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Using a Pervasive Invader for Weed Science Education

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Students studying weed science would expand their knowledge by conducting targeted experiments on invasive weeds. *Tamarix* spp., some of the most problematic weeds known in the United States, have value for weed science education. *Tamarix* was used in an undergraduate laboratory course to demonstrate weed science principles for a minimal cost and with great potential for academic enhancement. The laboratory exercise was designed to teach weed science students about the difficulty associated with controlling invasive weeds even at a relatively young age in a region where plants have been detected but large-scale invasion has not occurred to emphasize the importance of early detection and rapid response. The successful execution of this exercise and the positive student response suggests that *Tamarix* and other weeds with similar reproductive capacities could be valuable additions to weed science curricula. Innovative approaches to teaching weed science facilitate greater learning of this complex subject by students from diverse backgrounds and academic disciplines.
Nomenclature: *Tamarix* spp.
Key words: Invasive plant management, laboratory exercise, saltcedar, tamarisk, young professional training.

Los estudiantes que estudian la ciencia de malezas podrían ampliar su conocimiento al realizar experimentos enfocados en malezas invasivas. *Tamarix* spp., algunas de las malezas más problemáticas conocidas en Estados Unidos, tienen valor para la educación de la ciencia de malezas. Se usó *Tamarix* en un curso de laboratorio de pregrado para demostrar principios de la ciencia de malezas con un costo mínimo y con un gran potencial para el mejoramiento académico. El ejercicio de laboratorio fue diseñado para enseñar a los estudiantes de malezas acerca de la dificultad asociada al control de malezas invasivas inclusive a edades relativamente tempranas en una región donde las plantas han sido detectadas, pero una invasión a gran escala no ha ocurrido aún, y de esta forma hacer énfasis sobre la importancia de la detección temprana y la respuesta rápida. La ejecución exitosa de este ejercicio y la respuesta positiva por parte de los estudiantes sugieren que *Tamarix* y otras especies de malezas con capacidades de reproducción similar podrían ser adiciones valiosas a los currículos en la ciencia de malezas. Formas innovadoras para enseñar la ciencia de malezas facilitan mucho el aprendizaje de este tema tan complejo a estudiantes con diversos historiales y disciplinas académicas.

Invasive plants continue to expand in range with escalating costs to agricultural, managed, and natural ecosystems in the United States (Pimentel et al. 2005). Despite this advance, U.S. institutions face a shortage of weed science faculty and courses needed to train young professionals in invasive plant management (Derr and Rana 2011). In an older survey, it was reported that weed science curricula offered at North American institutions was fairly homogenous, even though weed species and management needs often differ among regions (Pearce and Appleby 1992). More recent studies suggest that some weed science programs are moving toward more diverse curricula, both in the classroom and laboratory (Gallagher et al. 2007; Gibson and Liebman 2003a,b, 2004). Courses that offer diverse curricula focused on locally important weed issues may improve the students' ability to master complex subjects. In particular, weed science courses that include experimentation with living weeds have been reported to enhance critical thinking skills and increase student understanding of important weed science concepts (Gibson and Liebman 2004). Using weed species that pose the greatest threat to United States' resources would help prepare future weed science professionals to control invasive weeds.

Tamarix spp. (*Tamarix ramosissima* Ledeb., *Tamarix chinensis* Lour., and hybrids; a.k.a. saltcedar, tamarisk) are listed among the most ecologically and economically damaging invasive plants in the United States (Duncan et al. 2004; Pimentel et al. 2005; Stohlgren and Schnase 2006) and in the top 100 worst weeds globally (Global Invasive Species Database). This nonnative tree/shrub was introduced in the United States in the 1800s as an ornamental and quickly spread across disturbed riparian areas (Robinson 1965). *Tamarix* has many traits that promote rapid colonization and persistence within disturbed areas. These plants produce millions of wind-dispersed seeds, grow rapidly once established, tolerate a wide range of environmental conditions, and produce new vegetative shoots following aboveground injury (Brotherson and Field 1987). *Tamarix* continues to expand its range at an unknown rate, with about 1 million km^2 of United States habitat projected to be vulnerable to future invasion (Jarnevich et al. 2011). Northern regions, while not extensively invaded at this time, are poised to be the next areas of large-scale invasion (Jarnevich et al. 2011).

