Indian ricegrass

Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth

Poaceae - Grass family

Ashlee Wolf and Casey Hensen |2023

ORGANIZATION

NOMENCLATURE

Indian ricegrass (*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth) belongs to the Poaceae, or grass family (USDA NRCS 2023). It is in the subfamily Pooideae and the tribe Stipeae, a group which has undergone repeated taxonomic revisions based on morphological and molecular evidence (Barkworth et al. 2008).

NRCS Plant Code.

ACHY (USDA NRCS 2023).

Synonyms.

Stipa hymenoides Roem. & Schult., *Oryzopsis hymenoides* (Roem. & Schult.) Ricker ex Piper, *Oryzopsis hymenoides* var. *hymenoides* (Roem. & Schult.) Ricker, *Eriocoma membranacea* (Pursh) Beal, *Eriocoma cuspidate* Nutt., *Fendleria rhynchelytroides* Steud., *Milium cuspidatum* (Nutt.) Spreng., *Oryzopsis cuspidata*, *Oryzopsis hymenoides* var. *hymenoides* (Roem. & Schult.) Ricker, *Oryzopsis membranacea*, *Stipa membranacea* Pursh, *Urachne lanata* Trin. & Rupr, *Eriocoma hymenoides* (Roem. & Schult.) Rydb. (ITIS 2023, SEINet 2023).

Common Names.

Indian ricegrass, Indian rice grass (SEINet 2023), Indian mountain-ricegrass (NatureServe 2023).

Subtaxa.

There are no recognized subtaxa for Indian ricegrass (Barkworth 2021, ITIS 2023).

Chromosome Number.

The chromosome number for Indian ricegrass is 2n=46, 48 (Columbus et al. 2012a).

Since Indian ricegrass possesses intraspecific ploidy variation (differences in chromosome numbers between populations), it may be necessary to assess the cytotypes of populations prior to mixing seed sources or starting propagation. Combining incompatible cytotypes can result in loss of fitness and fertility in plantings (Kramer et al. 2018).

Hybridization.

Indian ricegrass can naturally hybridize with related species in the Stipeae tribe, including western needlegrass (Stipa occidentalis var. occidentalis) (Columbus et al. 2012a). Crosses resulting from hybridization are typically sterile (Ogle 2006).

DESCRIPTION

Indian ricegrass is a perennial bunchgrass that grows 25-70 cm tall with 3-4 nodes per culm (Barkworth 2021). The sheaths are typically glabrous or minutely roughened, with collars that can be glabrous or have a tuft of 1 mm long hairs on the sides. Basal ligules are 1-4 mm long, membranous, and acute. The upper ligules are up to 2 mm long (Barkworth 2021). Blades are tightly rolled and 0.1-1 mm in diameter, giving them a wiry appearance. The inflorescence is an open panicle with diffuse and divergent branches terminating in a pair of pedicels holding one single-flowered spikelet each—the shorter pedicel in each pair is half the length of the longer pedicel. The glumes are subequal with an acuminate apex and are covered in short hairs. The black-brown lemmas are hardened and covered in silky hairs (2-6 mm long) that can be easily rubbed off. Lemma awns are straight, 2-6 mm long, and can be rapidly deciduous (2-6 mm long) (Columbus et al. 2012a). The palea is nearly equal to the lemma in length and texture (Barkworth 2021).

Figure 1: An Indian ricegrass individual. Photo: BLM SOS CA930A

Figure 2: The divergently branching inflorescences of Indian ricegrass. Photo: Patrick Alexander

Figure 3: Florets of Indian ricegrass with subequal glumes, covered in short silky hairs. Photo: Patrick Alexander

DISTRIBUTION AND HABITAT

Indian ricegrass is widely distributed in semi-arid regions across the Intermountain West and Rocky Mountain regions in plains, foothills, mountains, and intermountain basins (Ogle 2006; Figure 5). Within the North American Deserts Level 1 ecoregion it is found abundantly in the Mojave Basin and Range, Colorado Plateau, and Wyoming Basin, but is more sparsely distributed in the Sonoran and Chihuahuan Desert ecoregions. It also occurs commonly in the Southern Great Basin, Southern Rockies, Middle Rockies, and High Plains.

Figure 4: Indian ricegrass growing in a Joshua tree woodland in California. Photo: BLM SOS CA930A

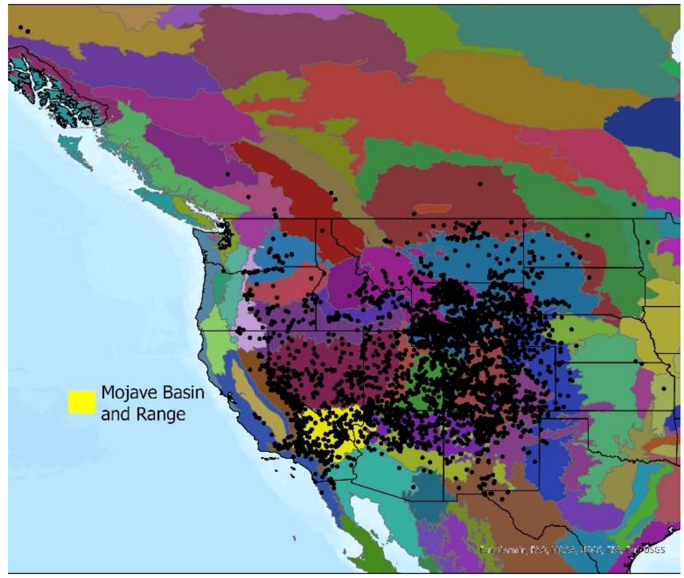

Figure 5: Distribution of Indian ricegrass (black circles) from georeferenced herbarium specimens and verified observations (SEINet 2022) with EPA Level III Ecoregions (US EPA 2015). The Mojave Basin and Range ecoregion is shown in yellow.

