, mined sites, unstable soils, and for roadside beautification (Wasser 1982). It is a natural colonizer of disturbed sites, thrives in harsh conditions, tolerates moderate grazing, establishes quickly, exhibits good seedling vigor and competitiveness, and produces seed in year one or two (Shaw and Monsen 1983; Stevens et al. 1985; Pendery and Rumbaugh 1986; Horton 1989). It is best suited for restoration of sites receiving less than 12 inches (305 mm) of annual precipitation (Pendery and Rumbaugh 1993) and has been used successfully in revegetation of pinyon-juniper, sagebrush-rabbitbrush, shadscale, and blackbrush sites (Shaw and Monsen 1983; Stevens et al. 1985; Pendery and Rumbaugh 1986; Horton 1989). Long flowering period, showy blooms, and low-maintenance growth make it desirable for revegetation of campgrounds, rest areas, visitor centers, or other recreation sites (Shaw and Monsen 1983).

Because of good early growth and rapid reproduction, gooseberryleaf globemallow is often used as a component of wildland seeding mixes (Stevens et al. 1985). Diversity in seed mixes may also reduce invasibility of restoration sites. In a field experiment near Spanish Fork, Utah, plots planted with a combination of native shrubs, forbs, and bunchgrasses were invaded less by seeded annual grasses than plots planted with two native bunchgrasses. The experiment used four forb species, one of which was gooseberryleaf globemallow in the more diverse plots. Researchers concluded that invasibility was reduced by structural diversity (Allen and Meyer 2014).

DEVELOPING A SEED SUPPLY

For restoration to be successful, the right seed needs to be planted in the right place at the right time. This involves a series of steps that require coordinated planning and cooperation among partners to first select appropriate species and seed sources and then properly collect, grow, certify, clean, store, and distribute seed for restoration.

Developing a seed supply begins with seed collection from native stands. Collection sites are determined by current or projected revegetation requirements and goals. Production of nursery stock requires less seed than large-scale seeding operations, which may require establishment of agricultural seed production fields. Regardless of the size and complexity of any revegetation effort, seed certification is essential for tracking seed origin from collection through use.

Seed Sourcing. Because empirical seed zones are also not currently available for gooseberryleaf globemallow, generalized provisional seed zones developed by Bower et al. (2014), may be used to select and deploy seed sources. These provisional seed zones identify areas of climatic similarity with comparable winter minimum temperature and aridity (annual heat:moisture index). In Figure 6, Omernik Level III Ecoregions (Omernik 1987) overlay the provisional seeds zones to identify climatically similar but ecologically different areas. For site-specific disturbance regimes and restoration objectives, seed collection locations within a seed zone and ecoregion may be further limited by elevation, soil type, or other factors.

The Western Wildland Environmental Threat Assessment Center's (USFS WWETAC 2017) Threat and Resource Mapping (TRM) Seed Zone application provides links to interactive mapping features useful for seed collection and deployment planning. The Seedlot Selection Tool (Howe et al. 2017) can also guide restoration planning, seed collection, and seed deployment, particularly when addressing climate change considerations.

Releases. As of early 2018, there were no gooseberryleaf globemallow germplasm releases.

Wildland Seed Collection. Gooseberryleaf globemallow seed ripens unevenly within plants and populations (Shaw and Monsen 1983). Because some seed is dispersed once the fruits are fully mature (Shock et al. 2008), the timing of seed collection is important. Harvests can be maximized by collecting when the lowest schizocarps start to split and the majority are just starting to open. Fruits will be light green-brown in color. At this stage, about 25% of seeds are mature (Pendery and Rumbaugh 1990 cited in Pendery and Rumbaugh 1993). Gooseberryleaf globemallow seed can be wildland collected in amounts large enough for local restoration project needs (S. Young, USU-retired, personal communication, February 2018). Sometimes seed can be mechancially harvested from wildland stands if stands are large and not especially weedy (Stevens and Monsen 2004a).

