MOJAVE DESERT NATIVE PLANTS: BIOLOGY, ECOLOGY, NATIVE PLANT MATERIALS DEVELOPMENT, AND USE IN RESTORATION

Brittlebush

Encelia farinosa A. Gray ex Torr.

Asteraceae - Sunflower family

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ORGANIZATION

NOMENCLATURE

Brittlebush (*Encelia farinosa* A. Gray ex Torr.) is a member of the Heliantheae tribe of the Asteraceae family, and in the *californica* clade of the genus *Encelia* (Clark 1998, Fehlberg and Ranker 2007, Singhal et al. 2021).

NRCS Plant Code.

ENFA (USDA NRCS 2023).

Synonyms.

Encelia farinosa var. *farinosa* A. Gray ex Torr., *Encelia farinosa* f. *phenicodonta* S. F. Blake, *Encelia farinosa* var. *phenicodonta* (S.F. Blake) I.M. Johnst., *Encelia farinosa* var. *radians* Brandegee (ITIS 2023, SEINet 2023).

Common Names.

Brittlebush, desert encelia (Clary and Slayback 1983), white brittlebush, white brittle bush, goldenhills (SEINet 2023, Clary and Slayback 1983). Common names in Spanish include rama blanca, incienso, hierba del bazo, hierba de las ánimas, palo blanco, and hierba ceniza (SEINet 2023).

Subtaxa.

No varieties or subspecies are currently recognized by the Flora of North America, the Integrated Taxonomic Information System (ITIS), or the Jepson eFlora (Clark 2020, Keil and Clark 2012, ITIS 2023). However, other sources describe three subtaxa for brittlebush: *Encelia farinosa* var. *farinosa*, *Encelia farinosa* var. *phenicodonta*, and *Encelia farinosa* var. *radians* (Fehlberg and Ranker 2009). Studies have found some phylogenetic support for the existence of these subtaxa based on molecular analyses (Singhal et al. 2021).

Chromosome Number.

The chromosome number for brittlebush is 2n = 36 (Kyhos et al. 1981, Clark 1998). Variation in chromosome number has not been documented in *Encelia* species.

Hybridization.

All *Encelia* species are obligate outcrossers, and natural hybrids are frequently documented where species co-occur (Kyhos et al. 1981, Clark 1998, Fehlberg and Ranker 2007, Singhal et al. 2021). In cultivation, all *Encelia* species can produce fertile offspring when crossed with one another, and following generations or backcrosses are all also fertile (Clark 1998, Fehlberg and Ranker 2007, DiVittorio et al. 2020, Singhal et al. 2021). However, hybrid offspring are rarely found in the wild and usually only in the ecotones between their two parent species, suggesting that strong selective pressures maintain species boundaries in this genus (Kyhos et al. 1981, Clark 1998, Fehlberg and Ranker 2007, DiVittorio et al. 2020, Singhal et al. 2021).

The recognized hybrid, *Encelia farinosa* x *E. frutescens*, co-occurs and can backcross with its parent species in the limited areas where they overlap in habitat (Keil and Clark 2012). These hybrids can be mistaken for Virgin River brittlebush (*E. virginensis*) (Keil and Clark 2012). Hybrids between brittlebush and Acton's brittlebush (*E. actoni*) can also occur (Clark and Sanders 1986). Genetic evidence suggests that brittlebush may hybridize with sticky brittlebush (*E. resinifera*) where these two species co-occur (Fehlberg and Ranker 2009). *Encelia canescens*, which occurs in Central and South America, may have originated as a hybrid of brittlebush and *E. palmeri* (Singhal et al. 2021). Sterile hybrids of *Encelia* species with its sister genus *Geraea* (desert sunflower) have also been found in the Sonoran Desert (Kyhos 1967), including hybrids of desert sunflower with brittlebush (Kyhos 1971). These hybrids were usually found in areas of human disturbance (Kyhos 1967).

DESCRIPTION

Brittlebush is a short-lived (less than 30 years) desert shrub that grows between 30–150 cm tall, with shallow roots, one to multiple trunks, and fragrant yellow sap (Tesky 1993, Clark 2020, Keil and Clark 2012; Figure 1).

Figure 1: A brittlebush individual. Photo: Sue Carnahan

Young stems are hairy, but the plant develops smooth bark with age. The tomentose leaves are clustered at the tips of the stems, 2–7 cm long, ovate to lanceolate, with obtuse or acute tips, and attach to the stem with 10–20 mm petioles (Clark 2020, Keil and Clark 2012). Brittlebush is drought deciduous, shedding leaves in the hottest and driest parts of summer (Bowers and Dimmit 1994). The silvery or grey-white color of the leaves come from hairs that likely reflect solar radiation, providing the plants with some protection from hot and dry desert conditions (Ehleringer and Cook 1987).

Figure 2: Brittlebush leaves, showing the silvery, reflective hairs. Photo: BLM SOS NV040

Leaf characteristics such as shape and hairiness show substantial plasticity and diversity, and they can vary based on habitat (Singhal et al. 2021). Brittlebush bears multiple (three to nine) flowerheads per stem, with yellow ray flowers and yellow or brown-purple disc flowers (Clark 2006, Keil and Clark 2012). The panicle of flowers is useful for distinguishing brittlebush from the co-occurring Acton' brittlebush, which has flowers born on single stems. Brittlebush (and all *Encelia* species in the *californica* clade) have corollas that reflect ultraviolet light (Clark and Sanders 1986, Ehleringer and Cook 1987). Fruits are 3–6 mm long, with no pappus (Clark 2020, Keil and Clark 2012).

Figure 3: Brittlebush in flower. Photo: BLM SOS NV052

Subtaxa.

While neither the Flora of North America nor the Jepson eFlora recognize any subtaxa of brittlebush, there is significant phenotypical variation in this species which drives efforts to parse out potential subtaxa. Two of the proposed varieties are distinguished by the color of their disk flowers (brown in *Encelia farinosa* var. *phenicodonta* and yellow in *Encelia farinosa* var. *farinosa*; Clark 1998). While little genetic distinction has been found between these two proposed varieties, they may have different thermal tolerances (Fehlberg and Ranker 2009). Plants with brown disc flowers are often restricted to relatively wetter and cooler areas, such as river bottoms or higher elevations, particularly in the Sonoran Desert. Populations with brown disc flowers are relatively rare in the Mojave Desert and occur at higher elevation. These patterns suggest some amount of selective pressure on the different brittlebush phenotypes (Kyhos 1971).

A third proposed variety found in Baja California (*Encelia farinosa* var. *radians*) does not have the distinctive leaf hairs found on other varieties of brittlebush. Additional variation in this species is apparent but no other named varieties have been proposed (Clark 1998). For example, plants from western San Bernardino and Riverside counties, a coastally influenced environment, showed difference in size and leaf reflectance when compared to plants from the Colorado Desert. In common garden experiments differences in leaf reflectiveness were maintained, suggesting genetic difference between the two ecoregions (Miller 1988 as cited by Clark 1998).