Habitat and Plant Associations.

Indian ricegrass is adapted to a broad range of ecological and climatic conditions (Ogle 2006). NatureServe recognizes one ecosystem division, one habitat group, two habitat alliances, and forty habitat associations defined by the presence of Indian ricegrass, indicating its importance as a dominant to subdominant member of vegetation communities across its distribution (NatureServe 2023).

Mojave Desert

In the Mojave Desert, Indian ricegrass grows on rocky or sandy slopes, dunes, desert flats, dry lakebeds, and ephemeral washes. Vegetation communities where Indian ricegrass occurs include Joshua tree woodlands, pinyon-juniper woodlands, sagebrush scrub, xeroriparian shrublands, and upland desert shrublands (Columbus et al. 2012b, SEINet 2022). Common associated species in the Mojave Desert include creosotebush (*Larrea tridentata*), blackbrush (*Coleogyne ramosissima*), Joshua tree (*Yucca* *brevifolia*), Eastern Mojave buckwheat (*Eriogonum fasciculatum*), Jame's galleta (*Hilaria jamesii*), Mojave yucca (*Yucca schidigera*), desert almond (*Prunus fasciculata*) and winterfat (*Krascheninnikovia lanata*) (BLM SOS 2022, SEINet 2022).

Figure 6: Indian ricegrass growing in an open desert habitat in Nevada. Photo: BLM SOS NV040

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 Indian ricegrass occurs (Shryock et al. 2018; Table 1). According to herbarium specimen locations (SEINET 2022), Indian ricegrass occurs in all PSZs in the Mojave Desert ecoregion but is most abundant in Zones 20 and 26 and least abundant in Zone 28 (Table 1). The average annual precipitation in the PSZs where Indian ricegrass occurs in the Mojave Desert ecoregion is 17.76 cm (6.99 inches), with an average of 5.7 cm (2.24 inches) falling in the summer and an average of 12.05 cm (4.74 inches) falling in the winter. Note, herbarium specimen locations may not represent the full distribution and abundance of Indian ricegrass due to sampling biases.

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).

Elevated atmospheric CO_2--a leading cause of anthropogenically accelerated climate change—may result in a competitive advantage for Indian ricegrass as evidenced by its increased root nitrogen uptake under elevated versus ambient CO2 in experimental greenhouse conditions (Yoder et al. 2000).

Table 1: Climate of the provisional seed zones (PSZ) where Indian ricegrass occurs within the Mojave Desert ecoregion (Shryock et al. 2018), showing the number of herbarium records or verified observations 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).

Seed Zone	# Records	MAP (cm)	SP (cm)	WP (cm)	MAT (C)	Temp Range (C)
26	119	14.5	2.7	11.8	16.8	34.9
20	105	25.5	10.5	14.9	15.3	34.5
29	66	25.5	4.2	21.4	13.8	31.7
21	55	15.6	6.2	9.4	18.8	38.4
23	39	15.8	5.4	10.4	16.1	35.9
24	37	10.7	2.8	7.9	18.8	38.6
25	30	16.5	6.2	10.3	18.9	34.6
22	17	36.1	13.3	22.8	10	32.4
27	8	9.6	3.3	6.3	20	36.7

Elevation.

Indian ricegrass is found at elevations of 1,067-1,981 m (3,500-6,500 ft) (SEINet 2023).

Soils.

Soil surface textures where Indian ricegrass occurs can vary across its distribution—it prefers sandy, coarse soils in the southern portion of its range and a broader range of soil textures (including sandy, loamy, silty, clayey, gravelly, rocky, and shale) in the mid- to northern areas of its range (Ogle 2006). It does not tolerate poorly drained soils. Parent materials include sandstone, limestone, and other sedimentary rock, gneiss, granite, basalt, and other volcanic rock (BLM SOS 2022).

Indian ricegrass has been shown to have higher establishment rates in areas with developed cryptobiotic soil crusts when outplanted from container stock in the spring in a salt desert ecosystem (Owen 2020).

ECOLOGY AND BIOLOGY

Indian ricegrass is a cool-season grass that utilizes the C3 photosynthetic pathway. However, Indian ricegrass stores carbohydrates as starch rather than fructans (Chatterton et al. 1989). This means that this grass is slower to green up in the spring, thus its phenology is intermediate between most cool-season grasses and warm-season grasses. Plants are relatively short lived and spread via seed distribution. This species is highly palatable to domestic livestock, and the seeds are nutritious to birds, small mammals, and humans. With unique seed ecology driven by dormancy, granivore dispersal, and variable morphology, Indian ricegrass possesses myriad bet-hedging adaptations that contribute to its ability to thrive in stressful and highly variable arid land conditions. Indian ricegrass has highly variable traits across ecotypes, driven by climate and landscape genomic patterns (Johnson et al. 2012). Compared to the abundance of ecological research on this species in the Great Basin and other regions of the Intermountain West, there is much less information available on its adaptations and ecology specific to the Mojave Desert.

Reproduction.

Breeding System.

Though capable of outcrossing, Indian ricegrass is highly self-fertilized (Jones 1990). It exhibits ecological cleistogamy, meaning its capability to outcross or self-fertilize is mediated by environmental conditions. Under hot and dry conditions, pollination occurs before the flower opens, but under more mesic conditions, anthers can be exserted and allow for cross-pollination (Jones 1990).

Reproductive Phenology.

In the Mojave Desert, Indian ricegrass can flower as early as February, but flowering is most often recorded in April and May. Seeds typically develop from April to June (SEINet 2022).

Pollination.

Like all grasses, Indian ricegrass can be wind-pollinated (Connor 1979). However, see discussion of self-pollination above.

Seed and Seedling Ecology.

