2016

Cattle Grazing Effects on *Phragmites australis* in Nebraska

Jerry D. Volesky
University of Nebraska-Lincoln, jvolesky1@unl.edu

Stephen L. Young
Cornell University, sly27@cornell.edu

Karla H. Jenkins PAS
Panhandle Research and Extension Center, University of Nebraska, kjenkins2@unl.edu

Cattle Grazing Effects on *Phragmites australis* in Nebraska

Jerry D. Volesky, Stephen L. Young, and Karla H. Jenkins*

Phragmites australis (common reed) is one of the most widely distributed flowering plants in North America. The introduced lineage occurs in wetland and riparian areas covering a range of climatic types. In Nebraska, an abundance of livestock could help to reduce *P. australis* with proper timing and grazing intensities. In 2011, a 3-yr study was initiated to evaluate targeted cattle grazing and herbicide effects and the nutritive value of this species. Treatments included a single application of imazapyr (Habitat®, BASF Corporation, Research Triangle Park, NC) herbicide applied in the first year, grazing, and a control. Grazing was applied for up to five consecutive days in June and August 2011 and 2012 and in June 2013. Stem density, height, and biomass of *P. australis* were determined before each grazing period and in 2014. Diet samples were collected from rumenally fistulated steers each grazing period. Imazapyr provided 100% control of *P. australis*; however, re-establishment began 2 yr posttreatment. Grazing significantly reduced pregrazing *P. australis* biomass in the second and third growing season ($P < 0.05$). Stem density and height in the grazed treatment was similar to the control through 2012; however, in 2013 and 2014, control stem density was 1.5 times greater and height was 1.4 times that of the grazed treatment. Crude protein content of diet samples was greater in 2011 (16.8%) compared with 2012 (14.3%, $P < 0.05$). In vitro dry matter digestibility (IVDMD) of diet samples (45.4%) was not affected by year or month ($P > 0.05$). The relatively low IVDMD suggests that some form of energy supplementation would be needed to create a better nutritional balance. The cumulative effect of grazing does have the potential to reduce *P. australis* populations, but other methods would have to be used for greater control and site restoration.

Nomenclature: Common reed, *Phragmites australis* (Cav.) Trin. ex Steud. PHRCO.

Key words: Common reed, crude protein, digestibility, grazing management, herbicides, targeted grazing, wetlands.

In North America, *P. australis* is one of the most widely distributed flowering perennial grass plants (Saltonstall et al. 2010). The introduced form of *P. australis* has invaded many regions and established large monocultures that cover hundreds to thousands of hectares (Carlson et al. 2009; Herrick and Wolf 2005; Meyerson et al. 2010; Whyte et al. 2008). The effects of these large infestations include loss of habitat for threatened and endangered species, reduced plant diversity, and impediment of surface water flow in river systems (Knezevic et al. 2008). The effects from the establishment of *P. australis* can be long lasting, leaving legacies that are neither desirable nor easy to change (Corbin and D'Antonio 2012).

In many riparian areas located in arid to semiarid climates, significant alterations have occurred to hydrological regimes through the construction of dams, bridges, and irrigation diversion structures (Auble et al. 2005; Kustu et al. 2010). The changes in stream flow and subsurface moisture content from scheduled releases and periodic pulse flows of water have allowed for the creation of new plant assemblages that include many nonwetland types (Glenn and Nagler 2005; Merritt and Wohl 2002). Although the conditions of low water flow and availability can deter the establishment of native riparian plant species, some invasive plants, such as *P. australis*, are thought to be able to survive and even spread because of extensive underground rhizomes, stomatal distribution on leaves, and a high leaf area index (Saltonstall and Stevenson 2007; Saltonstall et al. 2007). In addition to rhizomes and stolons, *P. australis* also reproduces sexually from seed. Local spread of *P. australis* is predominantly through

DOI: 10.1614/IPSM-D-15-00056.1

* Professor, Department of Agronomy and Horticulture, West Central Research and Extension Center, University of Nebraska–Lincoln, North Platte, NE 69101; Adjunct Professor, Soil and Crop Sciences Section, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853; Associate Professor, Department of Animal Science, Panhandle Research and Extension Center, University of Nebraska–Lincoln, Scottsbluff, NE 69361. Corresponding author's E-mail: jerry.volesky@unl.edu

Management Implications

Integrated management is important to control invasive plant species effectively. Reliance on a single technique can lead to poor containment, a failed eradication effort, and re-establishment of the target species over the long term. Natural areas can be challenging to implement integrated approaches effectively because of inaccessibility issues for machinery and lack of available biocontrol agents. By investigating previously untested techniques, the potential for implementing integrated management in an existing system could be high.