DISTRIBUTION AND HABITAT

Brittlebush is the most widespread of the *Encelia* species (Clark 1998). In the United States brittlebush is found in Arizona, California, and Nevada, and in Mexico it is found in Baja California, Baja California Sur, Sinaloa, and Sonora (Figure 4). Sources also report this species from Utah (Tesky 1993). Brittlebush is an introduced species in Hawaii (Tesky 1993). Most brittlebush records occur in the Sonoran Desert ecoregion (SEINet 2022), but this species' range also extends into a several other ecoregions including; the Mojave Desert, Central Basin and Range (Great Basin), California Coastal Sage, Chaparral, Oak Woodlands, Southern and Baja California Pine-Oak Ranges, Arizona/New Mexico Plateau, Arizona/New Mexico Mountains, Baja Californian Desert, La Laguna Mountains, Los Cabos Plains and Hills, Madrean Archipelago, Sierra Madre Occidental, Sinaloa and Sonora Hills and Canyons, and Sinaloa Coastal Plain (SEINet 2022, Omernick 1987, USDI EPA 2022).

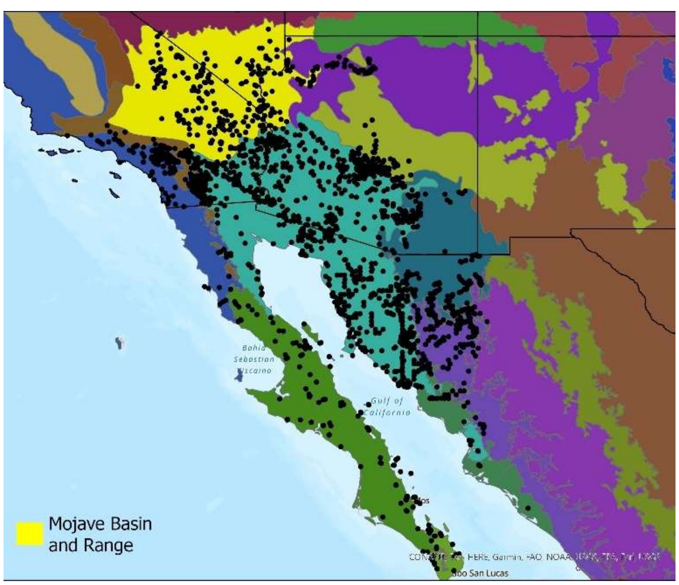

Figure 4: Distribution of brittlebush (black circles) from georeferenced herbarium specimens and verified observations. (CCH2 Portal 2022, SEINet 2022) with Omernik Level III Ecoregions (Omernik 1987). The Mojave Basin and Range ecoregion is shown in yellow.

Habitat and Plant Associations.

Brittlebush is generally a dominant species in the communities where it is found and can form large monospecific stands (Tesky 1993). NatureServe recognizes one habitat alliance (Brittlebush Desert Scrub Alliance) and nine habitat associations defined by the presence of brittlebush. Three of these habitat associations are known from the Mojave Desert (NatureServe 2023):

- Creosotebush—Brittlebush—Bush Arrowleaf Desert Shrubland
- Brittlebush—Schott's Pygmy-cedar Desert Shrubland
- Creosotebush—Brittlebush—Burrobush Desert Shrubland

The Manual of California Vegetation defines brittlebush associations as having at least 1% absolute (and at least 50% relative) brittlebush cover, with brittlebush dominant to other shrubs; or, where brittlebush is associated with either burrobush (*Ambrosia dumosa*) or coastal sagebrush (*Artemisia californica*), brittlebush comprises more than 30% of the relative cover (Sawyer et al. 2009).

Brittlebush occurs in pine-oak and oak woodlands, arid grasslands, and desert or coastal sage scrub (Tesky 1993). Brittlebush communities are generally found in shallow soils in uplands or rocky bottomlands, including upper bajadas and lower mountain slopes, rocky and erosional highlands, alluvial fans, and plains. Brittlebush usually grows on south to west-facing aspects with variable slope, or transitions zones between slopes and washes that are no longer subjected to flooding. Brittlebush is vulnerable to flooding and doesn't survive being covered by flood debris, so is rarely found in active washes

(Schulz 2016, Ehleringer 1988). Brittlebush associations are the most drought-tolerant communities in coastal sage and creosote scrub. In southern California mountains frequented by fire, brittlebush associations can replace communities of coastal sagebrush, Eastern Mojave buckwheat (*Eriogonum fasciculatum*), and white sage (*Salvia apiana*) (Sawyer et al. 2009, Schulz 2016). Brittlebush is not found in some cooler parts of the Mojave Desert (e.g. the western Mojave Desert), possibly due to occasional freezing temperatures and infrequent summer rainfall (Charlton and Rundel 2017).

Frequently associated shrub species include burrobrush (*Hymenoclea salsola*), burrobush (*Ambrosia dumosa*), creosote bush (*Larrea tridentata*), jointfir (*Ephedra* spp.), Eastern Mojave buckwheat, sweetbush (*Bebbia juncea*), cholla (*Cylindropuntia* spp.), California barrel cactus (*Ferocactus cylindraceus*), ratany (*Krameria* spp.), Bigelow's nolina (*Nolina bigelovii*), pricklypear (*Opuntia* spp.), Schott's pygmycedar (*Peucephyllum schottii*), Parish's goldeneye (*Viguiera parishii*), desert lavender (*Hyptis emoryi*), California fagonbush (*Fagonia laevis*), American threefold (*Trixis californica*), coastal sagebrush, and jojoba (*Simmondsia chinensis*). Frequently associated native forbs include brownplume wirelettuce (*Stephanomeria pauciflora*), desert trumpet (*Eriogonum inflatum*), *Cryptantha* spp., San Felipe dogweed (*Adenophyllum porophylloides),* fiddleneck (*Amsinckia* spp.), brittle spineflower (*Chorizanthe brevicornu*), starry bedstraw (*Galium stellatum*), and wishbone-bush (*Mirabilis laevis* var. *villosa*). Frequently associated native grasses include big galleta (*Pleuraphis rigida*) and desert needlegrass (*Achnatherum speciosum*), and the invasive annual grass Mediterranean (*Schismus* spp.) (BLM SOS 2022, SEINet 2022).

Figure 5: Brittlebush growing in canyon bottom habitat in California. Photo: BLM SOS CA930A

Figure 6: Brittlebush growing on a rocky slope in California. Photo: Jean Pawek

Climate.

The Mojave Desert is characterized by low annual precipitation (2–9.8 inches or 5–25 cm in valley areas), with most rainfall occurring in the winter and a smaller amount during summer thunderstorms (Randall et al. 2010). heterogeneous climate patterns across the region are influenced by large-scale patterns and regional topography and are important drivers of local adaptation and intraspecific variation (Shryock et al. 2018, Baughman et al. 2019) and phenological events (Beatley 1974). The reproductive phenology of many desert plant species is highly responsive to pulses in rainfall over short time scales (Bowers and Dimmitt 1994, Zachmann et al. 2021).