Indian ricegrass seeds are dispersed by wind, water, and animals (Tirmenstein 1999). The seeds are a preferred food for a variety of granivorous animals due to their high protein and fat content (McDonald and Khan 1977). Heteromyid rodents such as kangaroo rats (*Dipodomys* spp.) and pocket mice (*Chaetodipus* and *Perognathus*) influence seed germination rates and spatial patterns of Indian ricegrass (McAdoo et al. 1983, Longland and Ostoja 2013). These rodents preferentially select filled and highly germinable seeds and, although they consume roughly 35% of the seed, they cache a portion in microenvironments favorable to germination. Moreover, by removing the seed hull of cached seeds, rodents effectively enhance germination by reducing physical dormancy (McAdoo et al. 1983). Seedlings that germinate from rodent caches typically grow in dense clumps. While intraspecific competition among seedlings has the potential to reduce recruitment, researchers in the Great Basin found that Indian ricegrass seedlings growing in clumps had higher survival rates than seedlings growing singly. These results suggest that benefits from seed-caching rodents can influence not only germination, but long-term survival of plants (Longland and Dimitri 2016). Harvester ants (*Pogonomyrmex* and *Veromessor*) hoard and consume Indian ricegrass seeds, but seldom contribute to dispersal or germination (Longland et al. 2001).

Many species of birds also consume Indian ricegrass seeds. For example, doves have been observed eating shattered seeds (Tirmenstein 1999).

Indian ricegrass can produce a large proportion of empty seeds consisting of unfilled hulls (Jones 1990). These hollow seeds are typically lighter in color than filled seeds and remain attached to the plant after the glumes open. Heavier, filled seeds are more likely to shatter and disperse from the plant upon ripening due to formation of an abscission layer (Whalley et al. 1990). However, seed shattering and retention can vary across populations based on variation in seed weight and glume pair angles that influence how long ripe seeds are held on the plant (Whalley et al. 1990). Longer periods of seed retention are favorable for agricultural seed production since seeds are not as easily lost from the plants and the window for harvesting increases.

Indian ricegrass seed dormancy and germination has been formally studied for nearly ninety years, indicating this species' importance as an economic crop and rangeland species (McDonald and Khan 1977). The seeds possess both physical dormancy due to a hard lemma and palea that surround the embryo and physiological dormancy due to inhibitory compounds that prevent germination (McDonald Jr. and Khan 1977). The hard lemma and palea prevent O2 uptake, but do not inhibit water imbibition (Jones 1990). The degree and mechanisms of dormancy can vary within and across populations, as evidenced by variation in the thickness of the palea and lemma (Jones and Nielson 1999) as well as differing responses of various seed sources to dormancy-breaking treatments (Young et al. 1985).

Indian ricegrass seeds can be categorized according to three seed morphs based on distinct shapes—jumbo, globose, and elongate—each with different degrees of dormancy related to the thickness of the lemma and palea (Jones et al. 2007). The jumbo seed morph has the highest degree of dormancy due to its thicker lemma and palea. These seed morphs occur separately on individual plants and are genetically distinct. The unique genetic lineages of the different morphs are maintained, even when individuals with different seed morphs occur at the same site, because high rates of self-pollination in this species limit outcrossing. The relative frequency of seed morphs at a site can fluctuate over time based on how environmental conditions select for varying degrees of dormancy inherent in the different morphs (Jones and Nielson 1999).

Methods for breaking dormancy when propagating this species are described in Seed Pre-Treatments below.

Species Interactions.

Belowground Interactions.

Indian ricegrass roots are typically surrounded by a rhizosheath, a structure composed of a mucilaginous coating to which soil particles attach and form a cylinder around the root (Barkworth 2021). Rhizosheaths can harbor nitrogen-fixing bacteria and improve moisture retention, contributing to Indian ricegrass' success in relatively inhospitable environments (Bergmann et al. 2009).

Indian ricegrass also forms relationships with arbuscular mycorrhizal fungi (AMF) which positively influence plant cover and density (Bethlenfalvay and Dakessian 1984, Al-Agely and Reeves 1995). Research in semiarid rangelands of northern Nevada found that AMF colonization rates in this species were significantly higher in ungrazed (86%) compared to grazed plots (40%) (Bethlenfalvay and Dakessian 1984). However, in a study in the Mojave Desert, Indian ricegrass roots showed relatively low rates of AMF colonization across spring and fall sampling (Titus et al. 2002).

Insect Interactions.

At least three species of insects feed on the roots and underground stems of Indian ricegrass: two larvae in the moth family Pyralidae and one larvae in the beetle family Cerambycidae. These insects impede plant growth (Guerra 1972).

Indian ricegrass is a likely larval host plant for several lepidopteran species, including the Juba skipper (*Hesperia juba*), common ringlet (*Coenonympha tullia*), Nevada skipper (*Hesperia nevada*), Uncas skipper (*Hesperia uncas*), and the white-lined sphinx moth (*Hyles lineata*) (Calscape 2023).

Wildlife and Livestock Use.

Indian ricegrass is desirable and nutritious forage for wildlife and livestock. The large and nutritious seeds are a favored food source for birds and rodents (Ogle 2006). Indian ricegrass was the seventh most abundant species in the diets of the endangered desert tortoise (*Gopherus agassizii*) in five different sites across the Mojave and Colorado Deserts (Esque et al. 2021).

However, Indian ricegrass is not as digestible or nutritious for desert tortoise adults and juveniles compared to native forbs (Nagy et al. 1998, Hazard et al. 2010).

