Cultivating *Tamarix* for Research and Education

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For decades researchers have studied *Tamarix* in controlled and natural environments to better understand propagation, growth, and control tactics. Much of what we know about *Tamarix* today has come from studies on cultivated plants in controlled environments. Researchers continue to grow these plants for experimental use yet, to our knowledge, there are no resources available that describe successful methods for growing *Tamarix*. Cultivated *Tamarix* may also be used as an education tool to demonstrate pervasive plant traits or weed control (Ohrtman and Clay 2013, in review). *Tamarix* has several traits that contribute to its invasiveness; many of these traits also promote cultivation of this plant for experiential teaching and research (Table 1). The objective of this paper is to review methods and growing conditions associated with successful *Tamarix* cultivation that can be used to produce plants for education and research. It is important to note that there are several potential disadvantages to growing *Tamarix* (Table 1), most of which can be overcome with careful handling, treatment, and disposal of *Tamarix* propagules and tissue.

Tamarix Cultivation

Tamarix cultivation can be achieved by several methods with few limitations for plant survival and growth. High fecundity and high seed viability immediately after seed shed has led many researchers to grow *Tamarix* plants from seeds (e.g. Merkel and Hopkins 1957; Shafroth et al. 1995; Sher et al. 2000). In addition, aboveground portions of *Tamarix* develop adventitious roots and form new plants if kept in warm, moist conditions (Gary and Horton 1965; Merkel and Hopkins 1957); this vegetative reproductive ability has prompted several researchers to use cuttings to propagate *Tamarix* (e.g. Berry 1970; Glenn et al. 1998; Vandersande et al. 2001).

***Tamarix* Establishment From Seed.** *Seed Collection and Storage*. Cultivating *Tamarix* begins with identification of a mature source population and collection of propagules. Propagules can be collected from numerous individuals if genetic diversity is desired or thousands of viable seeds can often be obtained from a single individual. Seed collection is most efficient when *Tamarix* capsules, borne on panicles at the end of stems, are mature but mostly unopened (Figure 1). However, some capsules should be releasing seeds to ensure that mature seeds are present. Viability of *Tamarix* seeds varies by season, year, and location (Ohrtman et al. 2012; Merkel and Hopkins 1957; Young et al. 2004) so more seeds should be collected than are required for use. Capsules are best stored in porous containers that allow them to desiccate or in sealed containers containing a desiccant (e.g. silica gel). If moisture is not removed from the capsules (as would occur with storage in glass or plastic containers without moisture absorption), seeds may absorb water and viability may quickly diminish. Capsules typically open and release seeds within a few days of collection following drying at room temperature (Joo and Lee 2011; Shafroth et al. 1995; Sher et al. 2000). If long-term seed storage is desired, seeds can be immediately placed in

cold storage (Horton and Clark 2001; Joo and Lee 2011; Levine and Stromberg 2001; Ohrtman et al. 2011, 2012; Shafroth et al. 1995). Dry cold storage (5 to -18 C) can preserve *Tamarix* seed viability for up to 12 months (authors' unpublished data; Buhler and Hoffman 1999; Lehnhoff et al. 2011; Merkel and Hopkins 1957; Zaman et al. 2009).

Seed Preparation. *Tamarix* seeds have no after-ripening requirement and can be placed directly on the growing medium following collection. However, it is recommended that seed viability be tested to determine the number of seeds needed to achieve a desired plant quantity. *Tamarix* seeds require direct and continuous contact with a water-saturated surface for germination (Buhler and Hoffman 1999; Horton et al. 1960; Merkel and Hopkins 1957). Germination tests can be performed by applying a known quantity of *Tamarix* seeds to wetted filter paper inside closed germination dishes (Merkel and Hopkins 1957; Ohrtman et al. 2012; Young et al. 2004). Purified water may be applied to minimize fungal growth (Marler et al. 2001; Ohrtman et al. 2012). Temperature optima for germination are between 20 and 25 C (Young et al. 2004) although greater than 87% germination can be obtained at temperatures from 19 to 43 C (Buhler and Hoffman 1999). High germination levels are obtained in complete darkness (Merkel and Hopkins 1957; Young et al. 2004) and with light/dark cycles (8/16 to 14/10 hours) (Ohrtman et al. 2012; Sexton et al. 2002). Germination is visible within 12 hours, with epicotyl and cotyledons present within 24 hours (Merkel and Hopkins 1957; Ohrtman et al. 2011, 2012). The majority of seeds germinate within 48 hours of wetting, and nearly all viable seeds germinate within 5 d (Merkel and Hopkins 1957).

