MOJAVE WOODYASTER

Xylorhiza tortifolia (Torr. & A. Gray) Greene

Asteraceae - Sunflower Family

Sophia Goss and Ashlee Wolf | 2024

ORGANIZATION

NOMENCLATURE

Mojave woodyaster (*Xylorhiza tortifolia* (Torr. & A. Gray) Greene) is in the sunflower family, or Asteraceae (USDA NRCS 2023).

NRCS Plant Code.

XYTO2 (USDA NRCS 2023).

Synonyms.

Aster tortifolius, Haplopappus tortifolius, Machaeranthera tortifolia, Machaeranthera tortifolia var. *imberbis*, *Xylorhiza tortifolia* var. *imberbis*, *Xylorhiza tortifolia* var. *tortifolia* (Tropicos 2023).

Common Names.

Mojave woody-aster, Mojave woodyaster, Mohave aster, Mojave aster (SEINet 2023).

Subtaxa.

The Flora of North America and the Integrated Taxonomic Information System (ITIS) recognize two varieties in the *Xylorhiza tortifolia* classification:

- *Xylorhiza tortifolia* var. *imberbis* (Torr. & A. Gray) Greene
- *Xylorhiza tortifolia* var. *tortifolia* (Cronq.) T.J. Wats.

Chromosome Number.

The chromosome number for Mojave woodyaster is 2n=6, 12 (Watson 1977). *Xylorhiza tortifolia* var. *tortifolia* chromosome number is 2n=12, 24 (Keil 2012) and *Xylorhiza tortifolia* var. *imberbis* chromosome number is 2n=12 (Nesom 2020).

Hybridization.

There are no records of hybridization between Mojave woodyaster and related species. It is closely related to two other species of *Xylorhiza*, but all are separated by geographic barriers (Mcglaughlin 2008).

DESCRIPTION

Mojave woodyaster is a perennial subshrub with stems that grow 20-80 cm tall from a much-branched caudex atop a thick, woody taproot (Watson 1977, Nesom 2020). Stems are generally branched proximally, not at the end. Plant stems and leaf surfaces are covered in long hairs with glands on the tips (Nesom 2020). The lanceolate to oblanceolate or linear leaves are arranged alternately along the stem with sessile and often subclasping bases and sharp spine-tipped margins around the leaf edge (Keil 2012). A solitary flower head is borne on a long peduncle (Keil 2012). Flower heads are comprised of 15-85 lavender or white ray florets and 70-110 yellow disc florets (Nesom 2020). The involucre shape is campanulate to hemispheric, 1-2 cm in length with 25- 45 phyllaries arranged in 3-6 series that are narrowly lanceolate (Nesom 2020). Achenes are 3-6 mm long with a persistent pappus of barbellate bristles up to 9 mm long (Nesom 2020).

Figure 1: A Mojave woodyaster individual. Photo: BLM SOS CA930A

Figure 2: The inflorescence of Mojave woodyaster with yellow disc flowers and lavender-tinged rays. Photo: BLM SOS CA930A

Varieties.

Xylorhiza tortifolia var. *tortifolia* is distinguished by stems with long non-glandular hairs and shorter stalked glands, as well as shorter pappus bristles (less than 9 mm) (Keil 2012).

Xylorhiza tortifolia var. *imberbis* has stems, leaves and phyllaries with stipitate glands but no pubescence (Hazelton 2015).

DISTRIBUTION AND HABITAT

Mojave woodyaster occurs in arid regions of the southwest on dry rocky slopes and washes in northern and western Arizona, southern California, southern Nevada and southwestern Utah (SEINet 2023; Figure 3).

Variety *tortifolia* is widespread in the Mojave Desert in southern California and southern Nevada, also extending into northwestern Arizona and eastern Utah (Watson 1977).

Variety *imberbis* primarily occurs along the canyons of the Colorado River from the Grand Canyon of Arizona upstream to southern Utah (Watson 1977).