As a cool-season grass, it is most productive as livestock forage from mid-June through mid-July, but retains its nutrient value after it has matured and cured (Ogle 2006). Because it is a favored forage for domestic livestock, Indian ricegrass can become extirpated or diminished from heavily grazed sites compared to ungrazed sites (Jeffries and Klopatek 1987). Packrat midden analyses document a decline in palatable species, including Indian ricegrass, associated with European settlement and livestock introduction in the western United States (Fisher et al. 2009). Recovery of Indian ricegrass and other palatable species can take decades or longer, even with rest or cessation of livestock grazing (Wolf and Mitchell 2021). This is especially true in the severely arid conditions of the Mojave Desert, where grasses are vulnerable to even occasional overutilization (Hughes 1982). Proper grazing management practices can prevent overutilization and resulting declines in Indian ricegrass abundance. Plants can be moderately grazed in winter and early spring if livestock are removed while there is still sufficient moisture and time to allow for vegetative growth and seed production. Heavy spring grazing will cause populations to decline (Ogle 2006).

Wild burros also favor Indian ricegrass--one study in the Mojave Desert showed that it was 11 times more abundant in burro diets than expected based on its frequency in the habitat (Abella 2008).

Disturbance Ecology.

Indian ricegrass is an early seral species on open disturbed sites, especially on sandy soils (Ogle 2006). It can be a successful colonizer in disturbed areas including bladed roadways (Jaynes and Harper 1978) and burned areas (Anjozian 2009). The timing of fire may influence how this species recovers: spring burning did little damage and plants showed regrowth within three weeks post-fire in Utah. Summer fires in Nevada reduced basal area of plants, but little mortality occurred (Wright 1979).

Ethnobotany.

Indian ricegrass seeds are a traditional staple for many indigenous tribes including the Havasupa, Apache, Hopi, Kawaiisu, Navajo, Paiute and Zuni people (NAEB 2022). They can be ground to make porridge, soup, or cakes (NAEB 2022).

Horticulture.

Indian ricegrass can make an attractive addition to xeriscape gardens, but it does not appear to be commonly available as nursery stock for residential or 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), 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).

To guide restoration seed souring, empirical zones were developed for Indian ricegrass in the Southwestern Unites states. These seed zones are based on a common garden study using seeds collected from sources across the Southwest (Johnson et al. 2012). Plants from different sources were evaluated on a variety of morphological and phenological traits which were found to significantly differ among source locations, indicating widespread genetic variation. Then, traits and climate were fed into regression models to develop a map with 12 seed zones that capture patterns of variability in local adaptation and climate (Johnson et al. 2012). Within this framework, Mojave Desert Indian ricegrass is most commonly found in the H1L2H3 and the M1L2H3 seed zones, which comprise most of the land area within the ecoregion. However, it is important to note that the Mojave Desert was poorly represented in this study, with only three samples, all from the eastern part of the ecoregion. USGS, Western Ecological Research Center, is currently conducting a new Indian ricegrass seed transfer zone study, focused specifically on the Mojave Desert ecoregion, to better understand genetic dynamics of this species in the Mojave (Perkins 2023, personal communication).

The Desert Southwest Provisional Seed Zones (PSZs; Figure 7) may also be used to plan seed sourcing. 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 extant 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 guide seed sourcing according to current and projected climate conditions.

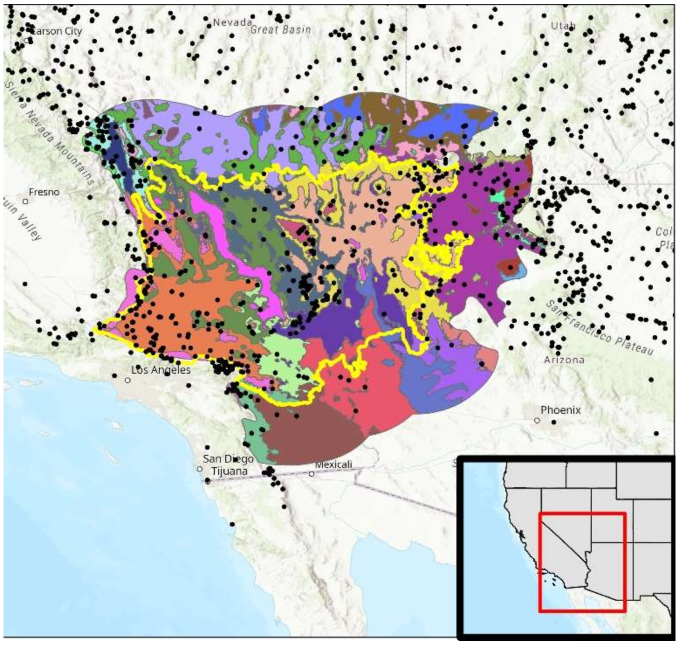

Figure 7: The distribution of documented Indian ricegrass (black dots) across the Desert Southwest Provisional Seed Zones (Shryock et al. 2018). Occurrences are based on georeferenced herbarium specimens and verified observations (SEINet 2022). The Mojave Basin and Range Level III ecoregion (yellow outline) 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.

Indian ricegrass is frequently available for purchase from large-scale commercial seed vendors. However, 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 five conservation plant releases of Indian ricegrass. None of these releases are sourced from populations in or with a climate similar to the Mojave Desert (NRCS 2023).

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 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, Indian ricegrass is typically collected April through June with the majority of collections occurring in June (BLM SOS 2022).

Collection Methods.

Indian ricegrass seed can be collected by stripping ripe seeds from the panicles by hand (Wolf, personal observation). McDonald et al. (1977) developed a simple tool made from a gallon jug, a pet comb, and a quart-sized bottle specifically designed to collect Indian ricegrass seed.

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).

Seed Cleaning.

Methods for cleaning Indian ricegrass seed first involve separating florets from vegetative and spikelet materials either by rubbing it over a medium screen or putting material through a brush machine with a .05 mm brush and #5 mantle with front door all the way open (Wall and MacDonald 2009, Saidnawey and Cain 2023). Then additional chaff and fuzz can be removed either by rubbing material over a #10 sieve or running seed through the brush machine with a 0.05 mm brush and #10 mantle with the front door open slightly with a container below the door to catch seeds that fall out. Lastly, the material can be run through a blower or air separator at medium to high speeds to separate any unfilled seeds (Wall and MacDonald 2009, Saidnawey and Cain 2023).