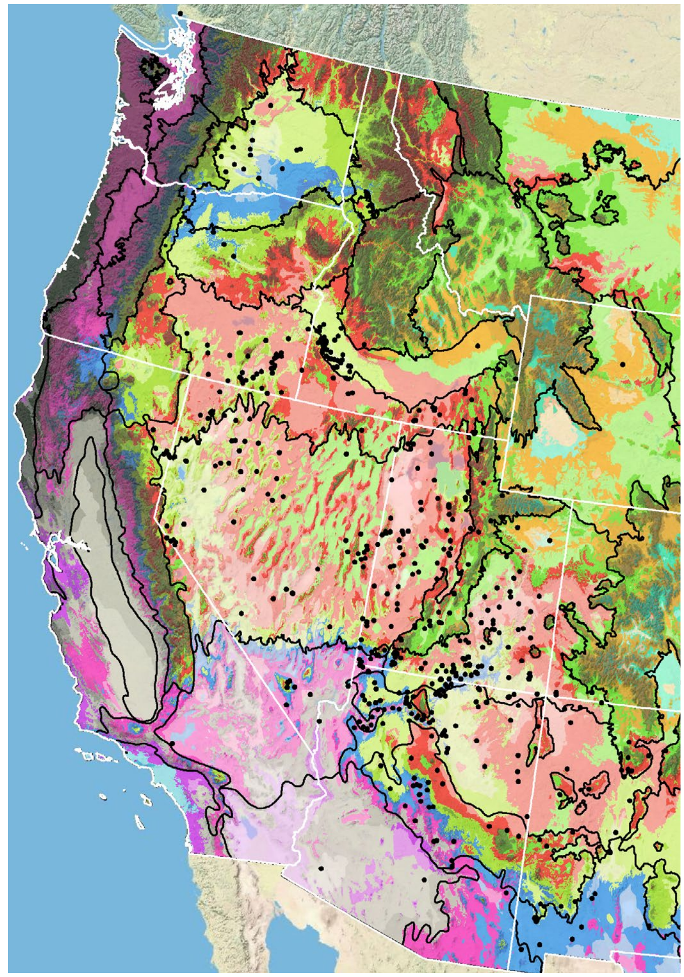

Figure 6. Distribution of gooseberryleaf globemallow (black circles) based on geo-referenced herbarium specimens and observational data from 1881-2016 (CPNWH 2017; SEINet 2017; USGS 2017). Generalized provisional seed zones (colored regions) (Bower et al. 2014) are overlain by Omernik Level III Ecoregions (black outlines) (Omernik 1987; USDI EPA 2018). Interactive maps, legends, and a mobile app are available (USFS WWETAC 2017; www.fs.fed.us/wwetac/threat-map/TRMSeedZoneMapper2.php?). Map prepared by M. Fisk, USGS.

Wildland seed certification. Wildland seed collected for direct sale or for establishment of agricultural seed production fields should be Source Identified through the Association of Official Seed Certifying Agencies (AOSCA) Pre-Variety Germplasm Program that verifies and tracks seed origin (Young et al. 2003; UCIA 2015). For seed that will be sold directly, collectors must apply for certification prior to making collections. Applications and site inspections are handled by the state where collections will be made. For seed that will be used for agricultural seed fields, nursery propagation or research, the same procedure must be followed. Seed collected by some public and private agencies following established protocols may enter the certification process directly, if the protocol includes collection of all data required for Source Identified certification (see Agricultural Seed Certification section). Wildland seed collectors should become acquainted with state certification agency procedures, regulations, and deadlines in the states where they collect. Permits or permission from public or private land owners is required for all collections.

Collection timing. While seeds typically mature in July or August (Plummer et al. 1968; Shaw and Monsen 1983; Jorgensen and Stevens 2004), timing of seed maturation can vary widely by location, elevation, plant age, and weather (Wasser 1982; Pendery and Rumbaugh 1990). Wildland seed collections made by Seeds of Success Project field crews ranged from an earliest date of June 7, 2016 at 2,760 feet (840 m) in Owyhee County, Idaho, and a latest date of October 1, 2003 at 6,132 feet (1,869 m) in Kane County, Utah. The most common collection dates fell between mid-June and mid-July (USDI BLM SOS 2017). In stands established from transplants, flowering was earlier at a northern Utah (early June) than at a southern Idaho site (late June). Flowering date also varied by year and plant age. Average date of first flowering was 1.5 months earlier (mid-July) in the second experiment year (1988) than in the establishment year (1987, early June) in northern Utah and southern Idaho (Pendery and Rumbaugh 1990).