Most land managers, agronomists, and weed professionals in the western United States will encounter *Tamarix* at some point during their career. Applied experience with this species during undergraduate or graduate education will enhance their ability to detect its presence and implement effective control. The goal of this laboratory exercise was to increase awareness of *Tamarix* invasion in northern regions and

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Figure 1. *Tamarix* plants established from seed that are (a) 4, (b) 8, and (c) 12 wk old prior to treatment in the fall 2011 weed science laboratory exercise on October 7, 2011. Initial plant heights ranged from about 3 cm for 4-wk plants to greater than 60 cm for 12-wk plants.

provide students with knowledge needed to identify and treat *Tamarix* infestations before plants become well established. Removal of mature *Tamarix* typically requires a combination of mechanical, chemical, and fire treatments for effective control (McDaniel and Taylor 2003). The laboratory exercise combined research on the effectiveness of chemical, mechanical (clipping), and fire treatments on young *Tamarix* plants.

Materials and Methods

Tamarix Laboratory Exercise. A laboratory exercise (see Supplemental File 1) that was performed in fall 2011 and fall 2012 at South Dakota State University was designed to demonstrate the effectiveness of various control scenarios on young *Tamarix*, while providing students with firsthand experience controlling a troublesome weed. The response of immature *Tamarix* plants (less than 1 yr old) to the selected treatments was unknown prior to our first experiment in 2011. This exercise compliments courses focused on chemical control (Pearce and Appleby 1992) and exposes students to additional and combined methods of weed control. Biological control has also been successful for controlling *Tamarix* but this method was not tested because of the difficulty associated with simulating this treatment in a classroom laboratory setting.

Experimental Setup. A literature review of methods used to propagate, grow, and dispose of *Tamarix* plants can be found online (Ohrtman and Clay 2013). For this specific experiment, *Tamarix* plants were grown from seeds collected in western South Dakota (stored at 3 C prior to use) by applying several seeds directly on sandy clay loam soil obtained from eastern South Dakota that had been passed through a 2-mm sieve. Seeds were sown on soils inside Ray Leach SC10 Super cone-tainer cells (Stuewe and Sons, Inc., Tangent, OR) (3.8 cm diam by 21 cm length) supported with racks, immediately surface-watered, and placed inside 38-L tubs with subsurface water maintained at a 15-cm depth for the first 2 wk and a 10-cm depth thereafter. Tubs were placed in a greenhouse maintained between 20 and 30 C. Plants were thinned to one per cell after 3 wk. In 2011, three plant age classes were established (4, 8, and 12 wk of age; Figure 1) to receive no treatment (control) or mechanical, chemical, fire, or combined treatments. Only two age classes (6 and 12 wk of age) were treated in 2012 because the previous year's experience suggested that these ages would be sufficient to demonstrate age effects on control treatment response and reduce student confusion during treatment applications.

Student Experiential Experience. Students assisted with treatment applications during a 2-h laboratory period.

Tamarix plants were (1) clipped to 2 cm, (2) sprayed with herbicide using an Agricultural Spray Booth (EDA Inc., Folsom, CA), (3) treated with fire, (4) clipped and then sprayed with herbicide, or (5) clipped and then burned. The herbicide spray solution contained 3% isopropyl amine salt of imazapyr (22.6% ai or 240 g ae L^{-1}) (Arsenal®, BASF Corp., Research Triangle Park, NC) with 0.25% Chemsurf 90 nonionic surfactant (Chemorse, LTD, Urbandale, IA) which is similar to field treatments that have achieved 95% control

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Figure 2. *Tamarix* plants 6 wk after treatment with (a) fire, (b) herbicide application, (c) clipping, (d) clipping followed by fire, (e) clipping followed by 1× herbicide application, and (f) control (no treatment). Plants were 12 wk old when treated in 2011.

of mature *Tamarix* in South Dakota (R. Moehring, personal communication). Herbicide was applied with a boom speed of 0.8 km h^{-1} and 206 kPa pressure that delivered 238 L ha^{-1} using a flat fan nozzle. The solution amount applied per plant was determined by weighing circular filter paper (4 cm diam) before and after application ($n = 6$). The herbicide application rate on a per plant basis was calculated. In 2011, herbicide-treated plants received either one (1×; 0.36 mg ae $plant^{-1}$) or two (2×; 0.72 mg ae $plant^{-1}$) applications. Only the 1× dose was applied in 2012 because the 2× dose is unrealistically high for field application. Clipped and unclipped plants were treated with fire using a blowtorch. Three fire durations were

Table 1. Percent survival and average shoot height of young *Tamarix* plants ($n = 9$ age^{-1} treatment^{-1}) following control treatments performed by fall 2011 and fall 2012 weed science students. Final plant data were recorded about 6 wk after treatment.