Climate information is derived from the climate-based provisional seed transfer zones (PSZs) where brittlebush occurs according to herbarium specimen locations (Shryock et al. 2018; Table 1). An important caveat is that herbarium specimen locations may not represent the full distribution and abundance of brittlebush due to sampling biases. Brittlebush is documented in all PSZs in the Mojave Desert ecoregion, except Zone 22. It is most abundant in Zones 21 and 24 and is least abundant in Zones 29 and 20 (Table 1). The average annual precipitation in the PSZs where brittlebush occurs in the Mojave Desert ecoregion is 15.7 cm (6.2 inches), with an average of 4.8 cm (1.9 inches) falling in summer and an average of 10.9 cm (4.3 inches) falling in winter. Brittlebush is frost-intolerant, meaning that below-freezing temperatures may damage the plants (Tesky 1993).

Climate change.

Southern California, western Arizona, and southern Nevada (the Mojave and Sonoran Desert ecoregions) may experience the largest shift in climate in temperate North America. (Diffenbaugh et al. 2008). Climate change predictions for the Mojave Desert include increases in mean summer and winter temperatures, decreases in precipitation leading to more frequent and intense droughts, more variability in precipitation patterns, and an increase in frequency and intensity of wildfire due to these changes (Barrows et al. 2014).

Barrows et al. (2014) modeled the response of several species, including brittlebush, to a 3 degree (C) rise in maximum summer temperature in Joshua Tree National Park. Model results predicted a medium risk of local extinction, and they classified brittlebush as one of the most climate change resilient species in the region.

Table 1: Climate of the provisional seed zones (PSZ) where brittlebush occurs within the Mojave Desert ecoregion (Shryock et al. 2018), showing the number of herbarium records or verified observations of brittlebush that occur within the PSZ. Mean annual precipitation (MAP) is the mean of yearly rainfall. Summer precipitation (SP) is the mean precipitation that falls in the summer (May-October). Winter precipitation (WP) is the mean precipitation that falls in the winter (November-April). Monthly average temperature (MAT) is the average of the monthly temperatures. Range is the average of the monthly temperature ranges (monthly maximum minus monthly minimum).

PSZ	#	MAP (cm)	SP (cm)	WP (cm)	MAT (C)	Range (C)
21	76	15.6	6.2	9.4	18.8	38.4
24	67	10.7	2.8	7.9	18.8	38.6
25	55	16.5	6.2	10.3	18.9	34.6
27	49	9.6	3.3	6.3	20	36.7
26	19	14.5	2.7	11.8	16.8	34.9
23	18	15.8	5.4	10.4	16.1	35.9
28	14	7.8	2.4	5.3	22.3	41.3
29	7	25.5	4.2	21.4	13.8	31.7
20	6	25.5	10.5	14.9	15.3	34.5

Elevation.

Brittlebush generally occurs below 4,920 ft (1,500 m) (Keil and Clark 2012, SEINet 2022). Herbarium specimens of brittlebush have been collected between -210 (below sea level) and 6,820 feet (-65-2,078 m).

Soils.

Brittlebush prefers rocky, shallow soils derived from a wide variety of materials including alkali-granite, alluvium, limestone, sandstone, basalt, conglomerate, gypsum, rhyolite, dacite, dune sand, gneiss, granodiorite, and schist (BLM SOS 2022, SEINet 2022). Brittlebush grows poorly in clay soils (Tesky 1993).

ECOLOGY AND BIOLOGY

Brittlebush is an early colonizer of disturbed areas, including burns, in the Mojave Desert. Brittlebush, like many other species of *Encelia*, produces secondary compounds for defense against insect herbivory, which could make it unpalatable for browsing by wildlife and livestock. *Encelia* species bloom abundantly and thus are possibly an important resource for pollinators (Sturwold et al. 2022, personal communication).

Reproduction.

While hybridization in *Encelia* species is well-studied, there is little information on the reproductive ecology of brittlebush. Studies on pollination, seed dispersal, and other reproductive ecology of this species are also limited.

Breeding System.

Brittlebush is an obligate outcrosser and cannot self-pollinate (Kyhos et al. 1981, Clark 1998, Fehlberg and Ranker 2007, Singhal et al. 2021).

Reproductive Phenology.

Herbarium specimens document brittlebush flowering and fruiting every month of the year with peak flowering February through May, and peak fruiting March through May (SEINet 2022). Rainfall and temperature are more important triggers for flowering in this species than time of year (Bowers and Dimmitt 1994, Zachmann et al. 2021). High summer temperatures may inhibit flowering in brittlebush. The effect of rainfall and drought on flowering is cumulative, meaning that a small amount of rain can still trigger flowering if the previous season has been relatively cool and wet, but a large rain after a prolonged drought might fail to trigger flowering. Length of flowering period also appears to be related to moisture, with droughts shortening the flowering season (Bowers and Dimmit 1994). A study of phenological responses to climate change conducted in the Sonoran Desert found that the average first flowering date of brittlebush had only shifted one day earlier since 1982 (Zachmann et al 2021).

Pollination.

Documented floral visitors include a wide variety of insects, including flies, bees, butterflies and moths, true bugs, and beetles (Simpson and Neff 1987). Hurd and Linsley (1975) reported that bees of the genera *Anthidium*, *Colletes*, and *Megandrena* visit *Encelia* species. Brittlebush is also the primary pollen source for the bee *Calliopsis pugionis* (Visscher and Danforth 1993). One study found that a beetle*, Tanaops abdominalis* (Malachiidae) was the most frequent visitor on brittlebush (10 times more frequent than all other visitors combined). *T. abdominalis* can inadvertently collect pollen and transfer it between brittlebush plants, suggesting it may be a successful pollinator for this species (Kyhos 1971).

Seed and Seedling Ecology.

Brittlebush seeds are wind dispersed and germination generally occurs after heavy winter rains. While brittlebush can resprout vegetatively, it reproduces almost entirely from seed. While populations of brittlebush appear to be stable, seedlings often don't survive more than seven years. Precipitation and water availability may limit recruitment, with low rain years or high intra- or interspecific competition reducing seed germination (Tesky 1993).

Physiology.

Brittlebush's adaptations to drought have been well-studied. Brittlebush leaves, which have dense silvery hairs on both sides, reflect up to 70% of solar radiation. This leaf pubescence, comprised of dead air-filled cells, alters the leaf boundary area to reduce water loss and lower leaf temperatures (Ehleringer and Björkman 1978), which allows plants to carry out photosynthesis in hotter and drier conditions. Brittlebush individuals with denser leaf hairs can keep their leaves longer in the summer than individuals with glabrous leaves (Ehleringer 1983) and brittlebush also produces hairier and thicker leaves in warmer parts of the year.

The maximum observed rooting depth for brittlebush is 80 cm (31.5 inches), giving it less reliable water access than deeper rooted species. Brittlebush has lower transpiration rates than the deeper-rooted button brittlebush (*Encelia frutescens*) and relies on its leaf hairs, in addition to evaporative cooling, to deal with heat stress. Brittlebush stores carbohydrate reserves in its stems (Ehleringer 1988).

Demography.

Brittlebush populations undergo almost complete turnover of individuals over a 40-year period and plant size is a fairly reliable estimate of plant age (Driscoll et al 2021).

Brittlebush individuals may be negatively impacted by intraspecific competition. In an experiment that compared productivity, growth, and reproduction of brittlebush individuals with neighbors to individuals that had all neighbors within a 2 m radius removed, individuals without neighbors had more and larger leaves, higher cover, and higher fecundity than those with neighbors (Ehleringer 1984).