Collection methods. Seeds can be collected by hand-stripping (Jorgensen and Stevens 2004), which is best in low density or weedy stands. Collectors may also use tennis racquets to swat seed heads over a container to dislodge and collect ripe seed (Fig. 7). Where unusually dense stands occur on nearly level terrain, mechanical harvesting by combine is possible (Shaw and Monsen 1983). For hand-harvesting, gloves are recommended because the hairs covering all parts of the plant can be irritating (USFS GBNPP 2014).

Several collection guidelines and methods should be followed to maximize the genetic diversity of wildland collections: collect seed from a minimum of 50 randomly selected plants; collect from widely separated individuals throughout a population without favoring the most robust or avoiding small stature plants; collect from all microsites including habitat edges (Basey et al. 2015). General collecting recommendations and guidelines are also presented in available manuals (e.g., USDI BLM SOS 2016; ENSCONET 2018).

Figure 7. Collecting gooseberryleaf globemallow seed in Sevier County, UT. Photo: S. Young, USU.

Post-collection management. Seed should be thoroughly dried before storing. Seed is attractive to weevils, which can be controlled with insecticides (Stevens and Monsen 2004a).

Seed Cleaning. Dry seed is easily cleaned (Stevens and Monsen 2004a). Using a gravity table can improve seed purity to over 90% (Stevens et al. 1996).

Several seed cleaning processes have been reported:

- Process dry seed through a debearder, then an air-screen separator, and then a gravity table (Jorgensen and Stevens 2004).
- Process dry seed through a Dybvig seed cleaner and then through a Clipper or Fanning Mill if necessary (Wasser 1982).
- Process dry seed through a brush machine or hammer mill and then through an air-screen separator (Tilley et al. 2011).
- Thresh seed using a small-plot combine with an alfalfa seed concave (Shock et al. 2008).

Seed Storage. Seeds are orthodox and can be dried to low moisture contents (RBG Kew 2017). Seed viability was 95% after drying to a moisture content in equilibrium with 15% relative humidity and storage for 2.2 years at 4 º F (-20 ºC) (RBG Kew 2017). A low percentage (2%) of germination occurred after 25 years of storage in an open warehouse where temperature extremes ranged from -22 ºF (-30º C) to 100 ºF (38 ºC). Germination was greater but still low (6-9%) when tested after 2 to 15 years of storage. Stored seed was germinated at 34 to 38 ºF (1.1-3.3º C) in the dark (Stevens and Jorgensen 1994).

Seed Testing. There is an Association of Official Seed Analysis (AOSA) tetrazolium (TZ) viability testing guideline for globemallow species (AOSA 2010) but no germination testing rule. For routine laboratory analysis, 5 grams of seed is required for purity testing and 50 grams for noxious weed counts (Belcher 1985). In most cases, and especially for dormant or hard to germinate seed, TZ testing will provide a more accurate picture of seed lot viability than germination testing.

To quickly evaluate seed viability, the 'pop test' may be useful. This test uses a hot plate to heat seeds until the moisture contained in the seed is converted to gas and breaks the seed coat. Seeds that pop are those with intact seed coats. Although germination and TZ tests were not done on gooseberryleaf globemallow seeds that popped, the test may still be a good predictor of seed fill (Tilley et al. 2011).

Germination. Seed is dormant and without pre-treatments low levels of germination can be expected (14-40%) (Young and Young 1986; Whitacre and Call 2006). A variety of physical, mechanical (Page et al. 1966; Roth et al. 1987; Barak et al. 2015), chemical (Page et al. 1966; Roth et al. 1987), and combined treatments (Smith and Kratsch 2009) to break seed dormancy have been tested.

Researchers with experience using gooseberryleaf globemallow in restoration, indicate that erratic germination is common and maximum germination is not reached until one month after seed is harvested (Stevens et al. 1996). High levels of germination were achieved after nicking seeds and subjecting them to cool-moist stratification (87%) (Smith and Kratsch 2009) or a 4-hour soak in diethyl dioxide alone (67%) (Page et al. 1966), however, these treatments are not practical or feasible on a large scale.

Seeds exhibit double dormancy (Smith and Kratsch 2009). Scarification of the impermeable seed coat is necessary for high initial germination (Tilley et al. 2011). Seeds first need to be made permeable to water through some scarification method (heat or mechanical treatment) and then seeds must be stratified to break physiological dormancy (Smith and Kratsch 2009).