Targeted cattle grazing and herbicides can reduce the density and growth of common reed [*Phragmites australis* (Cav.) Trin. ex Steud.], which is a widely established invasive plant species in wetlands and riparian areas. To date, no biocontrol agent has been identified or released for *P. australis*. The presence of cattle in pastures and meadows adjacent to riparian areas infested with *P. australis* could be combined with herbicides for an integrated management approach.

We found that cattle effectively reduced stem density and height of *P. australis* over a 3-yr period. A single herbicide application was more effective than grazing. Although crude protein content of *P. australis* was adequate for most livestock classes, *in vitro* dry matter digestibility was relatively low, suggesting that some form of energy supplementation would be needed to create a better nutritional balance.

vegetative growth and regeneration, whereas establishment of new populations occurs through dispersal of seeds, rhizomes, stolons, and sod fragments (Gucker 2008). Extensive rhizome and stolon growth produces dense *P. australis* stands. Rhizomes are thick, "deep seated," and scaly and can grow to 20 m long and at depths > 1 m (Holm et al. 1977). When *P. australis* replaces other vegetation and creates dense monotypic stands, changes occur in native plant diversity, soil properties, nutrient use patterns, sedimentation rates, bird and fish habitat use, and entire food webs (Gucker 2008; Saltonstall and Stevenson 2007).

In Nebraska, the most extensive populations of *P. australis* are along the Platte River and, to a lesser extent, in the river's associated tributaries, canals, and ditches. In many of these locations, *Phragmites* populations have become so dense that the most effective and economical management treatment has been limited to the use of herbicides. This is of particular concern with an increased awareness of potential off-target movement of chemicals and the rise in regulations for landowners and private applicators using herbicides (Rapp et al. 2012).

Alternatively, the use of livestock to graze *P. australis* might have the potential to reduce stands, which may help lower the need for herbicides or mechanical restoration in sensitive habitats, such as riparian and wetland areas. Although herbicide and mechanical treatment research has been common, Hazelton et al. (2014) reviewed *P. australis* management in the United States and found relatively few empirical studies evaluating grazing in North America. Brundage (2010) found that targeted grazing by goats significantly reduced *P. australis* density, height, and biomass and increased species diversity in a Maryland wetland. In Utah, Hazelton et al. (2014) reported that some control of *P. australis* in wetlands was evident when managed under high-intensity, short-duration grazing and inland saltgrass [*Distichlis spicata* (L.) Greene] was used as an alternative species.

European studies involving targeted grazing of *Phragmites* are more common. In the Netherlands, for example, year-round, heavy grazing by cattle and horses was successful in reducing *P. australis* and creating a plant community with a mosaic structure of short, desirable forage grasses and tall forb species (Vulink et al. 2000). Van Deursen and Drost (1990) concluded that timing and extent of grazing must be such that the cycle of carbohydrate storage is significantly altered by leaf area removal during mid and late summer when storage of new reserves is occurring.

The time when grazing occurs has been shown to influence plant carbohydrate reserves, annual current-year herbage yields, and plant physiology and morphology characteristics of other grassland species (Engel et al. 1998; Mullahey et al. 1990; Reece et al 1996). In particular, Mullahey et al. (1991) found that prairie sandreed [*Calamovilfa longifolia* (Hook.) Scribn.], a common warm-season grass in the Nebraska Sandhills, had reduced rhizome bud development with June, July, and August defoliation treatments compared with plants defoliated in October. Furthermore, Reece et al. (1996) report that prairie sandreed had reduced biomass of etiolated tillers when single–growing season grazing periods occurred in June, July, or August compared with grazing that occurred during plant dormancy in October. In general, the most pronounced negative effects of defoliation on grass species were thought to occur when plants were in a rapid growth phase, such as elongation. However, some riparian or wetland species such as reed canarygrass (*Phalaris arundinacea* L.), a cool-season perennial, have been found to be very resistant to defoliation regardless of growth stage (Kilbride and Paveglio 1999). Marten and Hovin (1980) reported that this species was not affected by cutting to a height of 4 to 7 cm up to four times in a growing season. Only repeated, intensive defoliation (2-wk intervals) was found to provide some control of reed canarygrass in a seasonal wetland Lyford (1993).