Brittlebush can exhibit physiological adaptations to microclimates that vary within populations. For example, plants growing on ridges versus plants growing in washes were shown to have higher water use efficiency (Monson et al. 1992). These differences could not be explained by genetic distinctions between the two sites. Though evidence suggests relatively high gene flow between ridge and wash plants, there is apparently enough selective pressure for ridge plants to develop higher water use efficiency than wash plants (Monson et al. 1992).

Genetics and Adaptation.

Populations of brittlebush have high levels of genetic differentiation (Fehlberg and Ranker 2009). Genetic diversity in this species appears to be geographically structured, possibly due to range expansion and fragmentation patterns during glacial cycles (Fehlberg and Ranker 2009). Historic climate fluctuations and other natural causes of habitat fragmentation have probably increased the amount of genetic diversity within brittlebush (Singhal et al. 2021). Some haplotypes found in the Sonoran and Peninsular Deserts are not found in Mojave Desert populations of brittlebush, and the centers of genetic diversity in this species are found in the Sonoran and Peninsular Deserts. The Mojave Desert populations have lower levels of genetic variation, possibly because brittlebush expanded into this area after the last ice age (Fehlberg and Ranker 2009).

Brittlebush exhibits high within-population genetic diversity, which suggests high potential for local adaptation (Sandquist and Ehleringer 2003). Populations of brittlebush also have genetic differences related to drought tolerance and water use efficiency (Sandquist and Ehleringer 2003).

Species Interactions.

Belowground Interactions.

Brittlebush is associated with arbuscular mycorrhizal fungi (Valencia 2009). The density of mycorrhizal colonization, however, may be reduced when soil nitrogen concentrations increase, such as with atmospheric nitrogen deposition from urban air pollution (Egerton-Warburton and Allen 2000).

Insect Interactions.

Brittlebush produces secondary compounds that function as defenses against herbivory (Kunze et al. 1996, Redak et al. 1997). These compounds are most concentrated in new leaves and flowers, but are present in all parts of the plant, including roots and seeds. Experiments have demonstrated that several insect groups are sensitive to encecalin, one of the compounds found in brittlebush, including grasshoppers, cutworms, and armyworms (Proksch and Rodriguez 1984, Kunze et al. 1996). Chemicals that deter pathogens have also been documented in other species of *Encelia* (Proksch and Rodriguez 1984).

The Encelia leaf beetle (*Trirhabda geminata*) is associated with brittlebush and is likely resistant to its chemical defenses (Proksch and Rodriguez 1984, Kunze et al. 1996, Redak et al. 1997). Brittlebush is also a preferred food source for the master blister beetle (*Lytta magister*) (Snead and Alcock 1985) and is likely a host plant for several Lepidoptera species, including the fatal metalmark (*Calephelis nemesis*), white-lined sphinx moth (*Hyles lineata*), orange tortrix moth (*Argyrotaenia franciscana*) and the dwarf tawny wave moth (*Cyclophora nanaria*) (CalScape 2023). Harvester ants have been reported to take brittlebush seeds (Graham 2022, personal communication).

Brittlebush exudes a sticky yellow resin from stems and leaf nodes. Bee assassin bugs (*Apiomerus* spp.) preferentially lay egg masses on brittlebush and use the resin to attach eggs to the plant. They also cover their eggs with resin as protection against predation and desiccation. Resin-coated eggs have a 97% survival rate compared to 10% for eggs not coated in resin (Choe and Rust 2007). Larvae of the bee assassin bug also collect brittlebush resin, possibly as a defense or as an aid in predation. Leafcutter and resin bees (*Megachile* spp.) use brittlebush resin for nest building.

Wildlife and Livestock Use.

Brittlebush is common in areas protected for the threatened desert tortoise (*Gopherus agassizii)*. Maintaining and restoring habitat is a priority for protecting this species (Berry et al. 2014, Esque et al. 2021). Desert tortoises use brittlebush (and other *Encelia* species) as cover from predation and to minimize thermal stress (Esque et al. 2021, Shryock et al. 2022). Regeneration of long-lived shrub species can take up to 50 years after a disturbance, while short-lived shrub species such as brittlebush can provide cover for tortoises immediately after fire (Esque et al.

2021). Therefore, brittlebush can be important for maintaining tortoise habitat by bridging the gap between disturbance events and recovery of long-lived shrubs. While button brittlebush (*Encelia frutescens*) is consumed by tortoises in times of drought (Esser 1993), no sources mentioned desert tortoise browsing brittlebush.

Brittlebush also provides foraging habitat for several bird species (Tesky 1993). Kangaroo rats (*Dipodomys* spp.) will eat brittlebush seeds (Tesky 1993). Both ants and rodents have been observed removing and caching brittlebush seeds. Brittlebush can also germinate in rodent seed caches (DeFalco et al. 2012).

Livestock generally do not eat brittlebush, but it is browsed by mule deer (*Odocoileus hemionus*) and desert bighorn sheep (*Ovis canadensis* subsp. *nelsoni*). Grazing can reduce plant growth but doesn't appear to affect population size (Tesky 1993).

Other Notable Species Interactions.

Brittlebush may exhibit allelopathic properties and inhibit growth of neighboring plants. Extracts of brittlebush leaves inhibit growth or kill young tomato plants in the greenhouse (Gray and Bonner 1948). Another study suggested that the paucity of annuals under brittlebush was because of sandy and well-drained soils and not due to allelopathic chemicals (Muller 1953). Essential oils distilled from both brittlebush leaves and stems did not inhibit germination but did inhibit hypocotyl and radicle growth in both lettuce (*Lactuca sativa*) and perennial ryegrass (*Lolium perenne*), possibly due to the presence of the chemicals eupatoriochromene and limonene (Wright et al. 2013).

In the Mojave Desert, Went (1942) found several annual plant species that were associated with dead brittlebush shrubs, including plumeseed (*Rafinesquia* spp.), phacelia (*Phacelia* spp.), desert dandelion (*Malacothrix* spp.), and whisperingbells (*Emmenanthe* spp). This study also found that other shrub species may function as nurse plants for brittlebush seedlings (Went 1942).

Disturbance Ecology.

Brittlebush is an early colonizer. Recolonization is generally by seed dispersed from plants outside the disturbed area (Tesky 1993). Brittlebush is also adapted to the relatively more frequent occurrence of fire in coastal sage scrub and chaparral communities (Brown and Minnich 1986). While fire has historically been rare in the Mojave Desert (Esque et al. 2010, Vamstad and Rotenberry 2010), weather patterns and introduced annual grasses both contribute to increase fire frequency (Brown and Minnich 1986, Brooks and Matchett 2006). After fire, brittlebush-dominated communities can replace plant communities with longer-lived species like creosote scrub (Brown and Minnich 1986).