The small size of *Tamarix* seeds and their pappus (i.e. tuft of downy hairs) make them difficult to contain, clean, and count for studies that desire specific seed quantities. Collected

material can be cleaned by sieving (Shafroth et al. 1995) or removing chaff by hand (Sher and Marshall 2003; Young et al. 2004). It is important that these small seeds be handled with extreme care to avoid seed destruction by harsh handling and/or infestation of new locations with *Tamarix*. Application of surface water immediately following seed placement can minimize seed loss from air movement and ensures good seed contact with the soil surface (Marler et al. 2001; Ohrtman et al. 2011). Newly establishing seedlings are extremely sensitive to desiccation. Therefore, the substrate must remain moist for the first few wks of growth. Misting can provide the moisture needed to minimize seedling desiccation and disturbance caused by surface watering (Sher personal communication). Plants can be thinned or transplanted days to wks after germination to achieve the desired density (Horton and Clark 2001; Joo and Lee 2011; Levine and Stromber 2001; Marler et al. 2001; Sexton et al. 2002; Sher et al. 2000; Sher and Marshall 2003).

Establishment of *Tamarix* Cuttings. *Tamarix Cutting Collection and Storage*. Nearly all severed aboveground *Tamarix* tissues can produce viable plants (Gary and Horton 1965). Even uprooted seedlings discarded into standing water have been observed to produce new growth (author's observation). On the other hand, root cuttings rarely produce viable *Tamarix* (Gary and Horton 1965; Wilkinson 1966). *Tamarix* cuttings are typically taken from stems or branch tips (hereafter referred to as cuttings) that are at least 1 year old, between 0.5 and 4.0 cm (0.2 to 1.6 in) diameter, and 10 to 60 cm in length (Friedman et al. 2008, 2011; Gary and Horton 1965; Li et al. 2010; Ma et al. 2011; Sorensen et al. 2009; Tallent-Halsell and Walker 2002; Waisel 1961; Wilkinson 1966). Removal of leaves and lateral stems is done to encourage branching and establishes ramets at a similar stage of development (Sorensen et al. 2009; Tallent-Halsell and

Walker 2002; Wilkinson 1966). Cuttings can be stored in plastic bags (Friedman et al. 2008, 2011; Gary and Horton 1965) or inserted in moist soil (Li et al. 2010; Tallent-Halsell and Walker 2002) to prevent moisture loss. These propagules can be planted immediately or placed in cold storage (4 to 8 C) for wks to months prior to use (Friedman et al. 2008, 2011; Li et al. 2010).

Tamarix cuttings can be harvested at any time of the year for immediate planting (Gary and Horton 1965). Cuttings have been harvested for propagation in the U.S. from February through July (Dewine and Cooper 2008; Friedman et al. 2008, 2011) although collection in March through May have been reported to produce the most vigorous plants (Gary and Horton 1965; Wilkinson 1966). Cuttings collected in late fall and winter may have high viability but dormant stems may be slow to produce new shoots (Gary and Horton 1965). Cuttings collected in the summer, when stem moisture content is greatest, lost their sprouting ability more quickly than cuttings collected during other times of the year due to more rapid dehydration (Gary and Horton 1965). Environmental factors (e.g. water table depth) and climate likely determine the optimal time for harvesting cuttings and their susceptibility to desiccation (Gary and Horton 1965). Regardless of collection date or location, the sprouting ability of *Tamarix* cuttings is quickly reduced if they are allowed to dry for even one day (Gary and Horton 1965).

