Wet meadow response to Purple Loosestrife (*Lythrum salicaria*) control with Imazapyr

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Andrew J. Caven[1,2,3,*] and Joshua D. Wiese[1,4]

[1]Platte River Whooping Crane Maintenance Trust, Inc., 6611 Whooping Crane Drive, Wood River Nebraska, 68883, USA.
[2]Current Address: International Crane Foundation, E11376 Shady Lane Rd, Baraboo, WI 53913, USA
[3](ORCID: 0000-0002-5482-8191).
[4](ORCID: 0000-0003-4245-8143).
[*]Corresponding author email: acaven@savingcranes.org

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WET MEADOW RESPONSE TO PURPLE LOOSESTRIFE (*LYTHRUM SALICARIA*) CONTROL WITH IMAZAPYR

Andrew J. Caven and Joshua D. Wiese

Abstract.—Managing exotic-invasive plant species within high-quality remnant sites presents several challenges as actions intended to control invasive species can also negatively impact native plant communities. Purple Loosestrife (*Lythrum salicaria*) is an exotic-invasive species native to Eurasia that has colonized palustrine wetlands throughout temperate regions of North America. Mormon Island is the largest contiguous area of remnant wet meadow and shallow marsh habitat remaining in the Central Platte River Valley of Nebraska, which represents a continentally significant stopover habitat for migratory waterbirds in the Central Flyway. We assessed the impacts of a one-time Imazapyr application on Purple Loosestrife invasion and other dominant vegetation species via pre- and post-treatment surveys. Vegetation species abundance was assessed using a quadrat ocular cover estimation method and changes in Purple Loosestrife area were tracked throughout the study via repeat manual delineation of multiple invaded patches. Average Purple Loosestrife cover per quadrat initially declined from 63±9% to 20±9%, but then rebounded to 35±18% in the second growing season post-treatment. Nonetheless, the proportion of total vegetative cover comprised of Purple Loosestrife remained relatively constant throughout the study ranging from an average of 20% to 35% across survey years. Additionally, the cumulative area of Purple Loosestrife patches increased by >40% two years after treatment. Dominant graminoid species declined substantially one year after herbicide application (-65%) and remained suppressed two years post-treatment (-56%). Declines were most significant for Sedges (*Carex* spp.) as well as Cattails and relatives (*Typha* & *Sparganium* spp.). However, dominant forb species cover aside from Purple Loosestrife increased the first and second growing seasons post-treatment by +35% and +44%, respectively. The major beneficiaries were ruderal annual forbs such as Annual Ragweed (*Ambrosia artemisiifolia*), Beggartick species (*Bidens* spp.), and Annual Marsh Elder (*Iva annua*). One-time Imazapyr treatments may provide Purple Loosestrife the opportunity to expand into previously uncolonized suitable habitats where growth had been previously limited by competition from perennial graminoids. Individual aerial applications of Imazapyr are not likely an effective strategy for Purple Loosestrife control and may negatively impact desirable wetland plant species.

Keywords.—Purple Loosestrife, *Lythrum salicaria,* Imazapyr, wetland management, wet meadow, invasive species control, Central Platte River Valley.

INTRODUCTION

The invasion of exotic vascular plant species into novel environments can have a myriad of negative impacts on native ecosystems across several trophic levels (Simao et al. 2010, López-Núñez et al. 2017). Exotic-invasive species can displace native plants, which can alter the vegetation community, its physical structure, various ecological processes (e.g., nutrient cycling, wildfire intervals, etc.), and the resources available to wildlife species (Blossey et al. 2001, Ellis-Felege et al. 2013). The impacts of invasive plants on wildlife can be particularly severe for habitat specialists that depend on the services of a narrow subset of the native plant community, or the habitat conditions associated with remnant vegetation (Blossey et al. 2001, López-Núñez et al. 2017).