Brittlebush is frequently top-killed and has high mortality even in low-intensity, fast-moving fires. Damaged plants may take significant time to recover after fire. Individual *Encelia* plants rarely resprout after burning (Esser 1993), although it is more likely to resprout after fire in more mesic areas, such as north-facing slopes (Martin 1984). Brittlebush can rapidly re-seed post-fire and is often the dominant species recolonizing burned areas in the first growing season (Brown and Minnich 1986, Tesky 1993). One study of post-fire recovery in brittlebush found that while population size was initially reduced by 83%, it recovered to 76% of pre-burn population size nine months later. This increase in population size was attributed to seedling establishment post-fire (Cave and Patten 1984). A study in the Mojave Desert found brittlebush was the only species to increase in both cover and density post-fire (Lybbert et al. 2017). In coastal scrub, recolonization after fire may be more successful on south and west facing slopes (Martin 1984).

In a study assessing control of brittlebush for the purpose of maintaining non-native grasses for livestock forage, brittlebush survived mowing and seedlings recolonized areas where it had been hand pulled, returning the population to pretreatment densities in three months (Ibarra et al. 1986).

Ethnobotany.

The Cahuilla people used a mixture of blossoms, stems, and leaves of brittlebush as a treatment for toothaches. The Akimel O'odham (also called Pima) people used brittlebush as a poultice for pain. The O'odham used brittlebush resin as chewing gum. Brittlebush resin was also used to fasten arrows to arrow shafts, to waterproof containers used as water bottles and melted for use as a varnish by the Akimel O'odham people (NAEB 2022).

Horticulture.

Brittlebush does well in cultivation and is grown and sold in nurseries as an ornamental plant, where it is used for drought tolerant landscaping and for wildlife and pollinator gardens. This species is available in several nurseries in California (CNPS Calscape 2023). In cultivation, *Encelia* species often maintain old, withered leaves, which may make them less attractive for purchase (Sturwold et al. 2022, personal communication).

DEVELOPING A SEED SUPPLY

A robust and stable supply of genetically appropriate seed is needed to meet restoration demands in response to expanding environmental stressors from land degradation, invasive species, and climate change. Restoration success is, in part, predicated on applying the right seed in the right place, at the right time (PCA 2015). Developing a restoration seed supply involves coordination across many partners in all steps of the process: from conducting wildland collections to propagating materials in nurseries and agricultural fields to eventual seeding or outplanting at restoration sites. Appropriate protocols for preserving genetic diversity and adaptive capacity should be in place (Erickson and Halford 2020) and seed origin should be documented for certification purposes and other seed planning considerations.

Seed Sourcing.

Seed sourcing can influence restoration outcomes due to local adaptation (Custer et al. 2022), landscape genetic patterns (Massatti et al. 2020, Shryock et al. 2021) and differing ability to adapt to current and future climate conditions (Bucharova et al. 2019). However, there has been relatively little research evaluating seed sourcing strategies in actual restoration settings where many additional factors influence performance (Pizza et al. 2023). While non-local sources can perform well in meeting initial restoration goals such as establishment and productivity (Pizza et al. 2023), plants have coevolved with interacting organisms, such as pollinators and herbivores, that can exhibit preferential behavior for local materials (Bucharova et al. 2016, 2022). Further, evidence of local adaptation and its influence on restoration outcomes can take decades to emerge for long-lived species (Germino et al. 2019).

Empirical seed transfer zones have not been developed for brittlebush. The Desert Southwest Provisional Seed Zones (PSZs) may be used to plan seed sourcing in absence of species-specific information (USDA NRCS 2022; Figure 8). The Desert Southwest PSZs use twelve climatic variables that drive local adaptation to define areas within which plant materials may be transferred with higher probability of successful establishment and reduced risk of introducing maladapted ecotypes (Shryock et al. 2018). Overlaying PSZs with Level III ecoregions can serve to further narrow seed transfer by identifying areas of both climate similarity inherent in the PSZs and ecological similarity captured by the ecoregion, namely vegetation and soils. Within the PSZs and ecoregion areas, further site-specific considerations such as soil, land use, species habitat and microclimate affinities, and plant community may be relevant to seed sourcing decisions.

The USGS Climate Distance Mapper Tool incorporates the Southwest Deserts Seed Transfer Zones with climate models and can serve to guide seed sourcing according to current and projected climate conditions.

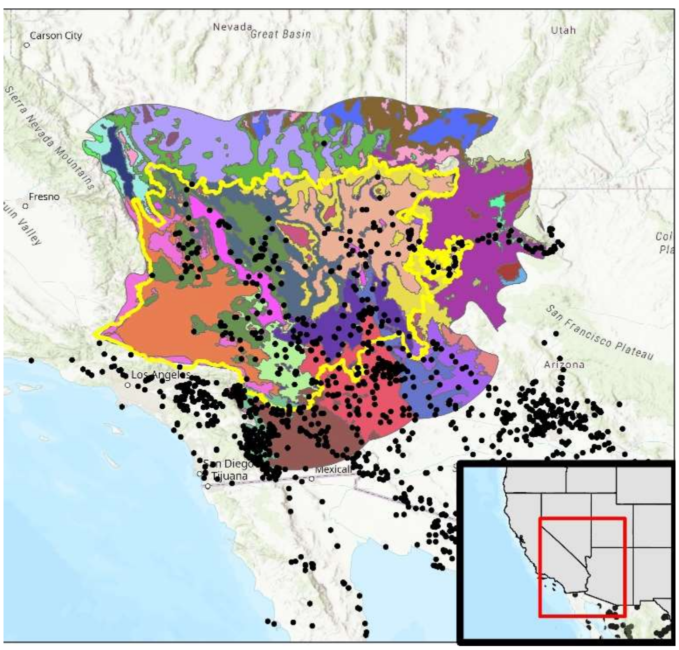

Figure 7: The distribution of documented brittlebush (black dots) across the Desert Southwest Provisional Seed Zones (Shryock et al. 2018). Occurrences are based on georeferenced herbarium specimens and verified observations (CCH2 Portal 2022, SEINet 2022). The Mojave Basin and Range Level III ecoregion (yellow outline) is buffered up to 100km in all directions. PSZs do not always extend a full 100km beyond the Mojave ecoregion.

Commercial Seed Availability and Germplasm Releases.

Seed for this species does not appear to be commonly available commercially, and there have been no conservation plant releases for brittlebush.

Wildland Seed Collection.

Wildland seed collection involves visiting naturally occurring populations of target species to collect source seed for propagation, restoration, and research. Ethical practices are intended to prevent overharvesting by limiting harvesting no more than 20% of available seed (BLM 2021). However, in arid regions and in drought conditions, it may be best to adapt this guidance to collect no more than 10% of available seed due to limited regeneration and low-density populations (Asbell 2022, personal communication). Several practices are in place to ensure proper genetic diversity is captured from the source population. These include collecting from the entire population uniformly, sampling a diversity of phenotypes and microclimates, and collecting in various time windows to capture phenological and temporal diversity (BLM 2021).

Seed Collection Timing.

In the Mojave Desert, brittlebush has been collected in April-May, with the majority of collections occurring in April (BLM SOS 2022). Summer heat can potentially damage the viability of seeds. Therefore, the suggested collection window for wild populations is in the 2–3 weeks before seeds have dispersed (Thomas et al. 2022, personal communication).

Collection Methods.