Figure 8: Collected Indian ricegrass material with seeds and chaff. Photo: BLM SOS NM930

Figure 9: Cleaned seed without chaff. Photo: Bend Seed Extractory

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).

Indian ricegrass seed is orthodox (SER SID 2023) and has extensive longevity in storage. Collections stored at the Key Royal Botanic Gardens under 15% relative humidity and -20°C (-4 °F) for nearly five years maintained 80% viability (SER SID 2023).

Because freshly harvested seed possesses higher concentrations of germination inhibiting compounds, physiological dormancy diminishes with storage time and several studies show that seed can have higher germination rates after several years in dry storage (Rogler 1960, Jones et al. 1988, Jones 2009).

In suboptimal storage conditions (an open warehouse with temperatures ranging from -30 °C (-22 °F) to 38 °C (100 °F) for 25 years), one seed batch showed an increase from 9 to 49%

germination while the other batch had no significant change after 14 years (Stevens and Jorgensen 1994).

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 pure seed unit—a combined unit of seed and attached structures that is classified as pure seed as opposed to inert material—for Indian ricegrass is defined by AOSA as a "single floret…with or without awn(s), provided a caryopsis with some degree of endosperm development can be detected" (AOSA 2016).

The AOSA outlines two methods for testing Indian ricegrass seed germination in a laboratory setting (AOSA 2016). Both methods require prechilling seed at 5 °C for four weeks. The first method involves placing seeds in covered petri dishes with blotter paper at 15 °C and performing the first count of radicle emergence at seven days and the final count at 42 days. The alternate method involves placing seeds in sand under temperatures alternating from 5-25 °C and performing the first count of radicle emergence at seven days and the final count at 28 days.

An AOSA tetrazolium test protocol for the *Achnatherum* genus may be followed to assess Indian ricegrass seed viability (AOSA 2010). The tetrazolium test protocol for *Achnatherum* seed viability assessments first involves preconditioning the seed by placing it on moist media overnight at 20-25 °C, then cutting the seed longitudinally and retaining one half of each seed to place in a 0.1% tetrazolium (TZ) solution overnight at 20-30 °C. Viability can then be quantified by assessing the percentage of seeds where the entire embryo is evenly stained. The endosperm will not stain (AOSA 2010).

Wildland Seed Yield and Quality.

Wildland-collected Indian ricegrass seed is generally of very high quality, with an average of 89% fill, 99% purity and 92% viability indicated by tetrazolium tests across 13 Seeds of Success collections (BLM SOS 2022, Table 2). Wildland collections contain an average of over 113,000 PLS/lb (BLM SOS 2022, Table 2).

Table 2: Indian ricegrass 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)	4.76	0.15-26.88	13
Clean Weight (lbs)	0.44	0.049-2.51	13
Purity (%)	99	99-99	13
Fill (%)	89	74-96	13
Viability (%)	92	80-98	13
Pure live seeds/lb	113,270	92,087-144,706	13

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

Indian ricegrass has been a successful crop for seed production in agricultural settings. Generally, it requires well-drained soils and full sun. It will do best in a neutral pH but can tolerate weakly saline and sodic substrates (Ogle 2006). Most information available on growing this species for seed production comes from the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS) and the Plant Materials Centers that have produced cultivars. There is relatively little information available on growing this species from Mojave Desert seed sources, or in warm desert farm settings. However, several efforts to grow this species from Mojave Desert sources are currently underway and described below when information was available.

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). Fields must be free of any prohibited noxious weeds. Restricted noxious weeds and common weeds difficult to separate must be controlled. Fields may be refused certification due to unsatisfactory appearance caused by weeds, poor growth, poor stand, disease, insect damage, and any other condition that prevents accurate inspection or creates doubt as to identity of the seed source.

Table 3 outlines the pre-variety germplasm certification standards for Indian ricegrass seed in the state of California with a minimum of ¼ lb sample size to be submitted for testing (Schlosser 2021). 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 (UCIA 2023).

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

Factor	G1	G2	G3 to G10
Pure Seed (minimum)	85%	85%	85%
Inert Matter (maximum)	15%	15%	15%
Total Other Crop Seed (maximum)	0.10%	0.25%	0.50%
Weed Seed (maximum)	0.15%	0.30%	0.50%
Noxious Weed	None	None	None
Germination and Hard Seed (minimum)	70%	70%	70%

Isolation Distances.

Sufficient isolation distances are required to prevent cross-pollination across seed production crops of Indian ricegrass from different sources or other *Achnatherum* species. Table 4 summarizes the isolation distances required for PVG certification in both Utah and California. California standards are described specifically for Indian ricegrass (CCIA 2022), while the Utah standards are general for outcrossing perennial species (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 Indian ricegrass. 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).

Seed Pre-treatments.

Since Indian ricegrass possesses mechanical and physiological dormancy (see Seed and Seed Ecology), most seed will not readily germinate without prior treatments. The degree of dormancy and resulting requirements for germination can vary across genotypes (Jones and Nielson 1999, Jones 2009). Physiological dormancy does not persist over time, and germination rates can increase after time in storage—though storage at low humidity and temperature will lengthen dormancy periods (Rogler 1960, Jones 1990). Soaking 1- and 2-

year-old seeds in water at 2-4 ° C for 40 days significantly increased germination rates (Rogler 1960).