Given the threats posed by exotic-invasive species, habitat managers have worked arduously to develop effective mitigation tools. These generally include chemical control, natural disturbances (e.g., grazing, controlled burning, etc.), mechanical control (e.g., mowing, disking, etc.), and biological control (Ellis-Felege et al. 2013, Gaskin et al. 2021). Nonetheless, data on treatment effectiveness is often very general and therefore not always relevant across the range of treatment applications (Rohal et al. 2019, Gaskin et al. 2021). Moreover, existing research often focuses directly on exotic-invasive species control and ignores the impacts of treatments on the ecosystem at large, which can be an equally important consideration, especially when operating in high-quality remnant ecosystems (Kaiser-Bunbury et al. 2015, Rohal et al. 2019).

There are several challenges posed by the management of exotic-invasive species in otherwise high-quality remnant ecosystems (Kaiser-Bunbury et al. 2015, Gaskin et al. 2021). Many rare species that persist in high-quality remnant ecosystems are sensitive to disturbance, and therefore, may decline more quickly than the targeted invasive species under a broad range of control options (Bennion et al. 2020). Additionally, many rare and remnant-dependent species are the hardest to restore once they have been lost as they may be dependent on a narrow set of habitat conditions, including mycorrhizal associations, which can also be disrupted by herbicide applications (Bennion et al. 2020, Caven 2022).

Purple Loosestrife (*Lythrum salicaria*) is native to the Eurasian continent and was introduced into eastern North America in the early to middle 1800s (Blossey et al. 2001, Knezevic 2002). It was likely introduced into North America on several occasions via multiple different vectors including through ship ballast, as an ornamental, and via livestock shipments from Europe (e.g., sheep and raw wool). The plant is a prodigious producer of seed with individual mature plants capable of dropping hundreds of thousands of viable seeds annually, which are small and easily spread through water, wind, wildlife, and livestock movements (Blossey et al. 2001, Yakimowski et al. 2005). Purple Loosestrife is a perennial but regularly colonizes disturbed environments. It not only spreads easily via seed but also via sturdy rhizomes, which can make the species more resilient to disturbances (Blossey et al. 2001). Purple Loosestrife is tolerant of a wide range of conditions (e.g., pH, nutrient levels, temperatures, etc.) and has no natural predators in North America (Young and Clements 2001, Knezevic 2002, Yakimowski et al. 2005). It can form dense monocultures and completely replace native wetland vegetation communities such as shallow marsh, wet meadow, and riparian corridor assemblages (Blossey et al. 2001, Knezevic 2002, Yakimowski et al. 2005). Purple Loosestrife is regularly controlled through chemical, mechanical, and biological means, but is very challenging to eliminate once established (Blossey et al. 2001, Knezevic 2002).

Our objective was to assess the impacts of Purple Loosestrife control efforts on the species itself as well as dominant vegetative components of a remnant wet meadow complex in southcentral Nebraska along the Platte River. This area is of great conservation concern and of value to a broad range of taxa (Caven et al. 2022a). Our results are intended to inform and refine management actions within an adaptive management framework.

METHODS

Study Area – The western extent of Mormon Island is the largest contiguous area of remnant and restored herbaceous habitat remaining in the Central Platte River Valley (>1,075 hectares; Caven and Wiese 2022). It is part of a larger conservation complex (>2,075 hectares) primarily protected through ownership and easements by the Platte River Whooping Crane Maintenance Trust, Inc (i.e., "Crane Trust"). As a result of subtle topographic variation and a high but fluctuating water table driven by the Platte River, Mormon Island supports several vegetation communities across a hydrological gradient including subirrigated lowland tallgrass prairie, wet meadow, and shallow marsh (Henszey et al. 2004, Brinley Buckley et al. 2021a, Caven and Wiese 2020). These resilient and variable wetland features likely prevented wide scale farming of the area historically (Currier 1982). The distinct hydrology of the site supports a diverse biological community including the endemic Platte River Caddisfly (*Ironoquia plattensis*; Whiles et al. 1999) and the endangered Whooping Crane (*Grus americana*) during migration (Baasch et al. 2022). Nonetheless, surface and groundwater resources have been heavily exploited, which has altered the natural hydrological patterns of the ecosystem (Brinley Buckley et al. 2021a, Caven et al. 2022a).