The two varieties only intergrade in southern Nevada, in Clark and Nye counties (Nesom 2020).

Mojave woodyaster is ranked as apparently secure (S4) by NatureServe. Variety *tortifolia* is ranked as vulnerable (S3) in Utah with no status rank in California, Nevada, and Arizona. Variety *imberbis* is ranked as critically imperiled (S1) in Nevada and has no status rank in Utah and Arizona (NatureServe 2023).

Habitat and Plant Associations.

Mojave woodyaster does not have a common geographic occurrence and occurs in more open habitat and dry canyons (Pendleton et al. 1989, Calscape 2023). Seed collections of Mojave woodyaster commonly take place in mixed Mojave shrubland or rocky slopes and ridges (BLM SOS 2022).

Mojave woodyaster grows in relatively barren areas dominated by shrubs, such as sagebrush (*Artemisia* spp.), shadescale (*Atriplex* spp.) and creosotebush (*Larrea tridentata*) (Watson 1977). Common associated species with Mojave woodyaster are desert marigold (*Baileya multiradiata*), broom snakeweed (*Guiteirrezia sarothrae*), Joshua tree (*Yucca brevifolia*), spiny hopsage (*Grayia spinosa*), eastern Mojave buckwheat (*Eriogonum fasciculatum*), winterfat *(Krascheninnikovia lanata)*, Nevada ephedra (*Ephedra nevadensis*), and desert dandelion (*Malacothrix glabrata*) (BLM SOS 2022).

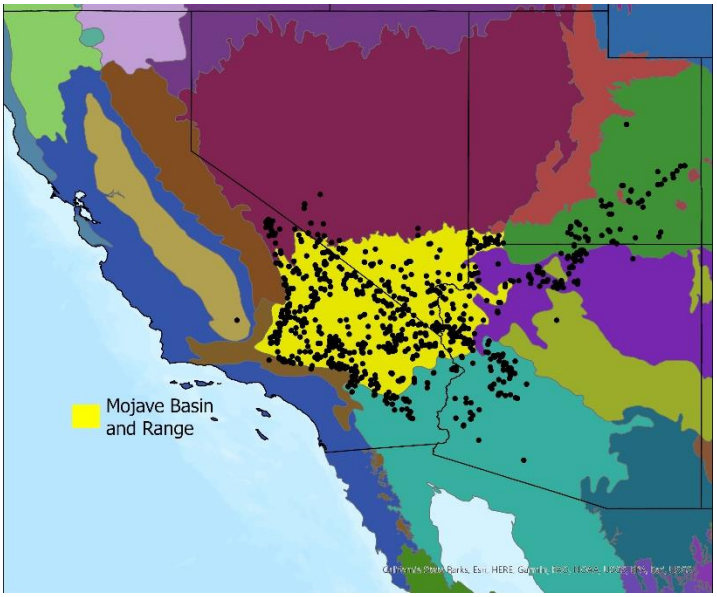

Figure 3: Distribution of Mojave woodyaster based on georeferenced herbarium specimens and verified observations (black circles, SEINet 2022) with EPA Level III Ecoregions (US EPA 2015). The Mojave Basin and Range ecoregion is shown in yellow.

Figure 4: Mojave woodyaster in an open desert habitat with Joshua trees in California. Photo: BLM SOS CA930A

Figure 5: Mojave woodyaster growing on a rocky slope Photo: BLM SOS MD1

Climate.