Tamarix Cutting Preparation. *Tamarix* cuttings are easier to handle and propagate than seeds but require a different treatment process to develop roots and shoots. Rooting solutions are often applied to the basal end of *Tamarix* cuttings to promote root growth (Carter and Nippert 2011; Li et al. 2010; Ma et al. 2011; Sorensen et al. 2009; Tallent-Halsell and Walker 2002), although successful propagation of stems occurs without these additions (Friedman et al. 2008, 2011). Roots can develop in moist vermiculite (Tallent-Halsell and Walker 2002), sand (Li et al. 2010;

Ma et al. 2011), potting mediums, perlite, or combinations of these substrates (Glenn et al. 1998; Friedman et al. 2008, 2011; Vandersande et al. 2001). Hydroponic solutions have also been used (Berry 1970; Sookbirsingh et al. 2010; Sorensen et al. 2009). Cuttings can be planted vertically with only 2 cm of the cutting protruding out of soil to promote root development along the stem (Gary and Horton 1965; Li et al. 2010). Unlimited moisture during root and shoot elongation is often provided through misting in a greenhouse (Dewine and Cooper 2008; Friedman et al. 2008, 2011; Wilkinson 1966). If necessary, cuttings can be transplanted after several wks (Glenn et al. 1998; Tallent-Halsell and Walker 2002; Vandersande et al. 2001) to months (Dewine and Cooper 2008) when roots are well developed.

Factors Affecting *Tamarix* Establishment and Growth

Although *Tamarix* grows slowly during the first few wks following germination or stem planting (Gary and Horton 1965; Merkel and Hopkins 1957; Ohrtman et al. 2011; Sorensen et al. 2009), plants can experience rapid growth once established. Roots and shoots have been observed to reach up to 35 cm at 8 wks and nearly 70 cm at 12 wks in greenhouse settings (authors' unpublished data; Li et al. 2010; Merkel and Hopkins 1957). Under suitable conditions, belowground crowns and roots of *Tamarix* develop adventitious buds in the first 6 to 8 wks of development (author's unpublished data). Injury to the main stem can stimulate these buds to begin growth, with multi-stemmed plants resulting.

Location and Containers. Growing location and pot size do not appear to be important factors contributing to successful *Tamarix* cultivation. *Tamarix* has been successfully grown in

greenhouses (e.g. Gary and Horton 1965; Merkel and Hopkins 1957), shadehouses (e.g. Friedman et al. 2008, 2011), non-insulated outdoor areas (with insulation only during early seedling development; Sher et al. 2000; Sher and Marshall 2003), and growth chambers (e.g. Joo and Lee 2011; Sexton et al. 2002). In addition, pot dimensions have been variable in diameter and depth. Many studies used pots about 25 cm deep (Dewine and Cooper 2008; Friedman et al. 2008; Glenn et al. 1998; Marler et al. 2001; Tallent-Halsell and Walker 2002; Vandersande et al. 2001), although shallower (e.g. 18 and 21 cm depth; Carter and Nippert 2011; Joo and Lee 2011) and deeper containers (e.g. 46 cm and ≥ 1 m depth; Horton and Clark 2001; Sexton et al. 2002; Shafroth et al. 1995; Sher et al. 2000; Sher and Marshall 2003) have been used. Deeper containers are optimal for accommodating the rapidly elongating roots of this species even during early growth.

Growing Medium. *Tamarix* cultivation has occurred on many different soil types. Studies have reported that *Tamarix* germinates and grows best in fine-textured soils (e.g. clays, clay loam) (Sher and Marshall 2003; Stromberg 1998); these soils are better able to retain the vital moisture needed for *Tamarix* establishment and early growth. Several studies have grown *Tamarix* on fine-textured soils, e.g., loamy river sediment (Dewine and Cooper 2008; Gary and Horton 1965; Levine and Stromberg 2001) and sandy clay loam (Ohrtman et al. 2011, 2012). However, media used for growing *Tamarix* in greenhouse and contained experiments are often dominated by sand, either commercial (Marler et al. 2001; Sexton et al. 2002; Sher and Marshall 2003; Waisel 1961), field-collected (Glenn et al. 1998; Tallent-Halsell and Walker 2002; Vandersande et al. 2001), or both (Horton and Clark 2001; Sher et al. 2000). *Tamarix* has also been grown in substrate mixtures containing vermiculite, perlite, cocopeat and commercial growing media

(Friedman et al. 2008; Joo and Lee 2011) occasionally mixed with field soil (Carter and Nippert 2011) and hydroponic solutions (Jackson et al. 1990; Sookbirsingh et al. 2010). Sediment washing (Li et al. 2010; Shafroth et al. 1995; Vandersande et al. 2001; Waisel 1961) and sterilization (Marler et al. 2001; Wilkinson 1966) often are used to reduce algae and other contaminants. Depending on the media, nutrient additions may be desired (Carter and Nippert 2011; Glenn et al. 1998; Sexton et al. 2002; Sookbirsingh et al. 2010; Waisel 1961).