Mormon Island's vascular plants have been inventoried on two separate occasions spanning 40 years, >420 species have been documented at the site, and about 550 across the broader conservation complex (Nagel and Kolstad 1987, Caven and Wiese 2023). Despite the impressive species richness at Mormon Island, some vascular plants such as the Western Prairie Fringed Orchid (*Platanthera praeclara*) have ostensibly disappeared in recent decades and several invasive species have become more abundant (Caven 2022, Caven and Wiese 2022). Purple Loosestrife was only detected at trace levels in surveys conducted from 1980 to 1981 but was present across 39% of research plots assessed from 2015 to 2020 (Caven and Wiese 2022). The area has been managed with rotational grazing (generally 2 of 3 years) and occasional prescribed fire (generally every 5 to 7 years) in recent decades (Caven et al. 2017, Glass et al. 2020).

Field and Analysis Methods – The Crane Trust treated portions of Mormon Island infested with high densities of Purple Loosestrife with Imazapyr via helicopter in collaboration with the Platte Valley Weed Management Area cooperative in the late summer of 2015, when the species was in peak flowering condition to maximize identification. Imazapyr is a non-specific imidazolinone herbicide that is absorbed through plants' leaves and root system that accumulates in the meristem region and interrupts cell growth by inhibiting the function of an essential enzyme (Shaner 2012). The study was centered in a >110-hectare paddock labeled "Northeast Mormon Pasture" (40.802301°, -98.407428°; ~577 m elevation). This area represents one of the wetter areas of Mormon Island and has been the focus of much wet meadow and shallow marsh related research (e.g., Currier 1995; Geluso and Harner 2013; Brinley Buckley et al. 2021a, 2021b).

We visually identified and geolocated relatively dense and distinct patches of Purple Loosestrife during multiple walkthroughs of the Northeast Mormon Pasture during the summer of 2015. All patches were marked using a Garmin handheld GPS device (GPS-73 Marine Handheld; Garmin International Inc., Olathe, Kansas, U.S.A.). To monitor pre- and post-Imazapyr treatment conditions, we selected four patches that were distributed throughout the pasture and varied in size. Pre-treatment data was collected in the late summer of 2015 before Imazapyr use and post-treatment monitoring was conducted during the same time window in 2016 and 2017, between the second week of August and the first week of September. We mapped the perimeter of distinct Purple Loosestrife patches we surveyed using the GPS unit's movement tracking feature and waypoints collected every 10 m of walking for higher resolution. We visually defined the patch boundary by determining where Purple Loosestrife was clearly a dominant or codominant species (Elzinga et al. 2009). We then estimated the size of those patches for pre- and post-treatment surveys using the polygon tool in Google Earth Pro version 7.0 (Google 2015). Results were rounded to the nearest 5 m^2.

We collected vegetation cover data within and across Purple Loosestrife patches using a quadrat ocular cover estimation method following Symstad et al. (2008) and Caven et al. (2022b). We used a 0.5 x 1.0 m quadrat marked in 10 cm increments along the frame to aid in cover estimation. Canopy cover was estimated to the nearest 5% for individual species and canopies were permitted to overlap; therefore, total cover often exceeded 100% (Symstad et al. 2008, Caven et al. 2022b). We intended to provide a repeatable rapid assessment for weed control research at the Crane Trust with this study and therefore we did not record cover data for all species present within each quadrat. Rather, we recorded the percent cover of Purple Loosestrife, as well as the two other most abundant forbs (broad leaf plants- i.e. dicots) and the two most abundant graminoids (grass and grass-like plants- i.e. monocots). We also recorded visible bare ground and exposed litter for all post-treatment samples in 2016 and 2017. Bare ground and litter values were imputed based on mean data from nearby long-term monitoring plots for 2015 pre-treatment data (Caven et al. 2022b).