The Mojave Desert is characterized by low annual precipitation (5-25 cm or 2-10 inches in valley areas), with most rainfall occurring in the winter and a smaller amount during summer thunderstorms (Randall et al. 2010). Heterogenous 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). Specifically, 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 Mojave woodyaster occurs (Shryock et al. 2018; Table 1). According to herbarium specimen locations (SEINET 2022), Mojave woodyaster occurs in all PSZs in the Mojave Desert ecoregion but is most abundant in Zones 25 and 26 and least abundant in Zone 22 (Table 1). The average annual precipitation in the PSZs where Mojave woodyaster occurs in the Mojave Desert ecoregion is 17.8 cm (7.0 inches), with an average of 5.7 cm (2.2 inches) falling in the summer and an average of 12 cm (4.7 inches) falling in the winter. Note, herbarium specimen locations may not represent the full distribution and abundance of Mojave woodyaster due to sampling biases.

Elevation.

Mojave woodyaster commonly occurs from 2,000 to 5,000 ft (609-1524 m) in elevation (Hazelton 2015).

Soils.

Mojave woodyaster typically occurs in infertile soils with pH from 7.5 to 8.3 (Watson 1977). It commonly grows in clays, rocky sands, and gravels derived from igneous, granite, limestone or sandstone parental formations (Watson 1977).

No associations with biological soil crust were noted in the literature.

Table 1: Climate of the provisional seed zones (PSZ) where Mojave woodyaster occurs within the Mojave Desert ecoregion (Shryock et al. 2018).#Records = the number of herbarium or verified observations within the PSZ (SEINet 2022); MAP=mean annual precipitation; SP=summer precipitation, or the mean precipitation that falls in the summer (May-October); WP= winter precipitation, or the mean precipitation that falls in the winter (November-April); MAT=monthly average temperature; Range= Average of the monthly temperature ranges (monthly maximum minus monthly minimum).

PSZ	#	MAP (cm)	SP (cm)	WP (cm)	MAT (C)	Range (C)
26	201	14.5	2.7	11.8	16.8	34.9
25	136	16.5	6.2	10.3	18.9	34.6
21	105	15.6	6.2	9.4	18.8	38.4
23	94	15.8	5.4	10.4	16.1	35.9
24	88	10.7	2.8	7.9	18.8	38.6
29	75	25.5	4.2	21.4	13.8	31.7
20	51	25.5	10.5	14.9	15.3	34.5
27	16	9.6	3.3	6.3	20	36.7
28	13	7.8	2.4	5.3	22.3	41.3
22	1	36.1	13.3	22.8	10	32.4

ECOLOGY AND BIOLOGY

Reproduction.

Breeding System.

Mojave woodyaster is polygamomonoecious: male, female, and hermaphroditic flowers occur on the same plant (Pendleton et al. 1989). No information on the prevalence of outcrossing versus self-fertilization in Mojave woodyaster was found in the literature. However, the frequency and abundance of insect floral visitors suggest this species is likely outcrossing and insect-pollinated.

Reproductive Phenology.

Mojave woodyaster typically flowers March through May and sometimes again in October, with seeds typically maturing in May (Baldwin et al. 2012, BLM SOS 2022). In general, species in the genus *Xylorhiza* exhibit maximum vegetation growth and flower in early spring to take advantage of higher moisture content and cooler temperatures (Watson 1977).

Pollination.

The flower heads offer a wide landing platform to insect visitors (Esque et al. 2021) and are visited by a diversity of insect pollinators. Native bee visitors to Mojave woodyaster include *Andrena linsleyana*, *Anthophora* spp., *Ashmeadiella* spp., *Hesperapis* sp., *Hylaeus* sp., *Lasioglossum sisymbrii*, and *Perdita* spp. Butterflies, moths, and beetles also visit Mojave woodyaster flowers (Sam 2020).

Seed and Seedling Ecology.

There is little information available on the seed and seedling ecology of Mojave woodyaster. The seed is likely dispersed short distances by wind (Pendleton et al. 1989).

A study of perennial dynamics in the Mojave Desert reported that Mojave woodyaster has a higher population turnover rate (defined by higher rates of birth and death) than other desert perennial species over a 15-year period (Cody 2000).

Species Interactions.

Belowground Interactions.

No associations between Mojave Desert woodyaster and belowground organisms were noted in the literature.