Earlier germination testing also found increased germination with scarification (acid and mechanical) (Page et al. 1966). The Royal Botanic Gardens Kew (2017) obtained 90 to 95% germination by chipping seed with a scalpel and germinating seeds on 1% agar solutions at alternating light and dark conditions (8 hrs/16 hrs) at 68 ºF (20 ºC) and 86 ºF (30 ºC). Boiling water makes seeds permeable to water and was better than cool-moist stratification alone to break dormancy (Tilley et al. 2011). Germination of seeds after nicking alone was 52%, but when nicked seeds were cool-moist stratified, germination was 87%. Germination was only 5% with cool-moist stratification alone (Smith and Kratsch 2009). Acid scarification and 1 to 3 months of cool-moist stratification can also be used to germinate seeds (Stevens et al. 1996; Rawlins et al. 2009). Suggested future research includes evaluating other mechanisms and associated timing requirements to break dormancy (Smith and Kratsch 2009).

Wildland Seed Yield and Quality. Post-cleaning seed yield and quality of seed lots collected by the Seeds of Success (USDI BLM SOS 2017) are provided in Table 3 (USFS BSE 2017). Results indicate that gooseberryleaf globemallow seed can generally be cleaned to high levels of purity and seed fill and that viability of fresh seed is generally high. Page et al. (1966) reported 85.7% viability of seed used in germination testing. A little more than half (58%) of seeds had hard seed coats and 13.6% were empty. Tetrazolium tests revealed 95.2% of hard seed was viable.

Gooseberryleaf globemallow seeds are small, averaging more than 350,000 seeds/lb (770,000/kg) (Table 3). Other sources (Belcher 1985; Horton 1989; Stevens et al. 1996; Jorgensen and Stevens 2004; USFS GBNPP 2014; RBG Kew 2017) report similar values, ranging from 191,000 to 500,660 seeds/lb (421,000-1,103,750/kg).

Table 3. Seed yield and quality of gooseberryleaf globemallow seed lots collected in the Intermountain region cleaned by the Bend Seed Extractory and tested by the Oregon State Seed Laboratory or the USFS National Seed Laboratory (USFS BSE 2017).

Characteristic	Mean	Range	Samples (#)
Bulk weight (lbs)	0.93	0.14-2.79	11
Clean weight (lbs)	0.12	0.008-0.15	11
Clean-out ratio	0.14	0.006-0.29	11
Purity (%)	97	89-99	11
Fill (%)[1]	87	50-99	11
Viability (%)[2]	92	79-98	9
Seeds/lb	363,072	248,140-667,000	11
Pure live seeds/lb	321,476	223,532-505,853	9

[1] 100 seed X-ray test
[2] Tetrazolium chloride test

Marketing Standards. For gooseberryleaf globemallow seed purchasing, recommended minimum seed viability is 90% and purity is 80% to 90% (Jorgensen and Stevens 2004; Walker and Shaw 2005). As of 2005, the Bureau of Land Management's minimum requirements for gooseberryleaf globemallow seed purchases were 90% purity, 75% germination, and 0.675 PLS (Lambert 2005). Recommended minimum germination of untreated market seed is 20% (Stevens et al. 1985; Jorgensen and Stevens 2004).

AGRICULTURAL SEED PRODUCTION

In cultivated stands (Fig. 8), plants produce seed within a year of fall planting (Shock et al. 2015), but seed production in the first year may be less than in following years (Stevens et al. 1996). Seed crops can be harvested for 4 to 6 years. Seed is harvested by hand stripping, beating seed into a container, or using a combine harvester (Jorgensen and Stevens 2004). Mowing established plants in the fall concentrates the timing of seed production and provides good yields with a single combine harvest (Shock et al. 2015).

Figure 8. Gooseberryleaf globemallow seed production at Oregon State University's Malheur Experiment Station in Ontario, OR. Photo: N. Shaw, USFS.

Seed production research plots were grown successfully at the Oregon State University's Malheur Experiment Station (OSU MES). Plants produced harvestable seed for 5 years (Shock et al. 2012; 2015), but by the 6th year, growth was poor and the plots were eliminated (Shock et al. 2013; 2015). Fall-seeded gooseberryleaf globemallow flowered in the first year. Flowering began in early May and continued through early September. Seed was hand-harvested three times (20 June, 10 July, and 13 August) (Shock et al. 2015). When crops were flailed each fall, flowering in the next year was concentrated enough to allow for a single combine harvest (Shock et al. 2015).