Vegetation cover measurements were initiated from the center of each Purple Loosestrife patch regardless of its size. One quadrat was read at the GPS-designated center point and four additional quads were thrown in the cardinal directions and interpreted where they landed to provide a relatively random assessment. This sampling process was repeated annually from 2015 to 2017 for a total sample of 60 quadrats during the study (4 patches*5 quadrats each*3 years).

We used simple summary statistics, including means and standard deviations, to elucidate patterns in cover category abundance over time in response to Imazapyr treatment. We also summarized abundance patterns for individual species that comprised >5.0% average cover.

RESULTS

Ocular Cover Estimation – Purple Loosestrife cover averaged 63.3±8.8% pre-treatment in 2015, 19.8±9.0% one year after treatment in 2016, and 35.0±18.4% two years after treatment in 2017, mirroring an inverse quadratic trend over time (Figure 1). Variability in Purple Loosestrife cover across patches increased with time since treatment. The combined mean cover of the two most dominant forbs aside from Purple Loosestrife demonstrated a positive trend averaging 38.1±12.4% in 2015, 51.5±22.8% in 2016, and 55.0±11.2% in 2017, but variability across plots was highest in the growing season after treatment (Figure 1). When separating the average cover for the most and second most dominant forbs, aside from Purple Loosestrife, the temporal trends were divergent, with the most dominant peaking in cover in 2016 at 39.0±22.9% (quadratic pattern) and the second most dominant peaking in 2017 at 22.3±4.3% (increasing pattern). The combined average cover of the two most dominant graminoids was 82.0±11.6% in 2015, 29.0±7.8% in 2016, and 36.3±8.2% in 2017, reflecting a weak inverse quadratic trend over time (Figure 1). Both dominant graminoids assessed demonstrated the same temporal pattern between declining and a weak inverse quadratic trend. Total overlapping vegetative cover averaged 183.3±6.2% in 2015, 100.3±25.2% in 2016, and 126.3±13.1% in 2017 (Figure 2). The proportion of total vegetative cover comprised of Purple Loosestrife remained relatively constant throughout the study but did demonstrate a weak inverse quadratic pattern across years averaging 34.5±4.8% in 2015, 19.8±9.0% in 2016, and 27.7±14.6% in 2017 (Figure 2).

Sedges (*Carex* spp.) had an average absolute decrease of 38.0% cover throughout the study, which equated to an 85.9% relative decline from 2015 to 2017 (Appendix 1). Dotted Smartweed (*Polygonum punctatum*) and Spikerushes (*Eleocharis* spp.) dropped 17.0% and 14.3%

in average absolute cover from 2015 to 2016 and rebounded in 2017 by 3.8% and 8.8%, respectively, but not to their former abundance levels (Appendix 1). Common Threesquare (*Schoenoplectus pungens*) followed a similar inverse quadratic pattern, declining from 2015 to 2016 and then rebounding in 2017, but ultimately surpassed its original average absolute cover by 5.0%, which represents an overall relative increase of 36.4% throughout the study (Appendix 1). Devil's Beggartick (*Bidens frondosa*) and Annual Marsh Elder (*Iva annua*) demonstrated absolute average increases across the study of 15.0% and 7.3% respectively. Annual Ragweed (*Ambrosia artemisiifolia*) represents the only species with >5% cover per quadrat throughout the study that demonstrated a quadratic pattern of abundance, being undetectable per 2015 samples before becoming the most common species in 2016 with 25.5% absolute cover, then dropping to 19.3% cover in 2017 (Appendix 1).