Palatability and nutritional quality of grazed forages must be adequate to provide a desired level of performance. Diet quality is largely affected by plant maturity and stage of growth. Baran et al. (2002) report a crude protein content of 12.1% in *P. australis* leaves and stems; however, in vitro dry matter digestibility was significantly lower than meadow hay and only slightly higher than wheat straw.

Table 1. Dormant-season, growing-season, and long-term mean precipitation (1980–2010) at the University of Nebraska–Lincoln Agricultural Research and Development Center, 2011–2014.[a]

	Precipitation[a]				
	2011	2012	2013	2014	Long-term mean
	cm				
Dormant season[b]	20.6	15.8	12.3	15.3	18.8
April	8.2	7.1	9.2	8.2	7.2
May	19.3	9.7	16.3	16.5	10.8
June	14.1	10.8	11.9	21.2	11.6
July	8.4	0.7	1.6	1.4	8.9
August	13.9	2.3	4.6	17.7	9.4
September	2.3	3.0	9.6	7.9	8.0
Total	86.8	47.0	72.1	87.5	74.7

[a] National Climatic Data Center (2014).
[b] Dormant season is previous October through March.

Similarly, Silliman (2014) found that *P. australis* had lower digestible dry matter content than five other marsh plant species, but crude protein was surprisingly high. The effect of maturity stage on nutritional value was also pronounced.

The goal of this project was to identify stocking and timing of defoliation variables that create a negative growth response in *P. australis*. Identification of these variables where this species has the greatest negative response could lead to the development of integrated management strategies. We chose grazing periods that would correspond with early summer rapid growth (June) and regrowth (August) phases of *P. australis*. The objectives were to (1) measure subsequent *P. australis* stem density, height, and biomass production in response to grazing and herbicide treatments and (2) determine forage quality of *P. australis* during grazing.

Materials and Methods

Site Description. The study was conducted from 2011 through 2014 at the University of Nebraska–Lincoln Agricultural Research and Development Center near Mead, NE (41°10′39″N, 96°25′54″W; elevation = 356 m [1,171 ft]). Climate is typical of a midcontinental prairie region with a humid classification. January temperatures average –4.1C (24.6F) and July temperatures average 25.3C (77.5F). The long-term average annual precipitation is 74.7 cm (29.4 in), with approximately 75% occurring from April through September (Table 1). Previously, the plots used in this study had been part of a constructed wetland used for other research (Ullah et al. 2004) and naturally transitioned to a well-established monoculture of *P. australis*. To remove excessive residue, all plots were burned in March 2011 before the start of the growing season.

Experimental Design. Three replicate plots for each of three treatments included a single application of imazapyr (Habitat®, BASF Corporation, Research Triangle Park, NC) herbicide in July 2011 (5.85 L ha^{-1}) (5 pt ac^{-1}), grazing, and a control. Plot size for the herbicide and grazing treatments was 300 m^2 (13 by 23 m) (3,268 ft^2, 43 by 76 ft), whereas control plots were 88 m^2 (8 by 11 m). The grazing treatment was applied with two yearling steers (340 kg) (750 lb) that were randomly assigned to each grazed plot for a 4- to 5-day period in mid-June and again in mid-August of 2011 and 2012. In 2013, plots were grazed only during the June period. Electric fencing was used to contain the cattle and water was provided in a corner of each grazed plot. The resulting stocking rate ranged from 195 to 244 animal unit days ha^{-1} (AUD ha^{-1}) (481 to 602 AUD ac^{-1}) at each grazing period and 390 to 488 AUD ha^{-1} for the year. Grazing pressure at the start of the grazing periods averaged 33 AUD Mg^{-1} (36.4 AUD ton^{-1}) in June and 95 AUD Mg^{-1} (104.7 AUD ton^{-1}) in August. This level of stocking would be considered moderate to heavy in relation to the amount of available biomass (Smart et al. 2012).