Wildlife and Livestock Use.

The threatened Mojave desert tortoise (*Gopherus agassizii*) rarely uses Mojave woodyaster for cover (used at one of nine sites by two individual tortoises) and the species has not been recorded in tortoise diets (Esque et al. 2021).

Mojave woodyaster is categorized as moderately-preferred forage for domestic sheep late in its growing season (Phillips et al. 1996).

In a study of the effects of cattle grazing on plant cover and diversity in the Mojave desert, native perennials, including Mojave woodyaster, had a negative association with livestock watering sites and displayed less cover when closer to watering sites (Brooks et al. 2006). The authors suggested this could be attributed to higher density and cover of invasive species and direct trampling by livestock in proximity to watering sites.

Insect Interactions.

Tephritid fruit flies (*Procecidochares* spp.) can form galls in the hallowed-out flower heads of Mojave woodyaster (RD Goeden unpublished data, cited in Headrick and Goeden 1998)

Mojave woodyaster is a confirmed host plant for owlet moths (*Cucullia intermedia* and *Schinia ligeae*) and the brush-footed butterfly, *Agathymus neumoegeni* (Robinson et al. 2010). It is a likely host plant for the sagebrush checkerspot (*Chlosyne acastus*) (Calscape 2023).

Disturbance Ecology.

There is limited information available on how Mojave woodyaster responds to disturbance, including fire. One study of vegetation community response to fire found Mojave woodyaster to be more strongly associated with burned than unburned sites in the Mojave Desert (Sam 2020). A different study found that the species was absent from burned sites but present in unburned sites in the Sonoran Desert (Shryock et al. 2015).

Mojave woodyaster has been categorized as an "increaser" in response to disturbance based on a quantitative literature review of studies in the Mojave and Sonoran Deserts (Abella 2010).

Ethnobotany.

The Havasupai people have used Mojave woodyaster as a fragrance by grinding leaves and carrying them in clothing (Whiting et al. 1985).

Horticulture.

Mojave woodyaster is commonly used in butterfly and bee gardens, as well as a groundcover in landscaping (Calscape 2023). It is available from retail plant nurseries for use in residential and commercial landscaping (Calscape 2023).

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), evidence of local adaptation and its influence on restoration outcomes can take decades to emerge for long-lived species (Germino et al. 2019). Further, plants have coevolved with interacting organisms, such as pollinators and herbivores, that can exhibit preferential behavior for local materials (Bucharova et al. 2016, 2022).

Empirical seed transfer zones have not been developed for Mojave woodyaster. The Desert Southwest Provisional Seed Zones (PSZs) may be used to plan seed sourcing in the absence of species-specific information. 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.

Commercial Seed Availability and Germplasm Releases.

Mojave woodyaster is not commonly available for purchase from large-scale commercial seed vendors. When available, sources may be limited to a narrow range of appropriate seed zones. Commercially available seed may not be source identified, and source seed zone information may not be available. There have been no conservation plant releases of Mojave woodyaster.