In total, 33 species were defined as dominant across the 60 quadrats assessed over three years (Appendix 1). A number of perennial wetland-dependent graminoids disappeared from quadrat samples post-treatment in 2016 and remained absent in 2017 including Broadfruit Bur-reed (*Sparganium eurycarpum*), Narrowleaf Cattail (*Typha angustifolia*), Bulrush species (*Scirpus* [*Bolboschoenus*] spp.), and Prairie cordgrass (*Spartina pectinata*). Softstem Bulrush (*Schoenoplectus tabernaemontani*) declined from 2015 to 2016 but did not immediately disappear from quadrat samples; nonetheless, it was not detected per 2017 sampling efforts. By contrast, several species were absent pre-treatment but became relatively abundant after treatment including Annual Ragweed, Beggartick species (*Bidens* spp.), some Smartweed species (*Polygonum* spp.), and some more disturbance-tolerant grass species including Marsh Muhly (*Muhlenbergia racemosa*) and Rough Barnyard Grass (*Echinochloa muricata*).

Purple Loosestrife Patch Size – The largest Purple Loosestrife patch decreased in area from 22,140 m^2 to 995 m^2 from 2015 to 2016, then rebounded vigorously to 33,960 m^2 in 2017, which equates to an overall increase in area of 53.4% during the study. The patch deemed “medium” sized decreased from 4,860 m^2 to 635 m^2 from 2015 to 2016, then returned to 3,780 m^2 by 2017 for an overall decrease of 22.2%. The first small patch assessed decreased from 220 m^2 in 2015 to 130 m^2 in 2016, and then grew to 1,015 m^2 by 2017 resulting in an overall increase in area of 361.4%. Finally, a second small patch decreased from 190 m^2 in 2015 pre-treatment to 115 m^2 in 2016, and actually continued to decrease to 75 m^2 in 2017 resulting in an overall decline of 60.5% in area. Cumulatively, patches declined from 27,410 m^2 total area in 2015 to 1,875 m^2 in 2016, but then vigorously recovered to 38,830 m^2 in 2017, demonstrating an overall increase in area.

DISCUSSION

Purple Loosestrife decreased in absolute cover within plots over the duration of our study (63% to 35% on average). However, observed decreases were generally proportional to overall declines in total vegetative cover. Average Purple Loosestrife cover remained a relatively constant fraction of total vegetative cover during this study (20-35%). We did note large decreases in the area of Purple Loosestrife patches one growing season after treatment (-40% to -96%), but that trend reversed two growing seasons after treatment for half of the assessed patches (+53% and +361%). Moreover, the cumulative extent of all four plots increased by >40% two years after treatment. One-time Imazapyr treatments may provide Purple Loosestrife the opportunity to expand into previously uncolonized suitable habitats as the species is disturbance-tolerant, can be early successional, and generally outcompetes less tolerant native species for space after artificial disturbances like non-selective herbicide application (Blossey et al. 2001, Knezevic 2002, Yakimowski et al. 2005, Stanley et al. 2005). These results suggest that occasional growing season aerial applications of Imazapyr are likely not an effective long-term control strategy for Purple Loosestrife, particularly in remnant wet meadow and shallow marsh ecosystems where recurrent spraying could degrade biologically important perennial plant communities (Knezevic 2002).

It is notable that variation in Purple Loosestrife cover across plots increased following Imazapyr treatment. Observed changes in patch area were also highly variable two growing seasons after treatment. This suggests that a single non-specific herbicide treatment set back Purple Loosestrife expansion in some areas, while providing it opportunities to expand in others. It is possible that Purple Loosestrife expanded into hydrologically appropriate areas where growth had been formerly constrained by strong competition from perennial graminoids, such as Sedge and Cattail species, which declined significantly post-treatment (Corona 2003, Yakimowski et al. 2005). Additionally, it is possible that Purple Loosestrife recolonization generally occurs more slowly in sub-prime habitats such as areas that are too dry or too wet. Corona (2003) found that Purple Loosestrife had the highest cover at mid-elevational habitats in herbaceous wetland systems that experienced spring but not summer flooding. These microsites were concentrated on hummocks within the marsh studied by Corona (2003). Hummocks are widespread throughout shallow marsh zones of our study area at Mormon Island and represent important nesting areas for waterbirds (Caven et al. 2019).