Vegetation Sampling. Aboveground *P. australis* biomass was determined immediately before each grazing event in June and August by hand-clipping standing, live vegetation to ground level in five randomly located quadrats (0.1 m^2) in each plot. Maximum height of *P. australis* stems was measured and recorded within each quadrat. The number of live stems (density) was counted while clipping. Clipped samples were bagged and oven dried at 60C to a constant weight. During June and August 2011, postgrazing biomass was also determined from five randomly located quadrats (0.1 m^2) in each grazed plot the day after cattle were removed. For this sampling, *P. australis* was sorted into standing live and trampled components and then dried and weighed. Trampled was defined as stems broken or bent to an angle of 45° or less. During 2012 and 2013, sampling was only conducted immediately before each grazing event. Although plots were not grazed in August 2013, vegetation sampling did occur at that time. A final sampling of *P. australis* stem density and height was conducted in the fall of 2014, 1 yr and 3 mo after the final grazing treatment and 3 yr and 3 mo after the herbicide treatment. Five quadrats (0.1 m^2) were randomly located in each plot, and stems were counted and height measured.

Table 2. *Phragmites australis* live biomass before the start of the grazing period in June and August 2011, 2012, and 2013.[a]

Treatment	Live biomass[a]		
	2011	2012	2013
	kg ha^{-1}		
June			
Control	10,990	7,210 a	5,800 a
Grazed	10,890	6,040 a	6,590 a
Herbicide[b]	8,200	0 b	0 b
August			
Control	13,780 a	6,980 a	8,690 a
Grazed	2,190 b	2,780 b	2,920 b
Herbicide	0 c	0 c	830 c

[a] Within years and months, biomass means followed by the same lowercase letter are not significantly different ($P > 0.05$).

[b] Single application of imazapyr (Habitat) applied in July 2011 (5.85 L ha^{-1}).

Diet Quality. The six steers used to graze the *P. australis* plots were previously ruminally fistulated under the University of Nebraska's Institute for Animal Care and Use Committee's approval. Steers grazed cool-season grass pasture before and during the period between *P. australis* plot grazing. After the steers had acclimated to grazing *P. australis* (days 2 to 3), they were held overnight in a nearby handling facility. Early the next morning, their rumens were evacuated, and the steers were taken back to their respective plots and allowed to graze for 30 to 40 min. Steers were then taken back to the handling facility, and the diet samples were removed from the rumens and immediately frozen (–4C) until subsequent analysis. Rumen contents that had been removed were returned to its respective steer, and steers were again returned to the plots for grazing. Samples were then lyophilized (–50C) and ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ) through a 1-mm screen. Samples were then analyzed for in vitro dry matter disappearance (IVDMD) using the method described by Tilley and Terry (1963), except for the inclusion of 1g urea/L of McDougall's buffer as described by Weiss (1994). The IVDMD values were adjusted by regressing them against a set of five hay standards included in the in vitro run whose in vivo digestibilities were known (Geisert et al. 2006). Crude protein was determined in diet samples by the combustion method (AOAC 1996) using a C : N analyzer (Leco FP-528, St. Joseph, MI).

Statistical Analysis. Stem density, height, and biomass data of *P. australis* were analyzed using a mixed model in a repeated measure analysis. Main effects included year, treatment, month, and associated two-way interactions. Diet quality (crude protein [CP] and IVDMD) data analysis used the same procedure with year and month as the main effects. Replications (plots) were considered the experimental unit. All statistical analyses were conducted using the GLIMMIX procedure of SAS (SAS v.9.1, SAS Institute, Cary, NC 27513).

Results and Discussion

Annual precipitation was 16% above the long-term mean during 2011 and 2014, 38% below the long-term mean in 2012, and near the long-term mean in 2013. In 2012, drought conditions were severe during July, August, and September, with precipitation 77% below the long-term mean for that period (Table 1). Conditions during that same period in 2013 were also dry, with precipitation 40% below the mean.