Table 4. Flowering dates, harvest dates, and seed yields for seed production fields grown at Oregon State University's Malheur Experiment Station in Ontario, OR (Shock et al. 2015).

Year	Start of flowering	End of flowering	Harvest date(s)	Seed yield (kg/ha)
2007	5 May	5 Sept	20 June, 10 July, 13 Aug	495.7*
2008	5 May	15 June	21 July	308.3
2009	1 May	10 June	14 July	303.2
2010	10 May	25 June	20 July	347.8
2011	26 May	14 July	29 July	250.9

*Seed yield represents multiple hand-harvests, which is likely the reason for high yields and not year, plant age, etc.

Agricultural Seed Certification. It is essential to maintain and track the genetic identity and purity of native seed produced in seed fields. Tracking is done through seed certification processes. State seed certification offices administer the Pre-Variety Germplasm (PVG) Program for native field certification for native plants, which tracks geographic origin, genetic purity, and isolation from field production through seed cleaning, testing, and labeling for commercial sales (Young et al. 2003; UCIA 2015). Growers should plant certified seed (see Wildland Seed Certification section) and apply for certification of their production fields prior to planting. The systematic and sequential tracking through the certification process requires pre-planning, understanding state regulations and deadlines, and is most smoothly navigated by working closely with state regulators.

Site Preparation. Weed-free sites are recommended when planting gooseberryleaf globemallow crops (Stevens et al. 1996).

Seed Pretreatments. If a high level of initial germination is essential, seed requires scarification. There are chemical, mechanical, and physical scarification methods that can be used (see Germination section). When researchers seeded in spring, an overnight soak in a 10% by volume solution of 13% bleach in distilled water followed by about a month of storage at 34º F (1º C), failed to mimic fall germination and emergence was poor (Shock et al. 2008).

Weed Management. Weeds in production fields can be controlled by hand, with pre-emergent herbicides, or through cultivation (Stevens et al. 1996). Herbicides are not registered for this species, and the results do not constitute an endorsement of specific companies or products or recommendations for use. The research, however, could contribute to future registration efforts.

In a controlled study, gooseberryleaf globemallow plants grown in soils treated with an imidazolinone herbicide produced significantly less biomass than those in untreated soils (De Graaff and Johns 2015). When various post-emergence herbicide mixtures were tested on fields in the spring following fall seeding, plant injury ranged from 23% to 95%. A mix of oxyfluorfen and pendimethalin resulted in 23% injury, and all other mixes tested resulted in injury greater than 55%. Researchers concluded plants were very sensitive to herbicides but use of a protective shield to direct spray to target plants, although not tested, may be a management option (Felix et al. 2015).

Seeding. Fall seeding allows for natural stratification and can result in more rapid and uniform germination (Stevens et al. 1996). Spring seeding even with a cold-water soak and cool temperature storage resulted in poor emergence, whereas fall seeding produced good stands (Shock et al. 2008; Shock et al. 2015). Acid scarification can improve speed and uniformity of germination if fall seeding is not possible (Stevens et al. 1996).

Guidelines for seeding depth range from 0.1 to 0.5 inch (0.3-1.3 cm) (Pendery and Rumbaugh 1993; Stevens et al. 1996; Rawlins et al. 2009). Emergence and plant survival may vary with planting depth and soil type (Rawlins et al. 2009). In a greenhouse study, seeding depth had a greater effect on emergence in sandy loam than clay loam field-collected soils. Survival was significantly better in sandy loam (87%) than in clay loam soils (52%), regardless of seeding depth (P = 0.024). Seeding on the soil surface resulted in poor emergence regardless of soil type. Based on emergence and short-term survival (45 days), researchers recommended seeding depths of 0.1 to 0.5 inch (0.3-1.3 cm) in clay loams and 0.3 to 0.5 inch (0.6-1.3 cm) in sandy loams (Rawlins et al. 2009).