The main beneficiaries of Imazapyr application two years post-treatment appear to be ruderal annual forbs such as Annual Ragweed, Devil's Beggartick, and Annual Marsh Elder, as well as rhizomatous perennial species adapted to colonize disturbed environments such as Common Threesquare and Purple Loosestrife (Stanley et al. 2005). It is unclear what the long-term trajectory of the plant community will be post-Imazapyr treatment. However, we already have evidence that Purple Loosestrife has expanded its range and increased in abundance in recent decades within the study area in the absence of recurrent treatment (Caven and Wiese 2022). Long-term Purple Loosestrife control in remnant wet meadows will likely require a multifaceted and dynamic management approach that integrates multiple treatment approaches and limits the use of non-selective herbicides to only the most degraded sites. Our study did not assess the use of "selective" herbicides for Purple Loosestrife control, and we recommend that tool also be assessed for effectiveness and impacts on native vegetation before widespread application in the Platte River Valley.

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Figure 1. Average percent cover (±SD) per quadrat by category and year.

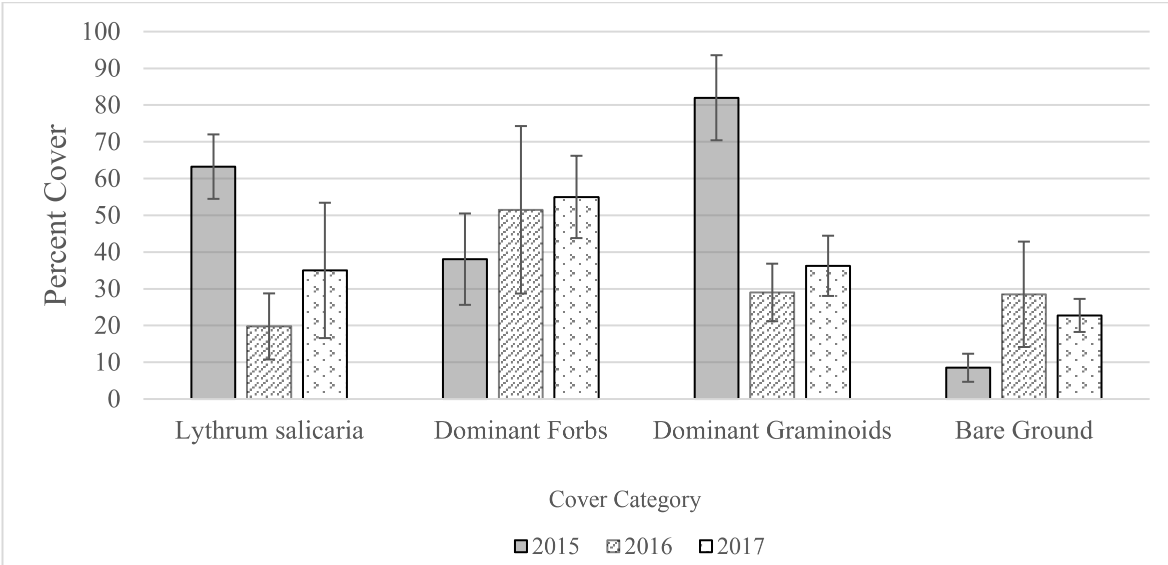
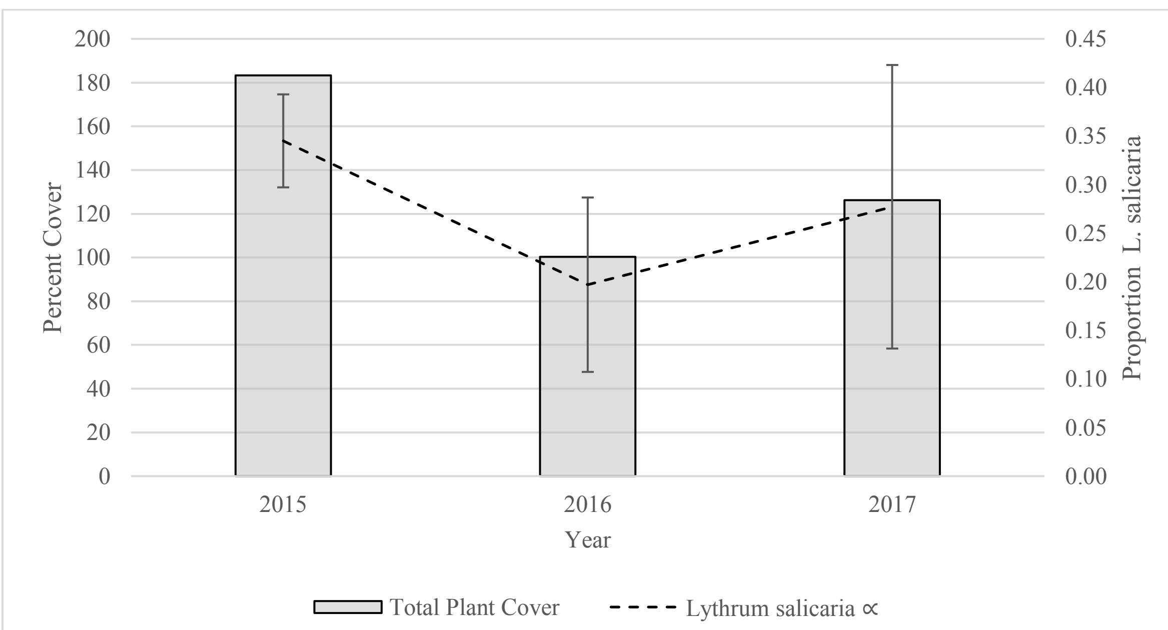