Stem Density. Stem density (mean ± SE; 239 ± 16 stems m^{-2}), height (132 ± 14 cm), and biomass (10,030 ± 843 kg ha^{-1}) of *P. australis* were similar between treatments at the start of the study ($P > 0.05$; Table 2) (June 2011). Our density estimate of *P. australis* was similar to that reported for sites along the Platte River in Nebraska (Rapp et al. 2012). Compared with fresh water (tidal and nontidal) and brackish tidal marshes, our observed *P. australis* stem density was substantially higher (two to four times) and height was shorter (40 to 60%) than that reported in studies summarized by Meyerson et al. (2000). Biomass, however, was comparable or slightly lower.

There was a significant year by treatment interaction for stem density ($P < 0.05$; Figure 1). The single application of imazapyr (Habitat) herbicide in July 2011 was effective in providing 100% control of *P. australis* through 2012. However, re-establishment was evident by August 2013 when average stem density was 2 stems m^{-2} and further increased to 7 stems m^{-2} in 2014. Musk thistle (*Carduus nutans* L.) and annual horseweed [*Conyza canadensis* (L.) Cronq.] were the other primary species present in the herbicide plots. There was no difference in density between the grazed treatment and control during either of the first 2 yr. However, in the third and fourth years after treatment initiation, stem density in the grazed treatment was 25 and 37% less than the control for the 2 yr, respectively. Although the reduction in the grazing treatment was not as great as the herbicide treatment, it is strong evidence of a cumulative effect of the grazing treatment on *P. australis* density and height over time. After 2 yr of periodic heavy grazing by goats, Silliman et al. (2014) found nearly a 50% reduction in stem density of *P. australis.* With year-round light grazing by cattle, Ausden et al. (2005) reported no

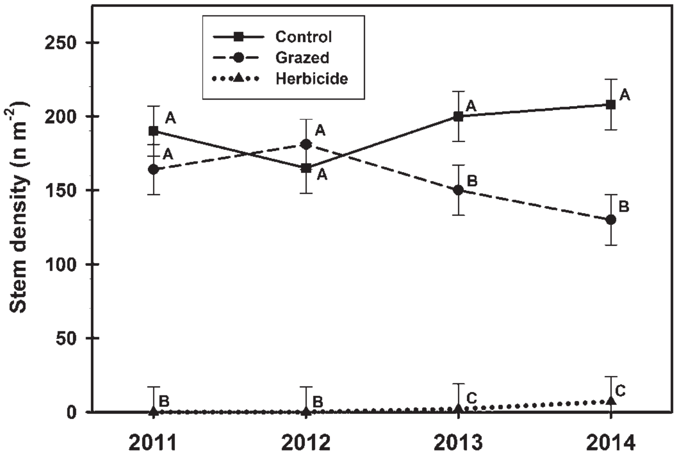

Figure 1. *Phragmites australis* live stem density (stems m^{-2} ± SE) by year and treatment. Sampling was conducted in August during 2011, 2012, and 2013 and in November 2014. Within years, treatment means with different letters are significantly different (P < 0.05).

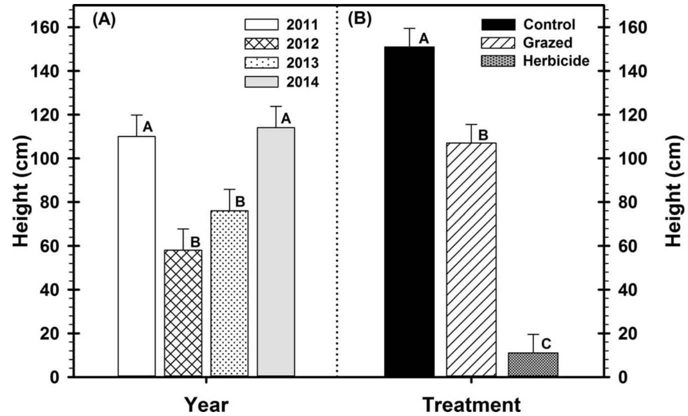

Figure 2. *Phragmites australis* height (cm ± SE) by (A) year and (B) treatment. Sampling was conducted in August 2011, 2012, and 2013 and in November 2014. For treatment or years, means with different letters are significantly different (P < 0.05).

difference in *P. australis* stem density between grazed and ungrazed areas. It was suggested that the lack of grazing effect on stem density was probably because cattle preferentially grazed the primary stems, which induces growth of larger numbers of secondary stems.