Due to the ruggedness of the terrain *Encelia* species occur in, hand-collection is usually the most effective way to harvest seeds from wild populations. Recommended hand collection methods for brittlebush include clipping seed heads (particularly mid-season or mid-ripeness), or using tools such as tennis racquets, brooms, or vacuums to shake ripe seeds from plants into a collection vessel. The second method also can reduce the number of non-viable or unripe seeds collected in Aster species (Kleiner 2023, personal communication). While plants may occasionally have aborted inflorescences, *Encelia* species usually produce abundant viable seed (Sturwold et al. 2022, personal communication).

Post-Collection Management.

Immediately following collection, seeds should be properly managed to avoid damage or declines in viability during transport and temporary storage. Seed should be dried and ventilated to prevent molding (Pedrini and Dixon 2020). Ventilation can be achieved by collecting and storing seed in breathable containers, such as paper or cloth bags. To dry material before storage or processing, spread it in a single layer on trays or newspaper indoors in a well-ventilated room, or outdoors in a shaded area (BLM 2021). Collected material should be visually inspected for seed-predating insects (Pedrini and Dixon 2020). If seed predation is observed, consider fumigation with No-Pest Strips. After collection, prevent exposure to excessively hot or cold temperatures during transportation and temporary storage by keeping seed in a dry, insulated container (e.g., a cooler) in a shaded area while in the field (BLM 2021).

Growers reported pests, such as seed parasites and fungal infections, are rarely a problem with *Encelia* species (Graham 2022, personal communication; Sturwold et al. 2022, personal communication).

Seed Cleaning.

Seeds from plants in the sunflower family can be difficult to process. In general, fertile seeds will separate easily from the flower head compared to infertile or parasitized seeds, which will not come free easily (Wall and MacDonald 2009; Asbell 2022, personal communication).

Brittlebush seeds should be completely dry before processing. To clean, seed material can be removed from receptacles by hand. Receptacle chaff can then be removed from seeds with a blower set at 1.0 speed. A blower set at 1.5 speed can then be used to separate good seeds from parasitized seeds, and a setting of 1.15 will remove hollow fruits and chaff. Fertile seeds can be separated from the rest of their chaff by gently rubbing them over a #20 sieve or rubber mat and then separating the resulting broken off chaff with a seed blower while increasing speed to 1.2 (Wall and MacDonald 2009).

Relative difficulty of processing *Encelia* seeds may depend on collection methods. One source rated processing *Encelia* seeds as relatively difficult, and suggested a significant amount of time should be planned for cleaning seed collections (Wall and MacDonald 2009). Growers at Victor Valley College, who are currently working on developing growing practices for Acton's brittlebush describe the seeds as easy to clean with relatively little chaff to process (Brooks and Gault 2023, personal communication).

Figure 8: Brittlebush seeds with chaff (top) and without chaff (bottom), scale shown in cm. Photos: BLM SOS CA930A

Seed Storage.

In general, seeds should be stored in cool and dry conditions, out of direct sunlight, to maintain viability. Optimal conditions for medium-term storage of orthodox seeds (up to 5 years) are 15% relative humidity and 15° C (59° F). For long-term storage (>5 years), completely dried seeds should be stored at -18° C (0° F) (De Vitis et al. 2020, Pedrini and Dixon 2020).

Brittlebush, like all *Encelia* species, has orthodox seed. Brittlebush showed no reduction in viability after seven years of storage at -15 °C at the Kew Botanical Gardens (SER SID 2023). Seed pests and fungus were not reported as issues for *Encelia* species (Graham 2022, personal communication), and diseased seeds are generally easy to distinguish because they stick to the flower head in clumps instead of dispersing easily from the plant (Asbell 2022, personal communication).

Seed Testing.

After collection, a representative sample of each seed lot must be tested in an appropriate seed lab to ensure purity and germination meet minimum standards defined by AOSA (2016) and species standards from state-level certification programs as available. A set of "principles and standards for native seeds in ecological restoration" (Pedrini and Dixon 2020) outlines further guidelines specific to native plants, including procedures for obtaining representative samples of seed lots and incorporation of dormancy measures into seed testing and labels.

The AOSA includes *Encelia* species in its tetrazolium testing protocols for the Asteraceae family. These methods involve imbibing seeds overnight at 20-25 °C (68-77 °F), then cutting seeds longitudinally and placing them in a 0.1% tetrazolium solution for 6 hours to overnight at 30-35 °C (86-95 °F). Viability can then be quantified by assessing the percentage of seeds with embryos that are either evenly stained or have more than half of their cotyledons stained (AOSA 2010).

Wildland Seed Yield and Quality.

Wild-collected brittlebush from the Mojave Desert has an average of 90% fill and 93% purity, based on 24 Seeds of Success collections, and 90% viability as indicated by tetrazolium tests based on 22 Seeds of Success collections (BLM SOS 2022). One source reported 570,000 seeds per lb for brittlebush (Mirov and Kraebel 1937), but Seeds of Success collections averaged

386,831 seeds per lb across 24 samples, with an average of 322,499 pure live seeds (PLS) per lb.

Table 2: Brittlebush seed yield and quality from Mojave Basin and Range collections, cleaned by the Bend Seed Extractory and tested by the Oregon State Seed Lab or the USFS National Seed Lab (BLM SOS 2022). Fill (%) was measured using a 100 seed X-ray test. Viability (%) was measured using a tetrazolium chloride test.

Seed lot characteristics	Mean	Range	Samples (no.)
Bulk weight (lbs)	1.28	0.03-1.23	24
Clean Weight (lbs)	0.27	0.03-1.23	24
Purity (%)	93	75-99	24
Fill (%)	90	62-98	24
Viability (%)	90	45-98	22
Pure live seeds/lb	322,499	224,821-482,722	24

Wildland Seed Certification.

The Association of Official Seed Certifying Agencies (AOSCA) sets the standards for seed certification and provides guidance on production, identification, distribution, and promotion of all certified seed, including pre-varietal germplasm. Pre-varietal germplasm (PVG) refers to seed or other propagation materials that have not been released as varieties (AOSCA 2022). Pre-varietal germplasm certification programs for source-identified materials exist in several states encompassing the Mojave Desert ecoregion including California (CCIA 2022), Utah (UTCIA 2015), and Nevada (NDA 2021). Arizona does not have a PVG certification process at this time. Source Identified (SI) germplasm refers to seed collected directly from naturally occurring stands (G0), or seed grown from wildland-collected seed in agricultural seed increase fields (G1-Gx) that have not undergone any selective breeding or trait testing. These programs facilitate certification and documentation required for wildland-collected seed to be legally eligible for direct sale or seed increase in an agricultural setting. Certified SI seed will receive a yellow tag, also referred to as an SI-label, noting key information about the lot including the species, the generation of seed (G0-Gx), source location, elevation, seed zone, etc. (UTCIA 2015, NDA 2021, CCIA 2022).

Wildland seed collectors should be aware of documentation required for seed certification. The Seeds of Success data form and protocol (BLM 2021) include all appropriate information and procedures for site documentation and species identification verification to meet certification requirements for wildland sourced seed. Seed certifying agencies may also conduct site inspections of collection locations prior to certification—specific requirements for inspections vary by state and are at the discretion of the certifying agency.