Temperature and Light Conditions. Temperature and light have profound effects on *Tamarix* propagule establishment and growth. Exposure to colder temperatures (e.g. 11/5 and 25/11 C light/dark) significantly decreased *Tamarix* growth from seeds (Joo and Lee 2011; Sexton et al. 2002). Similarly, planting cuttings at colder temperatures delayed sprouting for up to 6 months (Gary and Horton 1965). Growth and survival of cultivated *Tamarix* was also reduced by ≥ 97% shade (Dewine and Cooper 2008). Successful cultivation of *Tamarix* has been observed with less shade (93% shade to full sunlight; Dewine and Cooper 2008; Li et al. 2010; Sher et al. 2000; Vandersande et al. 2001), although growth rates may be reduced at higher shade levels (Dewine and Cooper 2008). *Tamarix* seedlings respond poorly when grown with established vegetation (Ohrtman et al. 2011; Sher et al. 2000, 2002; Stromberg 1997), presumably due to light stress. A wide range of photoperiods (between 8 and 18 hours of light) have been used to grow *Tamarix* (Carter and Nippert 2011; Ma et al. 2011; Ohrtman et al. 2012, Sexton et al. 2002; Wilkinson 1966) although the greatest stem and root growth for cuttings was associated with 14 hours of light followed by 8 hours of dark (Wilkinson 1966).

Moisture. Relative humidity ranging from 20 to 90% may not impact *Tamarix* survival and growth (Horton and Clark 2001; Li et al. 2010; Ma et al. 2011; Vandersande et al. 2001). However, elevating local humidity by covering seedlings with plastic film, cups, or shade cloth during seedling emergence and early growth can reduce seedling desiccation (Glenn et al. 1998; Sexton et al. 2002; Sher and Marshall 2003; Vandersande et al. 2001).

Soil water is the most important factor for successful *Tamarix* establishment from seeds and cuttings (Young et al. 2004; Gary and Horton 1965; Horton et al. 1960). High to saturated surface soil water conditions must be maintained for 2 to 4 wks (Horton et al. 1960), whereas survival and growth of well-established plants (≥ 8 wks after planting) was not affected by lower water availability (Dewine and Cooper 2008). High surface soil water content during early development can be achieved by surface watering (Beauchamp et al. 2005; Sher et al. 2000; Sher and Marshall 2003) or maintaining high levels of subsurface water (Gladwin and Roelle 1998; Ohrtman et al. 2011). However, caution should be taken not to submerge young plants for extended periods. Eight-wk old *Tamarix* plants were observed to tolerate flooding in the field for 30 d without significant mortality (Sprenger et al. 2001) but complete submergence for shorter periods nearly eliminated potted *Tamarix* plants of similar age in controlled studies (Gladwin and Roelle 1998; Horton et al. 1960).

Subirrigation is the most effective and widely used method for watering *Tamarix*. *Tamarix* is a facultative phreatophyte and thus can extract water from a permanent groundwater layer or its capillary fringe. Surface watering can be detrimental to cultivation of *Tamarix* because (1) seeds are small and easily buried by soil, (2) seeds are attached to pappi that promote water transport, (3) seedlings may be damaged or uprooted by surface watering, and (4) soils are more likely to dry between watering which is lethal to young plants. With subirrigation, less

frequent watering is needed and plant roots can follow moisture in the soil as surface layers become dry. Subirrigation has been done by placing plants in metal stock tanks (Shafroth et al. 1995; Sher et al. 2000; Sher and Marshall 2003; Tallent-Halsell and Walker 2002) or other reservoirs (Beauchamp et al. 2005; Horton and Clark 2001; Merkel and Hopkins 1957; Ohrtman et al. 2011; Sexton et al. 2002). Water levels were either maintained at a specific level (e.g. 10 to 15 cm from the base of the containers) (Dewine and Cooper 2008; Beauchamp et al. 2005; Ohrtman et al. 2011; Sher et al. 2000; Sher and Marshall 2003) or allowed to drawdown at rates typical of field conditions (Horton and Clark 2001; Shafroth et al. 1995; Sher and Marshall 2003). Algal growth can occur within reservoirs and treatment to remove this growth may be desired.