Height. There were significant year and treatment effects on *P. australis* height before the start of the grazing periods in June and August (P < 0.05; Figures 2A and 2B). Height of *P. australis* in 2011 and 2014 (112 ± 9 cm) was greater than in 2012 or 2013 (67 ± 9 cm). Although dry conditions in 2012 likely contributed to the reduced height, treatment effects were also evident. Height of *P. australis* in the control (151 ± 8 cm) was greater than that in the grazed (107 ± 8 cm) and herbicide treatments (11 ± 8 cm). Height in the grazed treatment was greater than that in the herbicide treatment. The reduction in height of *P. australis* under grazing compared with a control is consistent with other studies (Ausden et al. 2005; Silliman et al. 2014). The effect of grazing on *P. australis* may be a result of lower overall energy reserves and vigor from repeated defoliation.

Biomass. A significant year by month by treatment interaction occurred for live *P. australis* biomass (P < 0.05; Table 2). In the control plots, an additional accumulation of about 2,000 kg ha^{-1} of plant material in 2011 was recorded from mid-June to mid-August and 2,900 kg ha^{-1} for this same period in 2013. No accumulation of biomass was observed from June to August during the drought year of 2012. In the grazed treatment, pregrazing June biomass averaged 7,840 kg ha^{-1} and declined to 2,630 kg ha^{-1} before grazing in August. This reduction of *P. australis* biomass under targeted grazing is consistent with that from other research, in which decreases in cover (Silliman et al. 2014) and biomass (Ausden et al. 2005; Brundage 2010) were reported. In 2011, June biomass was greater than in August, but months were similar in 2012 and 2013 (P < 0.05; Table 2). Likely, the mid- and late-summer drought conditions in 2012 and 2013 (Table 1) contributed to the lower biomass during those 2 yr. Re-establishment of *P. australis* in the herbicide treatment was evident by August 2013 when 830 kg ha^{-1} was present.

Trampling. Although within-season postgrazing biomass sampling was conducted only in 2011, considerable trampling of *P. australis* occurred, particularly during the June grazing period (73%) and to a lesser extent during the August period (46%). The high amount of trampling during June was likely attributed to the pregrazing *P. australis* density (244 stems m^{-2}) and biomass (10,890 kg ha^{-1}), whereas in August, pregrazing density (164 stems m^{-2}) and biomass (2,190 kg ha^{-1}) were less. Postgrazing standing live biomass averaged 2,370 and 1,250 kg ha^{-1} in June and August, respectively. Stems of *P. australis* were commonly broken under the impact of cattle movement and bedding (Volesky, personal observation). In many instances, stem breakage was observed to occur at the soil surface.

Forage Quality. There was a significant year effect on CP content of *P. australis* diet samples, where CP was greater in 2011 (16.8% ± 0.6) compared with 2012 (14.3% ± 0.5, *P* < 0.05). Our plots were burned only in spring

2011, and it is possible that this may have increased CP content that year. Others have reported increased CP content of grassland species after spring prescribed burns (Allen et al. 1976; Smith and Young 1959). There was no difference in CP content (15.6%) between the June and August grazing periods ($P > 0.05$). Regrowth of *P. australis* in August that occurred after the June grazing had apparently reached a similar stage of maturity to that when grazing occurred in June. We observed that *P. australis* was in a late boot to inflorescence emerging stage of growth during both the June and August grazing periods. Much of the regrowth that occurred after the June grazing came from newly emerged stems, and existing trampled stems died (Volesky, personal observation).

IVDMD of *P. australis* diet samples averaged 45.4% ± 2.4 across years and months, with no year, month, or interaction effects ($P > 0.05$). Compared with other warm-season grass species at a similar harvest date, this level of IVDMD would be considered low. Waramit (2010) reported IVDMD of late June–harvested switchgrass (*Panicum virgatum* L.) and big bluestem (*Andropogon gerardii* Vitman) to be 55 and 57%, respectively. In general, our *P. australis* quality results of high CP and low IVDMD are similar to those reported by Silliman et al. (2014). Overall, the relatively high levels of CP we observed would be more than adequate for a mature beef cow or even a growing animal. However, low digestibility would suggest that some form of energy supplementation would be needed to create a better nutritional balance if *P. australis* was the sole forage source for an extended period of time.