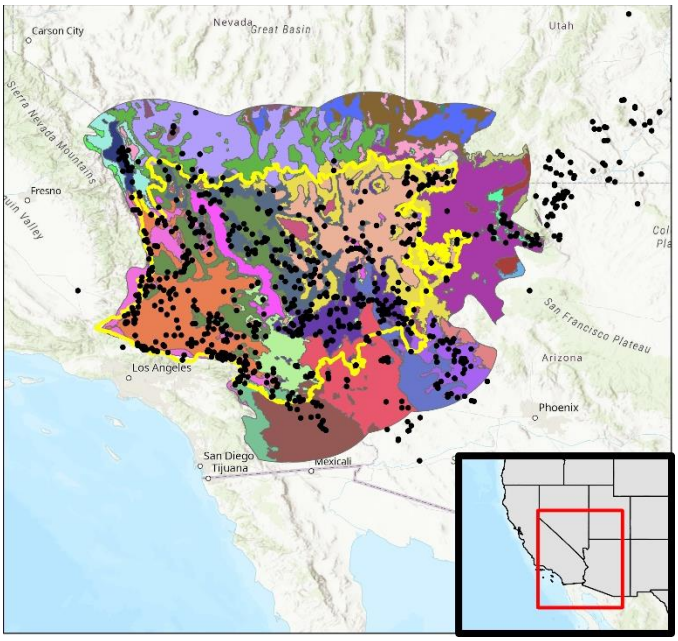

Figure 6: The distribution of Mojave woodyaster across the Desert Southwest Provisional Seed Zones (Shryock et al. 2018). Occurrences (black dots) are based on georeferenced herbarium specimens and verified observations (SEINet 2023). The Mojave Basin and Range Level III ecoregion (yellow outline) is buffered up to 100km in all directions. PSZs do not always extend a full 100km beyond the Mojave ecoregion.

Wildland Seed Collection.

Wildland seed collection involves visiting naturally occurring populations of target species to provide source seed for propagation, restoration, and research. Ethical practices are intended to prevent overharvesting by limiting harvests to 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.

Mojave woodyaster is typically collected between May and June with the majority of collections occurring in May (BLM SOS 2022).

Seeds should be collected when achenes are dry and mature and fall off flower receptacle easily (Wall and MacDonald 2009).

Collection Methods.

No information on specific collection methods was noted in the literature or through personal communications. It is assumed that seeds could be harvested by hand and placed into a paper bag to dry. Seeds should be collected when achenes are dry and mature and fall off flower receptacle easily (Wall and MacDonald 2009).

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).

Figure 7: Collected seed material from Mojave woodyaster; scale shown in cm. Photo: BLM SOS CA930A

Figure 8: Bare cleaned seed of Mojave woodyaster. Photo: Bend Seed Extractory

Seed Cleaning.

Mojave woodyaster seed can be separated from chaff and receptacle bracts by hand, then seed can be put in a seed blower at 1.75 speed (Wall and MacDonald 2009).

Seed Storage.

Mojave woodyaster seed is considered orthodox and showed no loss in viability after 7.5 years in storage at 4-15 °C (SER SID 2023). However, some growers in the Mojave Desert report that Mojave woodyaster seeds quickly lose viability in storage with some saying the seed has a maximum "shelf life" of one year (Kleiner 2023, personal communication; Plath 2023, personal communication; Johnson 2023, personal communication)

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).

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 the Association of Official Seed Analysts (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 does not specifically include *Xylorhiza* species in the tetrazolium testing protocols for the Asteraceae family to assess seed viability. However, methods for other Asteraceae species with similar seed morphology may be applicable. Methods involve imbibing seeds overnight at 20-25 °C, then cutting seeds longitudinally and placing them in a 0.1% tetrazolium chloride solution for 6 hours to overnight at 30-35 °C. 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 Mojave woodyaster seed is generally fair quality, with an average of 76% fill, 94% purity and 79% viability indicated by tetrazolium tests across 10 Seeds of Success collections (BLM SOS 2022, Table 2). Wild collections contain an average of over 190,000 PLS/lb (BLM SOS 2022, Table 2).

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

	Mean	Range	Samples
Bulk weight (lbs)	0.89	0.31-2	10
Clean weight (lbs)	0.26	0.025-0.94	10
Purity (%)	94	84-99	10
Fill (%)	76	40-97	10
Viability (%)	79	28-97	10
Pure live seeds/lb	190,450	85,858-271,382	10

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

Mojave woodyaster has not yet been successfully grown for seed production and the species possesses several traits, such as quickly dispersing seeds and potentially short seed longevity, that make large scale seed increase in agricultural settings potentially untenable (Schaff 2023, personal communication; Winters 2023, personal communication). Specifically, more trials and research are needed to understand agricultural practices for harvesting seeds prior to wind dispersal and overcoming the purportedly short "shelf life" of seeds.