Some regional growers in the Mojave Desert assert that the Mojave seed sources of Indian ricegrass do not require pre-treatment for nursery germination (Sale and Perez 2023, personal communication; Plath 2023, personal communication). Growers at Victor Valley College in Victorville, California have put seed in a rock tumbler to break dormancy prior to direct sowing in a seed increase field (Brooks and Gault 2023, personal communication). However, other growers have had difficulty germinating seed of this species in nursery settings, even with cold-stratification treatments (Graham 2022, personal communication; Asbell 2023, personal communication). Variability in germination and dormancy treatment responses is likely due to intraspecific variation and variable maternal environments across seed sources (Jones and Nielson 1994).

Breaking mechanical dormancy in Indian ricegrass can be accomplished by several techniques. Seeds can be scarified by hand using sandpaper or a brush machine (i.e. Westrup LA-H machine used for cleaning seeds) (Saidnawey and Cain 2023). If using a brush machine, seeds are poured into the machine which pushes a spinning set of brushes against a metal screen. This effectively tumbles the seeds against a rough surface and creates small cracks in the seed coat. An air scarifier uses compressed air to shoot individual seeds into an abrasive lined cylinder. Following scarification, ricegrass seeds can be exposed to cold-moist stratification where seeds are placed in a sealed container with a moisture holding medium such as perlite, and refrigerated at 4° C for three to four weeks (Saidnawey and Cain 2023).

Scarification with sulfuric acid has also been tried using seed from two cultivated varieties, 'Paloma' and 'Nezpar' (Young et al. 1985). Four replications of 100 seeds from each seedlot were placed in a concentrated sulfuric acid solution (17.28 mol L- 1 H_2SO_4) for 5-minute intervals up to 45 minutes in duration. The two cultivars exhibited different durations of acid scarification necessary to achieve maximum germination. 'Paloma' showed optimal germination (up to 40%) after 25 to 35 minutes of soaking while the Nezpar showed optimal germination (around 40-50%) after 15 to 25 minutes of soaking. These results indicate that effectiveness of acid scarification may vary across populations and seed lots of this species (Young et al. 1985).

In a study to determine the optimal germination conditions for Colorado Plateau restoration species, Indian ricegrass seeds from commercial sources of the 'Rimrock' cultivar were grown in a germination chamber under six different temperature regimes representative of sowing times and locations in the region (Foxx and Kramer 2015). All seedlots exhibited zero to low germination of viable seeds, regardless of temperature treatment. Germination on moistened (-0.17 MPa) sand, as described by Jones and Nielson (1992), is greater than that achieved with saturated blotter paper.

Seeding Techniques.

Indian ricegrass can be seeded using a furrow drill at ½ to 1 inch deep. This relatively deep planting reduces potential for rodent predation and allows seeds to access moist soil layers that aid in stratification and germination (Ogle 2006). The recommended seeding rate for field establishment is 8 pounds of pure live seed (PLS) per acre with 24-36 inches of spacing between rows, depending on precipitation and irrigation amounts (Ogle 2006). Timing of seeding can vary based on soil texture and seed dormancy.

In heavy to medium textured soils, early spring seeding is recommended. Late fall seeding is best for medium to light textured soils, or when seeding untreated seeds that require cold stratification in the field under natural winter conditions (Ogle 2006).

Growers at Victor Valley College in Victorville, CA established seed-increase trials of Indian ricegrass from wild-collected Mojave Desert sources (Brooks and Gault 2023, personal communication). Seeds were mixed with sand as a carrying medium and sown by hand in March into narrow furrows and buried about 1-2” deep. About 1 gram of seed was sown into three 16 x 25 foot plots (3 grams total). Germination was estimated to be between 10-15% using this method (Brooks and Gault 2023, personal communication).

While direct seeding seems to be a successful method, propagation and transplant of containerized plants may be desirable in some cases. 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 easily removed in a nursery (Winters 2023, personal communication).

Establishment and Growth.

Stands can take 2-5 years to fully establish (Ogle 2006), and initial establishment can be uneven due to dormancy and variable emergence (Winters 2023, personal communication).

Plants grown for seed increase from wildland seed sources for the Arizona-New Mexico Plateau ecoregion responded well to dry fertilizer applied monthly during the growing season (April-June) (SWSP 2023).

The seed increase trials at Victor Valley College (see Seeding Techniques) had an estimated 34% establishment compared to the total number of seeds sown (Brooks and Gault 2023, personal communication).

Weed Control.

Weeds can be manually removed or carefully spot-sprayed with a non-selective herbicide as they emerge. Bromoxynil can be applied at the 3-4 leaf stage to control broadleaf weeds. The herbicide, 2, 4-D should not be applied until plants are at least at the 4-6 leaf stage (Ogle 2006). 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.

Grasshoppers and other insects can damage new stands. Pesticides can mitigate impacts from insect herbivory (Ogle 2006).

Pollination Management.

See Reproduction for further information on Indian ricegrass’ breeding system. Since Indian ricegrass is wind pollinated, outcrossing plants should be able to readily exchange pollen within a seed production field without employing specific management strategies.

Irrigation.

Indian ricegrass crops respond well to light irrigation (Ogle 206) on coarse-textured (sandy) soils. Saturated fine-textured (clayey) may be detrimental to germination of this species (Jones 2023, personal communication)

In a study assessing the impacts of irrigation on germination of Paloma, researchers found that seed harvested from the Paloma crop had generally higher germination rates with irrigation while Rimrock (PI 478833) had higher germination rates without germination (Jones and Nielson 1994). This study highlights that response to irrigation and other growing practices is highly dependent on genotype.

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), though Indian ricegrass has not specifically been grown there. 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 avoid stressing plants and lowering seed yield (Dial 2023, personal communication).

Other growers administer water via drip irrigation as flood irrigation does not adequately penetrate into soil, resulting in significant evaporation in aridland farm settings (Hagman 2023, personal communication).

Seed Harvesting.