Discarding *Tamarix* Plants and Seeds

Cultivated *Tamarix* plants can provide valuable information but improper disposal of plants or seeds can lead to new infestations that will further set back efforts to control this noxious weed. Precautions must be taken to kill all seeds and plant materials before disposal. The following methods have successfully destroyed viable *Tamarix* tissues but other methods may also be suitable for killing seeds and plant fragments:

1. Plants (up to 12 wks of age) can be completely controlled by clipping top growth, and burning materials (clippings and rooted plants) for at least 60 s at temperatures exceeding 150 C (author's unpublished data). It is recommended that the soils containing plants or fragments be allowed to dry completely before burning.

2. Alternatively, tissues (seeds, cuttings, or plant fragments) and contaminated soil can be autoclaved at 121 C and 131 kPa (19 psi) for 20 minutes.
3. Soils and charred plant material should be bagged in heavy plastic ($\geq$ 2 ml) and taken to a landfill facility.

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Table 1. Characteristics of *Tamarix* which contribute to its invasiveness and promote cultivation for education and research.

Tamarix traits	Invasive characteristics[a]	Benefits for research or educational use	Challenges for use
Seeds	1. Continuous seed production for as long as growing season permits.	Propagules can be collected throughout the growing season in some regions.	Seeds need to be collected and handled with care to prevent introduction to new areas.
	2. High seed output in favorable environmental circumstances.	Many seeds are available for collection.	Difficult to separate mature from immature seeds.
	3. Able to produce seeds under a wide range of environmental conditions.	Seeds are available in many areas.	Duration of seed release and seed load vary by location. Make sure seeds are present.
	4. High seed viability	Seed viability is high after collection in most regions.	Viability quickly lost following wetting and storage at warmer temperatures.
	5. Seeds can remain viable for extended periods with proper storage.	Seeds can be stored for extended use.	
	6. Adapted for long or short range dispersal.	Small seeds enable the collection of thousands of propagules.	Seed morphology makes handling, cleaning, and counting difficult.

Asexual Reproduction	1. Vigorous vegetative reproduction capability. 2. Vigorous root sprouter.	Stem cuttings can be used for propagation. Plants show resilience to disturbance and develop new shoots following aboveground tissue injury.	Plant fragments need to be properly treated and discarded to prevent introductions.
Environmental Response	1. Capable of tolerating extreme range of environmental conditions.	Can be grown with different soil types, temperatures and light exposures.	Plants should not be propagated outdoors, lest they become invasive. Greenhouse space (often limited) is needed.
	2. Once established, can survive periods of inundation or in dry soils.	Can be grown with different moisture regimes once plants are established.	Seeds, young seedlings, and cuttings must remain wet for the first few wks of growth.
Plant Growth	1. Rapid growth from vegetative phase to flowering.	Plants can grow rapidly once well-established.	Slow growth in the first few wks. Growth inhibited by established vegetation. Taproot quickly outgrows most

		pots; plant use must be well-timed.
2. Stems are brittle and not easily drawn from the ground. Remaining fragments can re-root.	Demonstrates difficulty with mechanical weed control techniques.	Difficult to kill established plants. Proper handling of live material is needed.
3. Difficult to control with foliar chemicals.	Demonstrates problems with chemical control of weeds.	Must use a combination of control treatments.

[a]Information obtained from Brotherson and Field 1987, Baker 1974, Ohrtman et al. 2012, author's unpublished data.

Figure 1. *Tamarix* panicles with open and unopened capsules in Pennington County, SD.

Photograph taken by Michelle Ohrtman on July 2, 2012.