AGRICULTURAL SEED PRODUCTION

Brittlebush grows best in full sun and well-draining soils with a neutral PH (Granite Seed 2023). Growers had varying success with germinating brittlebush, with the majority describing it as easy to grow (Graham 2022, personal communication; Sturwold et al. 2022, personal communication; Plath 2023, personal communication). The one grower that found it challenging to grow suggested this was due to the quality of the seed collection and not attributed to growing conditions (Johnson 2023, personal communication).

Agricultural Seed Field Certification.

As with wildland source seed (see Wildland Seed Certification section), seed grown in an agricultural seed increase field must also be certified by an official seed certifying agency, where programs exist. Field grown seed is also certified and labeled as Source-Identified (SI), as long as it has not undergone selective breeding or testing. Seed field certification includes field inspection, seed testing for purity and germination (see Seed Testing section), and proof of certification for all source or parent seed used to start the field (AOSCA 2022). The SI-label or "yellow tag" for seed from a seed increase field denotes information about source seed, field location, and generation level (G1-Gx) indicating if there is a species-specific limitation of generations allowed to be grown from the original source (e.g., in a species with a three-generation limit, G1/G3, G2/G3, G3/3) (AOSCA 2022).

The state of California has pre-varietal germplasm (PVG) certification standards for brittlebush with a minimum of 5 oz sample size to be submitted for testing. The Nevada and Arizona Departments of Agriculture do not specify standards for PVG crops. The Utah Crop Improvement Association does not specify standards for PVG crops but may apply standards of similar species or crop groupings (UTCIA 2015).

Table 3: Pre-varietal germplasm (PVG) standards for seed analysis results of brittlebush seed increase crops in California.

Factor	G1	G2	G3 to G10
Pure Seed (minimum)	70%	70%	70%
Inert Matter (maximum)	30%	30%	30%
Total Other Crop Seed (maximum)	0.20%	0.30%	0.50%
Weed Seed (maximum)	0.20%	0.30%	0.50%
Noxious Weed	None	None	None
Germination and Hard Seed (minimum)	60%	60%	60%

Isolation Distances.

Sufficient isolation distances are required to prevent cross-pollination across seed production crops. California standards are described specifically for brittlebush, while the Utah standards are general for outcrossing annual species (Table 4; UCIA 2023). Nevada and Arizona do not specify these standards for Source Identified PVG seed.

Table 4: Crop years and isolation distance requirements for pre-varietal germplasm crops of brittlebush. CY= crop years, or the time that must elapse between removal of a species and replanting a different germplasm entity of the same species on the same land. I= isolation distance, or the required distance (in feet) between any potential contaminating sources of pollen.

	G1		G2		G3+	
State	CY	I	CY	I	CY	I
Utah	3	900-600	2	450-300	1	330-165
California	5	60	5	30	2	15

Site Preparation.

Fields should be as weed-free as possible prior to planting. Site preparation to reduce undesirable vegetation should be planned and implemented well in advance of field establishment (USDA NRCS 2004). If fields are uncultivated or fallow and have perennial or annual weeds, one or more years of intensive cultivation (e.g., cover cropping) and herbicide treatment may be necessary (USDA NRCS 2004). After managing undesirable species, final seedbed preparation can include shallow tilling followed by packing to promote a finely granulated, yet firm seedbed that allows soil to seed contact, as well as facilitation of capillary movement of soil moisture to support seedling development (USDA NRCS 2004). Pre-emergent herbicides may be useful if planting brittlebush as plugs but should not be used for direct seeding.

Seed Pre-treatments.

Some growers have successfully germinated brittlebush without seed treatments (Plath 2023, personal communication), and germination rates of 71% have been reported without pre-treatments (SER SID 2023). However, seed pre-treatments may improve germination. Soaking seeds in gibberellic acid, a commonly used germination stimulant, has been shown to improve germination (Padgett et al. 1999, Graham 2019). However, some growers have reported no success with gibberellic acid (Schaff 2023, personal communication). Cold stratification and seed coat removal can also increase germination rates (CalBG 2023, SER SID 2023).

Tests conducted by the California Botanic Garden found that untreated brittlebush seeds had an average germination rate of 34%, with a range of 1% to 83%. The highest germination rate reported was from a batch that received a cold, moist stratification treatment 20 °C (68 °F) days and 12 °C (53° F) nights (CalBG 2023).

Lower germination rates in aster species may be due to a high proportion of non-viable seeds produced (Graham 2022, personal communication), though some growers reported getting a high number of viable seeds from brittlebush (Sturwold et al. 2022, personal communication).

Seeding Techniques.

Seeding in the fall allows for maximum root growth during the winter and early spring months (Drennan and Nobel 1996). At least one grower reported direct seeding to be unsuccessful with other Encelia species, and recommended planting from plugs instead (Schaff 2023, personal communication). In general, plug planting may be more effective than direct sowing when there is a limited amount of seed available, if seed has low viability, or if the seed lot has weed seed contaminants that can be more easily weeded out in a nursery (Winters 2023, personal communication).

Establishment and Growth.

No specific information on establishment and growth of brittlebush seed increase crops was found in the literature or through personal communication.

Weed Control.

Weeds can be manually removed or carefully spot-sprayed with a non-selective herbicide as they emerge. There are limited number of herbicides registered and labeled for use on native plant crops. See the Native Seed Production guide from the Tucson Plant Materials Center (USDA NRCS 2004) for further details on weed management in native seed production fields.

Pest Management.

Growers reported very little issues with pests or disease in brittlebush. However, Chrysanthemum lacebugs (*Corythuca marmorata*) can cause heavy damage to brittlebush in greenhouses. These insects are usually found on the underside of the leaves. The initial infestation can be treated with pyrethrin, followed up with manual removal of any survivors as they are found (Asbell 2022, personal communication; Dial 2023, personal communication). Aphids and whiteflies are occasionally problematic in greenhouses but typically do not cause significant damage (Asbell 2022, personal communication; Thomas et al. 2022, personal communication; Graham 2022, personal communication; Sturwold et al. 2022, personal communication). Manually removing insects by hand or rinsing can be effective for treating greenhouse pests at small scales (Thomas et al. 2022, personal communication). Chain link or chicken wire fences extending below ground can be used to keep burrowing animals out of fields (Brooks and Gault 2023, personal communication). Pest issues in agricultural fields are unknown, but research on defensive chemicals in brittlebush (see Parasites and Predation) suggests that this species has some natural resistance to invertebrate herbivores (Srivastava et al. 1990).

Pollination Management.

Growing native plants in or near their native range increases the likelihood that compatible pollinators will be able to find and pollinate the crop (Cane 2008). In general, growers can implement pollinator management and stewardship practices to augment and attract existing pollinator communities. Specific practices will depend on the plant species' pollination needs, and the biology of the pollinators. For example, if a plant relies on native solitary bees, growers can create nesting opportunities adjacent to or within the field perimeter with downed woody material or crafted bee boxes (Cane 2008, MacIvor 2017).

Irrigation.