Our study found that grazing resulted in a significant reduction in *P. australis* stem density (38%) and stem height (33%) after 3 yr of treatment. Although our grazing pressure was considered relatively high, periods of grazing in June and August were short. The energy reserve capacity and reproductive potential of *P. australis* appears to mitigate some of the grazing effects. It might be possible to obtain greater suppression of *P. australis* through other grazing methods. Continuous grazing through the entire seasonal growth period, for example, would provide the potential for multiple stem defoliations as well as regrowth that occurs rapidly during midsummer. Nutritional balance of the grazing animals would need to be monitored closely when using this approach.

Acknowledgments

This research project was funded by the U.S. Department of Agriculture National Institute of Food and Agriculture AD-421 NEB-42-109.

Literature Cited

Allen LJ, Harbers LH, Schalles RR, Owensby CE, Smith EF (1976) Range burning and fertilizing related to nutritive value of bluestem grasses. J Range Manage 29:306–308

[AOAC] Association of Official Analytical Chemists (1996) Official Methods of Analysis. 16th edn. Arlington, VA: AOAC International. 1141 p

Auble GT, Scott ML, Friedman JM (2005) Use of individualistic streamflow-vegetation relations along the Fremont River, Utah, USA to assess impacts of flow alteration on wetland and riparian areas. Wetlands 25:143–154

Ausden M, Hall M, Pearson P, Strudwick T (2005) The effects of cattle grazing on tall-herb fen vegetation and mollusks. Biol Conserv 122:317–326

Baran M, Váradyová Z, Krácmar S, Hedbávny J (2002) The common reed (*Phragmites australis*) as a source of roughage in ruminant nutrition. Acta Vet Brno 71:445–449

Brundage A (2010) Grazing as a management tool for controlling *Phragmites australis* and restoring native plant biodiversity in wetlands. M.S. thesis. College Park, MD: University of Maryland. 88 p

Carlson ML, Kowalski KP, Wilcox DA (2009) Promoting species establishment in a *Phragmites*-dominated Great Lakes coastal wetland. Nat Area J 29:263–280

Corbin JD, D'Antonio CM (2012) Gone but not forgotten? Invasive plants' legacies on community and ecosystem properties. Invasive Plant Sci Manage 5:117–124

Engel RK, Nichols JT, Dodd JL, Brummer JE (1998) Root and shoot responses of sand bluestem to defoliation. J Range Manage 51:42–46

Geisert BG, Klopfenstein TJ, Adams DC, MacDonald JC (2006) Comparison of *in vivo* digestibility to *in vitro* digestibility of five forages fed to steers. J Anim Sci 84(Suppl 2):104

Glenn EP, Nagler PL (2005) Comparative ecophysiology of *Tamarix ramosissima* and native trees in western U.S. riparian zones. J Arid Environ 61:419–446

Gucker CL (2008) *Phragmites australis*. *In* Fire Effects Information System (FEIS). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. Accessed June 27, 2011

Hazelton ELG, Mozdzer TJ, Burdick DM, Kettenring KM, Whigham DF (2014) *Phragmites australis* management in the United States: 40 years of methods and outcomes. AoB Plants 6:plu001. DOI: 10.1093/aobpla/plu001

Herrick BM, Wolf AT (2005) Invasive plant species in diked vs. undiked Great Lakes wetlands. J Great Lakes Res 31:277–287

Holm LG, Plocknett DL, Pancho JV, Herberger JP (1977) The World's Worst Weeds: Distribution and Biology. Honolulu: University Press of Hawaii. 609 p

Kilbride KM, Paveglio FL (1999) Integrated pest management to control reed canarygrass in seasonal wetlands of southwestern Washington. Wildl Soc B 27:292–297

Knezevic SZ, Datta A, Rapp RE (2008) Noxious Weeds of Nebraska: Common Reed. Lincoln, NE: University of Nebraska–Lincoln Extension Rep. EC08-166. 8 p

Kustu MD, Fan Y, Robock A (2010) Large-scale water cycle perturbation due to irrigation pumping in the US High Plains: a synthesis of observed streamflow changes. J Hydrol 390:222–244

Lyford M (1993) Reed canary grass controls tested (Minnesota). Restor Manage Notes 11:169

Marten GC, Hovin AW (1980) Harvest schedule, persistence, yield, and quality interactions among four perennial grasses. Agron J 72:378–387