Seeds are ready for harvest when they have reached the "hard dough" stage--indicated by seed that is hard throughout, dark in color, and lacking in gooey endosperm (Smith 2006). Fields should be closely monitored for seed maturity to avoid seed loss as seed heads can have high rates of shatter. Indian ricegrass crops can be highly indeterminate and plants within a field can exhibit various stages of seed ripening at any given time. Windrowing—cutting the crop and leaving it to cure in place prior to using a combine—allows seeds to more readily and thoroughly separate from plants compared to directly combining (Ogle 2006). Seed is generally harvested in early July to early August and should be dried immediately after combining (Ogle 2006).

Smaller fields may be harvested by hand using techniques similar to those for wildland collections (see Collection Methods) (Brooks and Gault 2023, personal communication).

Seed Yields and Stand Life.

In general, Indian ricegrass crops are productive for about five years and yields will vary based on climate and irrigation (Ogle 2006). Annual yields can range from 100 to 200 lbs per acre in areas that receive at least 14" of rainfall. Irrigation can increase yields to 300 to 400 lbs per acre (Ogle 2006). Yields for irrigated crops in the Mojave Desert were not described in the literature, but may be less due to higher aridity and evaporation rates.

NURSERY PRACTICE

See Seed Pre-treatments for a discussion of dormancy breaking strategies to propagate Indian ricegrass in nursery settings.

Nursery managers in the Mojave Desert do not seem to regularly grow this species, largely due to poor germination. However, plants were grown from wild-harvested tillers of mature plants to propagate plants for a common garden study in the Mojave Desert (DeFalco 2023, personal communication). Tillers were harvested from field sites and transplanted into 10-12" deep plant bands with a standard potting mix with minimal organic matter. Transplants performed well in the greenhouse over a 6 to 8 month period prior to transplanting into the common garden (DeFalco 2023, personal communication).

REVEGETATION AND RESTORATION

Indian ricegrass is a highly desirable species for restoration efforts to meet a variety of goals including forage improvement for domestic livestock (Ogle 2006), remediation of contaminated soils (Hall and Anderson 1999), fugitive dust mitigation (Grantz et al. 1997), and post fire regeneration (Thompson et al. 2006, Madsen et al. 2014). The nitrogen-fixing rhizosheaths of Indian ricegrass can enhance soil fertility and facilitate reclamation of mine tailings or other nutrient-depleted substrates (Wullstein 1980).

Indian ricegrass is often directly seeded, though nursery-grown planting stock and divisions of mature plants are sometimes applied. Seeding of cultivars in the Mojave Desert often results in high initial germination and seedling densities, but stands may decline after several years following seeding (Hall 2023, personal communication). A metanalysis of stand establishment of cool-season grasses in the Intermountain West and Great Plains found that Indian ricegrass has extremely poor stand persistence (Robins et al. 2013). Across 34 restoration sites, the initial average stand establishment for Indian ricegrass was 43%. Stand persistence, 3 years after establishment, was 0% for Indian ricegrass. Indian ricegrass ('White River Garmplasm', Rimrock, and Nezpar) had the lowest persistence and establishment across all 69 cool-season grasses (Robins et al. 2013).

Seed used in the above instances was of cultivars with source locations often well beyond the appropriate planting site seed transfer zones, and often from entirely different ecoregions, making seed sourcing a confounding factor when interpreting the results. Appropriate seed sourcing may result in improved stand establishment and longevity for Indian ricegrass.

Wildland Seeding and Planting.

Wildland Seedings.

Seeding is most commonly done in the late fall to break dormancy under natural winter conditions (Jones 2009). However, Mojave Desert seedings may sometimes be applied in the spring when overwintering is not required for germination (Hall 2023, personal communication). Indian ricegrass can make up to 30-50% (or 2.5 to PLS lbs/acre) of a seed mix. Higher seeding rates are recommended in areas that are severely disturbed. Because Indian ricegrass requires deeper seeding depths than most species, two seeding applications may be necessary when including it in a mix—one to plant Indian ricegrass at depths of 1-1.5" and another to plant the rest of the mix at a shallower depth (Ogle 2006). Proper livestock grazing management following seeding is critical for successful Indian ricegrass establishment. To establish self-maintaining stands of Indian ricegrass, seeded plants must be allowed to produce seed and develop a substantial soil seed bank with variation in dormancy levels to effect seedling recruitment. Resting allotments from grazing every 2 to 3 years is recommended (Ogle 2006). Applying a seed coating surfactant to coat seeds has been shown to improve germination and establishment in severely burned areas where soil conditions are otherwise unfavorable to seed germination (Madsen et al. 2014).

Several examples of Indian ricegrass seeding in the Mojave Desert or adjacent ecoregions are reviewed below.

One study in the Great Basin used "diversionary foods" such as white millet to deter Indian ricegrass granivores (Longland and Ostoja 2013). Kangaroo rats (*Dipodomys* spp.) cache large amounts of mature Indian ricegrass seeds, and unrecovered seeds offer an opportunity for Indian ricegrass to recruit new seedlings. Sites in Nevada and California were either supplemented with diversionary millet or left untreated. When recruitment was recorded, the Nevada sites had a significantly higher level of seedling recruitment compared to control sites. However, the density of diversionary seed had only a marginal effect on seedling recruitment. Longland (2012) concluded that they may have had improved results with a more desirable diversionary seed type. This is a promising method to help increase seedling emergence for rodent dispersed species (Longland and Ostoja 2013).

In a study in western Nevada in the Great Basin, researchers found that Paloma and Nezpar Indian ricegrass had highest emergence when planted up to 2" deep and at the lowest attempted seeding rate of 0.03 seeds per meter of row (Young et al. 1994). Acid scarification did not increase emergence in seeded trials (Young et al. 1994).