General guidelines for seeding gooseberryleaf globemallow crops include pure stand seeding rates of 20 to 50 PLS/linear foot of row (Stevens et al. 1996; Shock et al. 2008) or 2 lbs PLS/acre (2.3 kg/ha) (Tilley et al. 2011). At a seeding rate of 1 lb PLS/acre (1.1 kg/ha), the average seeding rate is 17 seeds/ft^2 (183 seeds/m^2) (Ogle et al. 2012).

Recommended row spacings range from 28 to 36 inches (71-91 cm) (Stevens et al. 1996; Shock et al. 2008). A single-row seeder was used successfully for seed production fields in Utah (Stevens et al. 1996). At OSU MES, good stands were established by drill seeding 30-inch (76 cm) rows at 20 to 30 seeds/foot of row. Soils at this site were Nyssa silt loams with a pH of 8.3 and 1.1% organic matter (Shock et al. 2008).

Establishment and Growth. Once emerged, the growth, vigor, and survival of seedlings is considered good in field and wildland situations (Stevens and Monsen 2004a; Ogle et al. 2011). Seed is produced in the first year following fall seeding, and seed production fields can be maintained and harvested for up to 6 years (Stevens et al. 1996; Shock et al. 2015). Stand density is rarely a problem, but plant density can fluctuate year to year (Stevens et al. 1996; Stevens and Monsen 2004a). There are thresholds in plant density fluctuations that impact the seed certification process for commercial growers.

Table 5. Seed yield (kg/ha) for fall-seeded (November 2006) gooseberryleaf globemallow in response to supplemental irrigation. Seed production fields were growing at Oregon State University's Malheur Experiment Station in Ontario, OR (Shock et al. 2015).

Year	Supplemental irrigation (mm/season*)		
	0	100	200
2007**	496	364	394
2008	309	205	200
2009	303	335	366
2010	348	393	388
2011	251	293	166

*Irrigation season was from bud to seed set.

**3 hand harvests, the following years represent a single combine harvest.

Irrigation. Seed yield for gooseberryleaf globemallow seed production fields at OSU MES were not significantly improved with supplemental irrigation beyond that provided during establishment (Table 5; Shock et al. 2015). Findings suggest moderate levels of seed production, regardless of rainfall or supplemental irrigation (Table 6).

Table 6. Natural precipitation (amounts and timing) and temperature at Oregon State University's Malheur Experiment Station in Ontario, OR (Shock et al. 2012).

Year	Jan-June (in)	April-June (in)	Jan-June days 50-86 F
2006	9.0	3.1	1120
2007	3.1	1.9	1208
2008	2.9	1.2	936
2009	5.8	3.9	1028
2010	8.3	4.3	779
2011	8.3	3.9	671
Mean	5.8	2.7	1042

Others have recommended irrigation during establishment and again in the spring and during flowering and seed set at sites receiving 11 to 14 inches (279-356 mm) of annual precipitation (Stevens et al. 1996).

Pollinator Management. Gooseberryleaf globemallow is insect-pollinated and especially attractive to bees (Pendery and Rumbaugh 1986; Ogle et al. 2011; Tepedino 2017). Any practice to encourage visits by globemallow bees or other frequent visitors such as *Apis*, *Agapostemon*, *Calliopsis*, *Halictus*, and *Melissodes*, and *Ammoplanus* (Pendery and Rumbaugh 1986; Tepedino 2017) will benefit seed production.

Insect and Disease Considerations. Several microbes, insects, and animals can impact seed production fields. Powdery mildews (*Erysiphe plygoni* and *Leveillula* spp.) and rust fungus (*Puccinia sherardiana*), have been collected from globemallow plants (Sampangi et al. 2010; Mohan and Shock 2014). At OSU MES, rust fungus (*P. sherardiana*), infected seed production stands over two years and caused substantial leaf loss and reduced growth (Shock et al. 2011). Weevils (Coleoptera: Apionidae and Cuculionidae) are globemallow seed predators that can severely impact seed production (Pendery and Rumbaugh 1986; CSU Ext. 2016), especially the part of the seed in the indehiscent part of the fruit (Kearney 1935). When grasshopper (Orthoptera: Caelifera), Mormon cricket (*Anabrus simplex*), rabbit, and/or rodent population levels are moderate to high, damage to seed production fields, restoration seedings, and established stands can be expected (Wasser 1982).