Many growers apply uniform watering techniques regardless of species due to their set infrastructure and labor resources. For example, at the Tucson Plant Materials Center, all fields are watered with flood irrigation (Dial 2023, personal communication). After seeding, fields are irrigated to maintain a moist soil surface and avoid soil crusting that would interfere with germination. Once plants are established, fields are flooded approximately every four weeks during the growing season. Irrigation frequency will depend on heat and precipitation levels and may be as frequent as every two weeks during the hottest part of the year to minimize plant stress which can decrease seed yield (Dial 2023, personal communication).

Other growers utilize drip irrigation and find flood irrigation does not adequately penetrate the soil in arid growing conditions (Hagman 2023, personal communication).

Seed Harvesting.

Seeds are typically hand-harvested and possibly up to five times per season (Brooks and Gault 2023, personal communication, Schaff 2023, personal communication). Encelia seeds can shatter, so if harvesting equipment is used only experienced operators should be employed (Winters 2023, personal communication). Windrowing and direct combine harvest are not recommended for Encelia species (Schaff 2023, personal communication). With hand harvesting methods, only 10-15% of available seed can typically be harvested (Schaff 2023, personal communication).

Seed Yields and Stand Life.

As with most perennials, seed production from brittlebush should not be expected in the first year. However, *Encelia* species produce seed relatively quickly for perennial shrubs (Sturwold et al. 2022, personal communication) and can be mature enough for good seed yield and production in two years (Schaff 2023, personal communication). While field longevity was not reported for *Encelia* species, they generally do not live longer than 30 years.

NURSERY PRACTICE

Brittlebush seeds may be difficult to germinate (see Seed Pre-treatments), and flowering can be difficult to induce in the plants in green house conditions.

Encelia species have sturdy seedlings that propagate easily in a nursery setting (Graham 2022, personal communication). Most growers recommended sowing seeds in the fall into flats or pots for later transplanting (Thomas et al. 2022, personal communication; Graham 2022, personal communication), but at least one grower recommended planting during the warmer months for higher germination rates (Asbell 2022, personal communication). If plants are being grown for restoration projects, seed can also be sown directly into the final container instead of transplanting seedlings from flats or small pots. Sowing plants in their final container helps grow plants with stronger root systems (Asbell 2022, personal communication). Brittlebush grows deep taproots and doesn't transplant well (Thomas et al. 2022, personal communication), so planting into the final container may be the best approach for growing this species in the nursery. Growers reported using a standard soil mix when growing brittlebush, typically two parts peat to one part perlite (Sturwold et al. 2022, personal communication), or three parts perlite to one part vermiculite and ¼ cup of slow-release fertilizer (Asbell 2022, personal communication).

It is important to maintain a dry soil surface in the greenhouse when starting Encelia species, including brittlebush. If the soil surface is too damp, seedlings may snap off at the root collar. One recommended technique is to cover soil with a thin layer of perlite to keep soil surface dry (Johnson 2023, personal communication). Encelia species can be sensitive to overwatering. Watering recommendations vary from "as needed" to watering twice a month in the summer and once every three weeks in the winter and spring (Asbell 2022, personal communication; Graham 2022, personal communication). Growers used a combination of hand watering and drip irrigation (Graham 2022, personal communication; Sturwold et al. 2022, personal communication).

Figure 9: Brittlebush seedlings in cultivation in tall pots at Joshua Tree National Park. Photo: Ashlee Wolf

REVEGETATION AND RESTORATION

Brittlebush is useful for restoration and reclamation (Tesky 1993, Wetle et al. 2020). *Encelia* species are showy, and therefore often included in roadside revegetation projects. Brittlebush is frequently used by CalTrans, even outside its native range (Clary and Slayback 1983, CalScape 2023). In Arizona it is frequently used to stabilize and revegetate roadsides (Tesky 1993). Several practitioners report success with direct seeding brittlebush (Clary and Slayback 1983, Tesky 1993). CalTrans uses both direct seeding and outplanting (Clary and Slayback 1983). One rangeland study found that brittlebush could outcompete the introduced invasive species buffelgrass in the Sonoran Desert (Tesky 1993). Rodent predation can greatly reduce survival of brittlebush and other shrubs at restoration sites (Clary and Slayback 1983)

Encelia species generally do not require much water, but supplemental watering is suggested for up to two years after outplanting at restoration sites or for landscaping (Graham 2022, personal communication; CNPS Calscape 2023).

Wildland Seeding and Planting.

Wildland Seedings.

Brittlebush was included in a multi-species seed mix (1.85% of the seed mix at a rate of 7 viable seeds per square meter), and successfully germinated, in a project that restored abandoned farmland in the Sonoran Desert (Banerjee et al. 2006).

Brittlebush has been used for restoration via both seeding and outplanting methods after a fire in the Mojave Desert (Abella et al. 2012). Seeds were applied at a rate of 210 PLS/ m^2 and broadcast by hand followed by tamping to press seeds into soil. Plots were protected with wire cages to deter granivory and irrigation was applied at a rate of 4 L/ m^2 of water immediately after seeding and 2 L/m^2 each month for four months after seeding. No brittlebush or other seeded species emerged (Abella et al. 2012).

In an experimental seeding trial to study techniques for reducing seed loss from disturbed sites in the Mojave Desert, brittlebush was broadcast seeded in plots at a rate of 119 ± 8 seeds/m2 (DeFalco et al. 2012). Tested techniques for reducing seed movement included harrowing (dragging tines behind a tractor to create furrows and break up soil compaction) or applying a tackifier (a water-soluble, latex polymer emulsion sprayed over seeded areas to improve soil-seed contact). In sites that had been harrowed, brittlebush seedlings were the most common of the seeded species. While harrowing and tackifier applications reduce seed loss from restoration sites, granivory by ants and small mammals will cause additional loss. Drill seeding, which puts seeds below the soil surface, can reduce granivory. Seed losses to granivory were related to presence of ant nests and rodent burrows, and use of methods to prevent granivory could be planned based on observing ant nest and rodent burrow density before seeding (DeFalco et al. 2012).

Wildland Plantings.

Wildland plantings at restoration sites typically occur 10 to 16 months after sowing in the nursery (Graham 2019).

Fall is ideal for outplanting so that plants can establish before the hot, dry summer months (Graham 2022, personal communication; Sturwold et al. 2022, personal communication).

Brittlebush has been used to restore fire-damaged desert tortoise habitat in the Beaver Dam Wash National Conservation Area within the Mojave Desert (Kellam 2023). Plants were grown in one-gallon containers from locally sourced seeds and outplanted in November. Plants received two liters of water at the initial planting and 1-2 liters of water when soil moisture at 25 cm (9.8 inches) fell below 12%. Brittlebush plants had over 75% survival six months after the planting. After 4.25 years, about 25% of the original plants had survived (Kellam 2023).

In another trial of brittlebush outplantings after fire in the Mojave Desert, plants had zero survival three years after planting, regardless of whether they were given supplemental water or shelter from herbivory (Abella et al. 2012).

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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/default/files/docs/2021-12/SOS%20Technical%20Protocol.pdf

OMERNIK LEVEL III ECOREGIONS

https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

CLIMATE SMART RESTORATION TOOL

https://climaterestorationtool.org/csrt/

MOJAVE SEED TRANSFER ZONES

https://doi.org/10.5066/P9BQ6IYJ

MOJAVE SEED MENUS

https://rconnect.usgs.gov/MojaveSeedMenu/

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