Post-Fire Seeding

A post-fire study involving Indian ricegrass was conducted in a wildfire area in Tintic Valley, Utah (Thompson et al. 2006). The Railroad fire (1999) created an opportunity for a large-scale fire rehabilitation study that compared establishment of native versus introduced species in a seeding experiment. Two site areas were established using four different seed mixes (BLM predominantly introduced, Agricultural Research Service (ARS) native-introduced, native-high diversity, and native-low diversity). Plants were seeded either with a rangeland drill or furrowed by 1-way chaining. The Indian ricegrass PLS varied depending on seed mix and treatment (not included in the BLM mix). The Indian ricegrass established in all seed mix sites but did best in the high diversity mix. In the sandy soils of the drilled site, Indian ricegrass contributed to more cover than all other species combined. Thompson (2006) attributed this finding to Indian ricegrass having large seed and its ability to germinate at greater depths than other species (5 - 15 cm) (Thompson et al. 2006).

Indian ricegrass was seeded in a study in St. George, Utah along the boundary of the 2010 Mustang fire (Madsen et al. 2014). Soils in severely burned wildfire areas can become hydrophobic, impacting seed germination and establishment. Madsen (2014) tested application of a surfactant (SSC) to the lemma to help overcome soil water repellency and improve soil water availability within a seed's microsite. Indian ricegrass seeds were either coated with surfactant (SSC) or not coated before being broadcast onto the plots. In the spring after seeding, the plant density of Indian ricegrass at the SSC plots was 4.9-fold higher compared to control plots (in year two this decreased to 3.6). The SSC plots had 6.9-fold higher plant cover than controls in year one and 3.5-fold higher in year two. These significant increases of seedling emergence and establishment are important results for informing land managers on SSC technologies for maintaining the integrity of wildfire affected ecosystems (Madsen et al. 2014).

Reclamation Seeding

Indian ricegrass was included in a seed mix to remediate plutonium- and uranium-contaminated soils on the Nellis Air Force Range in the Great Basin-Mojave Desert transition region (Hall and Anderson 1999). Paloma made up 9% of the mix which included 14 other species. The mix was broadcast seeded in November at a rate of 21 lbs PLS/acre, along with polyacrylamide gel crystals used to increase soil moisture holding capacity to enhance germination. After seeding, the site was mulched with wheat straw at a rate of 4,000 lbs/acre, followed by crimping to hold the straw in place to reduce erosion and enhance the microclimate for germination. The seeded area was subject to four different irrigation/topsoil treatments: 1) fall and spring irrigation with topsoil removed), 2) fall and spring irrigation with some topsoil removed and later replaced, 3) spring irrigation with little or no topsoil removed, and 4) no irrigation with little or no topsoil removed. Indian ricegrass emerged and established under all treatments, but had the highest establishment in the spring irrigated, no topsoil removed treatment. Seedling emergence was low for all species when no irrigation was applied (Hall and Anderson 1999).

Indian ricegrass was included in a seed mix for a revegetation study program by the Castle Mountain Gold Mine (San Bernardino County, CA) (Walker and Powell 1999). The plots were developed in 1994 on a 225-yard stretch of entrance road to the mine. The seed mix was sown at the rate of 40 lbs per acre on either the road or the adjacent desert (Indian ricegrass rate comprised 12% of the seed mix). No irrigation treatment was mentioned, though Walker (1999) reported a wetter-than-average planting year (209 mm in 1994 and 263 mm in 1995). Unfortunately, Indian ricegrass was not present during the 1996 monitoring, across any plot type. The study concludes that their seed mix (source not known) may not have been appropriate for the area, as the unseeded portion of the road had a more "natural" species composition. Alternatively, early winds may have blown the seed mix out of the study plots (Walker and Powell 1999) .

Indian ricegrass was included in a large-scale revegetation program to reduce fugitive dust in abandoned farmland in the Antelope Valley of the western Mojave Desert by the Emergency Watershed Protection Program (EWP) in 1992 (Grantz et al. 1997). Over 2,500 acres received intensive ground revegetation via tillage and other soil surface disturbances. Site prep included burning tumbleweed, leveling mounds of soil, and creating 8-inch-deep furrows. Indian ricegrass (1.1 kg per ha), along with barley (*Hordeum vulgare*, 0.3 kg per ha), was drilled into the furrow bottoms. No irrigation was applied, but the site received above average rainfall during the planting year. Results of a 5-year report showed that Indian rice grass was outcompeted by barley except in sandy soils, where it performed very well. This could be partially attributed to Indian ricegrass adaptations to shifting soils with low moisture-holding capacity (Grantz et al. 1997).

Wildland Plantings.

There are relatively few examples of Indian ricegrass plantings from container stock in restoration settings.

A common garden study in Chaco Canyon using whole plant transplants found that Indian ricegrass did not differ in seed production, regardless of whether the plants came from a heavily grazed or un-grazed site (Orodho et al. 1998). However, among the transplants, Paloma (origin: eastern Colorado) displayed the highest seed output (312 kg/ha), the native Chaco Canyon source was intermediate (104 kg/ha), and Nezpar (origin: north-central Idaho) was the lowest (78 kg/ha). Therefore, it is important to consider the local adaptations of plants when collecting seed or locally transplanting to optimize restoration success and re-establishment (Orodho et al. 1998).

Indian ricegrass was used in an experiment testing how established seedlings could persist and help reduce invasive species halogeton (Halogeton glomeratus) (Smith et al. 2016). Seeds were started in a greenhouse in Logan, UT maintained at a constant 22°C. Seedlings were transplanted into containers (3.8 cm in diameter and 21 cm in depth) in a perlite-based soil mixed with sphagnum peat moss. Plants were overhead watered with a soluble fertilizer. In May, plants were transplanted into field plots (2 plants per m2) as monocultures, alternative with desert shrubs. Survival of Indian ricegrass was 100% the first year and decreased to 39% by the third-year post-transplant. Indian ricegrass did not have an effect on halogeton frequency compared to the control plots.

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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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