Seed Harvesting. Hand or mechanical harvests are possible for seed production crops. While multiple hand-harvests will likely result in larger yields than a single mechanical harvest (Shock et al. 2015), a cost-benefit analysis will establish the best method.

In seed production fields in Utah, gooseberryleaf globemallow seed was harvested by handstripping or windrowing then combining (Stevens et al. 1996). Mowing seed production fields in fall encourages more uniform and concentrated flowering, which allows for a single seed harvest using a small-plot combine (Shock et al. 2015). This also helps to ensure harvests from a greater percentage of the plants and serves to increase genetic diversity of seed (Basey et al. 2015). Threshing the combine-harvested seed using an alfalfa seed concave produced seed lots that required no additional cleaning (Shock et al. 2008).

NURSERY PRACTICES

Nursery production and transplanting of gooseberryleaf globemallow has been successful, and high establishment can be expected from bareroot or container-grown stock (Fig. 9) (Stevens 2004).

In greenhouse experiments, Cardoso et al. (2007) found gooseberryleaf globemallow grew well in peat-based media with a pH of 5.5 to 7.2. Negative responses to extremely high or low pH levels were more prevalent in the summer, and plants tolerated lower pH levels (4.5) in the fall and spring, perhaps because of lower temperatures and/or slower growth rates (Cardoso et al. 2007). Plant height and final biomass were not different when plants were grown using conventional above-ground production methods (containers side by side on weed barrier fabric) or a pot-in-pot system (containers placed within larger substrate-filled containers in the ground) (Cardoso et al. 2006).

Average survival was high for gooseberryleaf globemallow (94%) and gooseberryleaf × small-leaf globemallow hybrids (92%) a year after transplanting greenhouse stock (Pendery and Rumbaugh 1990). Stock was planted into clean-tilled sites in Utah and southern Idaho in mid-April. Transplants were grown from sand paper-scarified seed in 150 cm^3 cones filled with four parts sand, two parts peat moss, and one part vermiculite. One-year-old transplants weighed an average of 109 g. Weight for all accessions ranged from 64 to 188 g (Pendery and Rumbaugh 1990).

WILDLAND SEEDING AND PLANTING

Gooseberryleaf globemallow is a good candidate for use in wildland revegetation. It tolerates harsh conditions, reproduces early, competes well with cheatgrass and other annuals once established, provides desirable forage, and is attractive to pollinators (Plummer et al. 1968; Stevens et al. 1985; Monsen and Stevens 2004, 2004a; Eldredge et al. 2013).

While well suited and desirable in wildland restoration, several studies reported poor establishment following seeding. This may be a result of poor establishment conditions that failed to break seed dormancy (see Germination section) or use of seed not adapted to the restoration site.

Figure 9. Gooseberryleaf globemallow container stock grown by USFS in Provo, UT. Photo: N. Shaw, USFS.

When seeded as part of a mixture on disturbed sites near St. George, Utah, frequency, density, and cover of gooseberryleaf globemallow was low at the restoration site (Ott et al. 2011). The site was dominated by cheatgrass and prickly Russian thistle (*Salsola tragus*) before being scalped and drill seeded with native species. Although abundance was low, gooseberryleaf globemallow plants persisted to the last post-treatment visit, which occurred14 years after seeding. Researchers noted the gooseberryleaf globemallow seed used in the restoration came from commercially available material, which may or may not have been locally adapted (Ott et al. 2011). Establishment was also poor when gooseberryleaf globemallow was used in restoration of a pasture on the Humboldt-Toiyabe National Forest, Nevada. Seed was purchased from a local commercial source and seeded in the fall. Researchers indicated that irrigation and precipitation levels and timing may have been insufficient for germination and seedling establishment (Chambers et al. 2014).

Seeding and Planting Methods. Establishment from transplants has been successful (Pendery and Rumbaugh 1990). About a year after transplanted into clean-tilled dryland nurseries in mid-April in northern Utah and southern Idaho, average survival of gooseberryleaf globemallow was 94% and gooseberryleaf globemallow × small-leaf globemallow hybrids was 92%. Average weight of gooseberryleaf globemallow plants was 109 g/plant (range: 64-188 g). The largest plant came from a seed source collected within 6.2 miles (10 km) of the planting site (Pendery and Rumbaugh 1990).