	2011						2012			
Treatment	4 wk	8 wk	12 wk	4 wk	8 wk	12 wk	6 wk	12 wk	6 wk	12 wk
	%			cm			%		cm	
Control	100	100	100	12.3	30.3	50.3	100	100	21.4	45.9
Clip	89	100	100	11.4	14. 7	15. 8	100	100	14.8	10.1
Chemical (1×)	0	100	100	0	16.2	48. 9	100	100	9.6	41.1
Chemical (2×)	0	11	78	0	0.6	22.1	—	—	—	—
Clip–chemical (1×)	0	33	55	0	0.3	0.9	66	100	2.8	2.1
Clip–chemical (2×)	0	22	33	0	0.4	0. 7	—	—	—	—
Fire (30 s)	0	22	67	0	3. 6	6. 3	0	50	0	12.0
Fire (60 s)	0	22	45	0	1. 7	4. 9	0	29	0	1.7
Fire (120 s)	0	0	33	0	0	3.4	—	—	—	—
Clip–fire (30 s)	0	0	22	0	0	2. 6	0	43	0	2.3
Clip–fire (60 s)	0	0	0	0	0	0	0	0	0	0
Clip–fire (120 s)	0	0	0	0	0	0	—	—	—	—

tested in 2011 (30, 60, and 120 s). The similar responses observed for the 60- and 120-s exposures in 2011 permitted the exclusion of the 120-s duration treatment in 2012. Fire temperatures were monitored at the soil surface of each plant using a Type K thermocouple attached to a data logger (TC Direct, Hillside, IL). Temperatures were kept between 150 and 300 C to simulate conditions typical of prescribed grassland fires. Treatments were performed by two (2011) and three (2012) laboratory sections for a total of nine replicates for each plant age per treatment per year including untreated controls. Between 4 and 6 wk after treatment, the number of surviving plants (those with green tissue or regrowth), live stems, and height of the tallest shoot were recorded (Figure 2). Plants were excavated at the end of the exercise to examine roots by treatment.

Student Evaluation of Laboratory Exercise. Students formed hypotheses about treatment efficacy prior to the early October treatment and after the final observation wrote reports about how research results supported or refuted their hypotheses. After exercise completion, student evaluations were obtained using the online software Survey Monkey™ (Portland, OR; used in 2011) and in-class surveys (in 2012). Students were asked to rate nine statements reflecting their overall impressions about the exercise on a scale of 1 to 5, with 1 being strong agreement, 3 as neutral, and 5 as strong disagreement (Gibson and Liebman 2004).

Results and Discussion

Summary of Experimental Results. Specific treatment results for 2011 are presented in M. Ohrtman et al. (unpublished data). In general, *Tamarix* plant responses to treatments were similar for both years and were age dependent (Table 1). Clipping alone did not control plants of any age and most produced new shoots averaging between 10 and 16 cm tall by 6 wk posttreatment. More 8- and 12-wk-old plants survived the fire, herbicide, clip + fire, or clip + herbicide treatments than younger plants. These data indicate that even at 8 wk of age, this weed possesses resilience to numerous treatments typically used for its control in the field. Herbicide treatments alone (1× only) reduced plant vigor of 6-, 8-, and 12-wk-old plants (Table 1; Figure 2) but killed 4-wk-old plants during the monitoring period. In 2011, the 2× herbicide rate was more injurious to the 8- and 12-wk-old plants than the 1× rate, but some plants still survived this treatment. Four-week-old plants did not survive the clipping + herbicide treatment, but 6-wk or older plants, although severely stunted (having live shoots 2 to 20% as tall as the clipped only treatment), had 33% or greater survival. Fire of any duration alone killed all plants 6-wk-old and younger, but 12-wk-old plants, although injured, still had high survival rates. Clipping + fire was the most effective treatment, reducing young *Tamarix* survival and growth regardless of age. It should be noted that although fire treatments were effective at killing young *Tamarix* plants, burn programs to control this weed are not advised until field tests have been performed and should not be used in areas susceptible to ecological or economic damages from fire.

Student Evaluation of Laboratory Exercise. Survey response rates for the *Tamarix* laboratory exercise were 45% (21 out of 47 students) in 2011 and 74% (53 out of 72 students) in 2012. Responses were similar between years (Table 2). In both years, 60% or more students agreed or strongly agreed that this exercise was a valuable activity and increased their understanding of weed biology, weed science concepts, and weed management. This exercise appeared to be most effective at increasing awareness of *Tamarix* invasion in South Dakota. Seventy-one percent and 96% of respondents agreed or strongly agreed with this statement in 2011 and 2012, respectively. The 25% increase in student agreement to this statement in 2012 is attributed to the addition of supplemental lectures on *Tamarix* ecology and invasion in South Dakota to the curriculum. The generally favorable student response to the *Tamarix* control exercise in both years suggests that this and other activities using living invaders may be valuable additions to weed science curricula. Positive statements about the *Tamarix* exercise (when asked about the semester's labs in general) included comments such as "It was eye-opening to see how little we knew about how bad this species could become," "...appreciated the effort as it is spreading in our area," "enjoyed the hands-on experience

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Table 2. South Dakota State University weed science student evaluation of the *Tamarix* exercise for fall 2011 (response rate of 45%) and fall 2012 (response rate of 74%). Statements were rated on a scale of 1 to 5; 1 = strongly agree, 3 = neutral, and 5 = strongly disagree.