Merritt DM, Wohl EE (2002) Processes governing hydrochory along rivers: hydraulics, hydrology, and dispersal phenology. Ecol Appl 12:1071–1087

Meyerson LA, Saltonstall K, Windham L, Kiviat E, Findlay S (2000) A comparison of *Phragmites australis* in freshwater and brackish march environments in North America. Wetl Ecol Manage 8:89–103

Meyerson LA, Viola DV, Brown RN (2010) Hybridization of invasive *Phragmites australis* with a native subspecies in North America. Biol Invasions 12:103–111

Mullahey JJ, Waller SS, Moser LE (1990) Defoliation effects on production and morphological development of little bluestem. J Range Manage 43:497–500

Mullahey JJ, Waller SS, Moser LE (1991) Defoliation effects on yield and bud and tiller numbers of two Sandhills grasses. J Range Manage 44:241–245

National Climatic Data Center (2014) National Oceanic and Atmospheric Administration National Centers for Environmental Information. http://www.ncdc.noaa.gov. Accessed July 14, 2015

Rapp RE, Datta A, Irmak S, Arkebauer TJ, Knezevic SZ (2012) Integrated management of common Reed (*Phragmites australis*) along the Platte River in Nebraska. Weed Technol 26:326–333

Reece PE, Brummer JE, Engel RK, Northup BK, Nichols JT (1996) Grazing date and frequency effects on prairie sandreed and sand bluestem. J Range Manage 49:112–116

Saltonstall K, Glennon K, Barnett A, Hunter RB, Hunter K (2007) Comparison of morphological variation indicative of ploidy level in *Phragmites australis* (Poaceae) from eastern North America. Rhodora 109:415–429

Saltonstall K, Lambert A, Meyerson LA (2010) Genetics and reproduction of common (*Phragmites australis*) and giant reed (*Arundo donax*). Invasive Plant Sci Manage 3:495–505

Saltonstall K, Stevenson JC (2007) The effect of nutrients on seedling growth of native and introduced *Phragmites australis*. Aquat Bot 86:331–336

Silliman BR, Mozdzer T, Angelini C, Brundage JE, Esselink P, Bakker JP, Gedan KB, van de Koppel J, Baldwin AH (2014) Livestock as a potential biological control agent for an invasive wetland plant. PeerJ 2:e567. DOI: 10.7717/peerj.567

Smart AJ, Derner JD, Hendrickson JR, Gillen RL, Dunn BH, Mousel EM, Johnson PS, Gates RN, Sedivec KK, Harmoney KR, Volesky JD, Olson KC (2012) Effects of grazing pressure on efficiency of grazing on North American Great Plains rangelands. Rangeland Ecol Manag 63:397–406

Smith EF, Young VA (1959) The effect of burning on the chemical composition of little bluestem. J Range Manage 12:139–141

Tilley JMA, Terry RA (1963) A two-stage technique for the in vitro digestion of forage crops. J Brit Grassl Soc 18:104–111

Ullah A, Rundquist DC, Derry DP (2000) Characterizing spectral signatures for three selected emergent aquatic macrophytes: a controlled experiment. Geocarto Int 15:29–39

van Deursen EJM, Drost HJ (1990) Defoliation and treading by cattle of reed *Phragmites australis*. J Appl Ecol 27:284–297

Vulink JT, Drost HJ, Jans L (2000) The influence of different grazing regimes on *Phragmites*- and shrub vegetation in the well-drained zone of a eutrophic wetland. Appl Veg Sci 3:73–80

Waramit N (2010) Native Warm-Season Grasses: Species, Nitrogen Fertilization, and Harvest Date Effects on Biomass Yield and Composition. Ph.D dissertation. Ames, IA: Iowa State University Paper 11863. 202 p

Weiss WP (1994) Estimation of digestibility of forages by laboratory methods. Page 644 *in* Fahey GC Jr., ed. Forage Quality, Evaluation and Utilization. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America

Whyte RS, Trexel-Kroll D, Klarer DM, Shields R, Francko DA (2008) The invation and spread of *Phragmites australis* during a period of low water in a Lake Erie coastal wetland. J Coastal Res 55:111–120

Received December 28, 2015, and approved April 19, 2016.

Associate Editor for this paper: Stephen F. Enloe, University of Florida.