Seeding in the fall or winter provides the best opportunity to naturally break seed dormancy (Shaw and Monsen 1983). Broadcast, drill, surface compacting, or browse interseeding are all workable seeding methods (Monsen and Stevens 2004), but seed burial improves emergence (Rawlins et al. 2009). Gooseberryleaf globemallow is often seeded in mixtures and regardless of the seeding method or mix, newly revegetated sites should be protected from grazing for at least 2 years (Stevens et al. 1985).

Although often recommended for seeding mixtures and often described as competitive, gooseberryleaf globemallow may not do as well when seeded with aggressive non-native cultivars. Although gooseberryleaf globemallow establishment was good when seeded in April with 'Hycrest' crested wheatgrass in northern Utah and southern Idaho, its density dropped dramatically in the years following the establishment year (Pendery and Rumbaugh 1990).

In seed mixes, where gooseberryleaf globemallow may comprise 10% of less of the mixture (Wasser 1982), recommended seeding rates range from 0.75-3 lbs/acre (0.64-2.6 kg/ha) (Kitchen 1994). Increasing the seeding rate has not been successful in increasing establishment and survival (Monsen and Stevens 2004). Recommended seeding rates, however, vary by the potential climax vegetation of a site and the seeding method (Plummer et al. 1968). Rates are typically lower for drill seeding than for broadcast seeding methods. In Utah, seeding has been successful on pinyon-juniper, sagebrush-rabbitbrush, shadscale, and blackbrush sites and in disturbed areas with exposed, eroded soils and harsh environments. The recommended seeding rate for use in blackbrush or shadscale/winterfat (*Krascheninnikovia lanata*) vegetation is 1 lb PLS/acre (0.9 kg/ha) and in fourwing saltbush (*Atriplex canescens*)/big sagebrush communities with spiny hopsage (*Grayia spinosa*) is 2 lbs PLS/acre (2.3 kg/ha) (Horton 1989). On shadscale sites, 1.5 lbs PLS/acre (1.3 kg/ha) is recommended for broadcast seeding and 1 lb PLS/acre for drill seeding. On blackbrush sites, 1 lb PLS/acre (0.9 kg/ha) is recommended for broadcast seeding and 0.5 lb/acre (0.4 kg/ha) for drill seeding (Plummer et al. 1968).

Table 7. Seeding rates required to meet target densities for drill and broadcast seeding (Monsen and Stevens 2004).

Need	0.09 lb. seed/acre	0.45 lb. seed/acre	0.9 lb. seed/acre
To get Drilled	1 seed/ linear foot	5 seeds/ linear foot	10 seeds/ linear foot
To get Broadcast	9 seeds/ft^2	45 seeds/ft^2	90 seeds/ft^2

For drill seeding, the recommended seeding depth is 0.1 to 0.3 inch (0.3-0.8 cm) and row spacing is 15 to 18 inches (38-46 cm) (Monsen and Stevens 2004). However, adjustments based on soil type may improve emergence.

Wildland seeding recommendations for Nevada suggest use on sites where soil pH ranges from 5 to 7 and there is no salinity (Eldredge et al. 2013). However, in native habitats, plants occur on moderately saline soils (Wasser 1982), and plants are frequently found on basic soils (Kearney 1935; Horton 1989; Pendery and Rumbaugh 1993).

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RESOURCES

AOSCA NATIVE PLANT CONNECTION
https://www.aosca.org/wp-content/uploads/Documents///AOSCANativePlantConnectionBrochure_AddressUpdated_27Mar2017.pdf

BLM SEED COLLECTION MANUAL
https://www.blm.gov/sites/blm.gov/files/programs_natural-resources_native-plant-communities_native-seed-development_collection_Technical%20Protocol.pdf

ENSCONET SEED COLLECTING MANUAL
https://www.kew.org/sites/default/files/ENSCONET_Collecting_protocol_English.pdf

HOW TO BE A SEED CONNOISSEUR
http://www.utahcrop.org/wp-content/uploads/2015/08/How-to-be-a-seed-connoisseur20May2015.pdf

OMERNIK LEVEL III ECOREGIONS
https://www.epa.gov/eco-research/ecoregions

SEEDLOT SELECTION TOOL
https://seedlotselectiontool.org/sst/

SEED ZONE MAPPER
https://www.fs.fed.us/wwetac/threat-map/TRMSeedZoneMapper.php

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