	2011 Distribution								2012 Distribution							
Statement	1	2	3	4	5	Mean	SD[a]	% Agree	1	2	3	4	5	Mean	SD[a]	% Agree
The laboratory exercise on *Tamarix* control was a valuable activity.	3	10	6	2	0	2.3	0.9	62	2	41	5	5	0	2.2	0.7	81
This exercise increased my awareness of *Tamarix* invasion in South Dakota.	7	8	4	2	0	2.0	1.0	71	28	23	2	0	0	1.5	0.6	96
I had an increased understanding of weed biology after completing this exercise.	5	8	8	0	0	2.1	0.8	62	3	29	18	3	0	2.4	0.7	60
I had an increased understanding of weed management after completing this exercise.	3	12	5	1	0	2.2	0.7	71	8	37	6	2	0	2.0	0.6	85
This exercise increased my understanding of weed science concepts.	5	10	5	1	0	2.1	0.8	71	6	31	15	1	0	2.2	0.7	70
I can transfer the concepts learned in this exercise to other situations.	3	12	4	2	0	2.2	0.8	71	7	36	9	0	0	2.0	0.6	83
This exercise improved my critical thinking skills.	2	7	11	1	0	2.5	0.7	43	4	18	25	6	0	2.6	0.8	42
This exercise improved my ability to receive information effectively through observation.	5	10	5	1	0	2.1	0.8	71	12	24	15	2	0	2.1	0.8	68
This exercise improved my ability to summarize simple research data.	5	10	5	1	0	2.1	0.8	71	7	30	14	2	0	2.2	0.7	70

[a] Standard deviation of the mean based on response scores.

with multiple techniques," and "…results were clear and demonstrated important management concepts."

Several problems may be encountered during implementation of this exercise. It may be difficult to time *Tamarix* plantings so that the desired growth stage is reached by the laboratory exercise date and ensure that growth conditions stay optimal during the potentially long growth period (up to 18 wk or longer) from germination to final observation. During the treatment phase, students experience periods of inactivity if greenhouse space is limited or if treatments take too long to complete. This may be overcome by working in small groups while others are involved with lecture, discussion, or another activity. In addition, the long period (6 wk) between treatment and final data collection and another 2 wk to report submission caused some students to lose interest and attention. Indeed, negative comments from several students included that the "…long time between treatment, final observation, and reporting" negated their interest in the experiment, although no solutions were offered. Other negative comments were given by several students who did not see the value of the exercise including "I do not have this weed present in my area" or "I will only be working in row crops and will not encounter this weed." Somehow these short-sighted views must be challenged, so that (1) the value of understanding both current and potential threats to ecosystems is increased and (2) it is clear that early detection and rapid response are imperative for minimizing the spread of weeds that are resilient to harsh treatments at a fairly young age. Perhaps other activities such as class lectures, discussions, and field trips that involve *Tamarix* and other ubiquitous invasive species are needed to keep students focused on these issues throughout the course.

Weed science courses must deliver complicated subject matter on critical issues to students from numerous academic disciplines (Pearce and Appleby 1992). Past and present weed science courses have done an excellent job of training weed professionals in this challenging environment. Diverse training opportunities that use living weeds can enhance weed science education by providing education and training with real-world scenarios at little additional cost. This laboratory exercise utilized available equipment; however, greenhouse bench space availability and costs and compatibility with other experiments in the same bay (i.e., herbicide exposure, light/temperature requirements, etc.) may need to be considered. Rapid growth, multiple reproductive methods, pervasiveness, and resilience to multiple control tactics allow *Tamarix* to play a unique role in invasive plant management training. Other invasive species with similar reproductive traits may also be used for training the next generation of professionals to more effectively control weeds. We cannot overemphasize the importance of proper disposal of noxious weed materials following their use for education to prevent new invasions.

To our knowledge, this is the first program that linked research, education, and experiential techniques to train young professionals in *Tamarix* management. This integration increased student awareness of the threat of *Tamarix* invasion in new habitats and provided students with new information about the most effective method (or methods) for removing new infestations once they are identified. There are many opportunities to develop this and other educational training programs using invasive weeds that can effectively train individuals with diverse learning styles and backgrounds and provide valuable research contributions to the field of invasive plant management.

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