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).

There are no species-specific standards for Mojave woodyaster seed certification.

Isolation Distances.

Sufficient isolation distances are required to prevent cross-pollination across seed production crops of Mojave woodyaster from different sources or other *Xylorhiza* species. Table 3 summarizes the isolation distances required for PVG certification of outcrossing perennial species in Utah. California, Nevada and Arizona do not specify these standards for Source Identified PVG seed of Mojave woodyaster.

Table 3: Crop years and isolation distance requirements for pre-varietal germplasm crops of outcrossing perennial species in Utah. 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

Site Preparation.

Fields should be as weed-free as possible prior to sowing or transplanting Mojave woodyaster seeds or plugs. 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 (i.e. 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).

Seed Pre-treatments.

Growers at Joshua Tree National Park Native Plant Nursery find that Mojave woodyaster can germinate at a rate of 45% in soil without pre-treatments (Graham 2003). Time in storage is an important factor in germination success—fresh seeds have higher germination rates than seeds that have been stored for a year or more (Kleiner 2023, personal communication; Plath 2023, personal communication; Johnson 2023, personal communication).

At Victor Valley College in Victorville, California, growers have trialed three germination pre-treatments for Mojave woodyaster: hot water scarification and a 24-hour soak; wet-cold stratification for 14 days; and no treatment. Seeds that received no treatment had the highest germination rates (80%) while the hot water treatment resulted in 54% germination and the cold stratification had 34-52% germination (Victor Valley College, 2023).

Seeding Techniques.

No information on seeding or field establishment techniques for Mojave woodyaster was found in the literature or through personal communication.

Generally, plug planting may be preferrable 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). However, some species do not establish well after transplanting.

Establishment and Growth.

No information on the establishment and growth outcomes for Mojave woodyaster was found in the literature or through personal communication.

Weed Control.

Generally, 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. In smaller fields, hand rogueing weeds can be sufficient (Hagman 2023, personal communication).

Pest Management.

In a small-scale growing trial at the California City Correctional Facility, Mojave woodyaster plants were impacted by blister beetles (family Meloidae) (Corona 2023, personal communication).

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 consider implementing 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). In some cases, there may be a need to supplement with managed pollinators through honeybee or bumblebee rental services to ensure pollination of wildflower crops for seed increase (Cane 2008).

No recommendations for pollinator management specific to Mojave woodyaster were described in

the literature or through personal communications. However, adequate pollination may be a concern. When Mojave woodyaster was grown in a seed bulking project at California City Correctional Facility, the first year produced no viable seed despite abundant flowering. A lack of pollinators on site during this extreme drought year may have contributed to the failure, as seed production improved in the second year (Perkins, personal communication). More trials are needed to assess potential pollination management needs for Mojave woodyaster crops.

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 can be collected by hand when achenes have matured and browned (Graham 2003). Plants flower and set seed across the growing season and seeds can be available for harvest from March through September (Corona 2023, personal communication). Seeds can quickly disperse in the wind so harvests must be timed to capture optimal ripeness prior to dispersal. In small scale trials with around 80 plants, the grower put mesh bags over immature seed heads to prevent them from blowing away as they ripen (Corona 2023, personal communication). Specific outcomes of this practice were not detailed.

Seed Yields and Stand Life.

No information on seed yield or stand life was described in the literature or through personal communications.

NURSERY PRACTICE

Generally, Mojave woodyaster can grow well in containerized nursery production (Graham 2019, personal communication; Brooks and Gault 2023, personal communication). See Seed Pre-treatments for information on germinating Mojave woodyaster seeds in nursery and agricultural settings. Mojave woodyaster can exhibit declining germination rates correlated with seed age (Asbell 2023, personal communication). Since Mojave woodyaster has a taproot, it is likely best to sow seeds into the final restoration-sized container rather than germination flats (Asbell 2023, personal communication).

Growers at the Living Desert Zoo and Gardens have tried sowing Mojave woodyaster seed in the fall with poor germination results (5 of 49 pots had seedling emergence) (Thomas et al. 2022, personal communication). Seeds were sown ½" deep in 2" pots (three seeds per pot) with a 90% perlite and 10% organic soil medium. Seedlings emerged in 4-8 weeks (Thomas et al. 2022, personal communication).

At Joshua Tree National Park Native Plant Nursery, seeds are directly sown in the winter in

open flats using a substrate of two parts sand, one part mulch and two parts perlite (Graham 2003). Flats are placed in a greenhouse for at least four weeks under a drip irrigation system. This results in an estimated 45% germination rate. Once seedlings have two true leaves, they are transplanted into newspaper cylinders (29 cm tall and 7.5 cm diameter) wrapped with polyvinyl food wrap with a medium of sand, mulch, and perlite at a 2:1:1 ratio. After 8 to 12 weeks, plants are transplanted along with the newspaper cylinders (polyvinyl wrap removed) into tall PVC pots (37.5 cm tall and 15 cm in diameter). Four weeks after transplanting, plants are moved into an open growing area covered with 55% shadecloth in the summer months. Containers are irrigated by an automated drip system every other day with occasional deep soaks to leach out accumulated salts. (Graham 2003). To prepare plants for outplanting, shadecloth is removed; irrigation frequency and duration is reduced for four to eight weeks before out-planting; and plants are top pruned (Graham 2003).

REVEGETATION AND RESTORATION

Mojave woodyaster is considered a priority species for restoration in the Mojave Desert (Esque et al. 2021). The species is useful for supporting pollinator communities due to its ability to provide forage for a diversity of native bees and serve as a larval host plant for several moth species (see Pollination and Insect Interactions). Further, its potential to increase in abundance following disturbance (Abella and Newton 2009) can be beneficial in revegetation applications such as road closures (Walker and Powell 1999) and mine reclamation (Rodgers 1994).

Wildland Seeding and Planting.

Wildland Seedings.

Mojave woodyaster was included in a multi-species seed mix to revegetate roads in the Mojave Desert in Southern Nevada (Walker and Powell 1999). The mix included twelve native species hand sown in January at a rate of 40 pounds per acre. Mojave woodyaster was sown at a rate of 2 pounds per acre. Seed sourcing was not specified. The site was assessed in April and the researchers found 16 Mojave woodyaster plants per 40 square meters in the seeded area, making it one of the most dominant seeded species in the restored area. No further monitoring results were reported to assess establishment and persistence of seeded species.

The species was also used in a seeding project at Joshua Tree National Park which involved testing the effectiveness of imprinting—using a tractor-towed attachment to force depressions into the soil surface that can enhance water catchment and infiltration—followed by seeding with native species (Holden and Miller 1996). Mojave woodyaster seed was sourced from nearby wildland populations and included in a seed mix with sixteen other native species. Seeding rates were not specified. The treatments involved using a road grader to rip the soil surface (18" deep) and decompact the soil. Then the area was seeded by hand and the imprinter rolled over the seeded area to create depressions (4-6 inches deep) while tamping the seeds into the ground (Holden and Miller 1996). Unfortunately, outcomes of this project were not documented.

Wildland Plantings.

Mojave woodyaster was outplanted at a mining reclamation site at Joshua Tree National Park where it had >90% survival rates (Rodgers 1994). Plants grown in a nursery for seven months and transplanted from tree pot

containers (18 inches in height, 6 inches in diameter) had 97% survival. Plants transplanted from smaller containers had higher mortality rates (Rodgers 1994).

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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://www.sciencebase.gov/catalog/item/5ea88c8482cefae35a1faf16

MOJAVE SEED MENUS

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

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