Figure 2. Average cumulative percent cover and proportion of cover of *L. salicaria* (±SD) per quadrat by year.



Appendix 1. Species abundance as percent cover per quadrat sample per study year including species family name, species code used by the Crane Trust, and scientific name.

Species Information			**% Cover per Quadrat**			
Family	**Species Code**	**Scientific Name**	**2015**	**2016**	**2017**	**Average**
Apiaceae	CICMAC	*Cicuta maculata*	0.00	0.50	0.00	0.17
Asteraceae	AMBART	*Ambrosia artemisiifolia*	0.00	25.50	19.25	14.92
Asteraceae	BIDFRO	*Bidens frondosa*	0.00	0.00	15.00	5.00
Asteraceae	IVAANN	*Iva annua*	2.00	3.75	9.25	5.00
Asteraceae	BIDCOM	*Bidens tripartita* ssp. *comosa*	0.00	0.00	1.25	0.42
Asteraceae	BIDBIP	*Bidens bipinnata*	0.00	1.00	0.00	0.33
Asteraceae	HELAUT	*Helenium autumnale*	0.00	0.50	0.00	0.17
Cyperaceae	CAREX	*Carex* spp.	44.25	6.75	6.25	19.08
Cyperaceae	SCHPUN	*Schoenoplectus pungens*	13.75	12.00	18.75	14.83
Cyperaceae	ELEOCHARIS	*Eleocharis* spp.	18.00	3.75	12.50	11.42
Cyperaceae	CYPERUS	*Cyperus* spp.	0.00	3.25	1.25	1.50
Cyperaceae	SCIRPUS	*Scirpis* [*Bolboschoenus*] spp.	1.00	0.00	0.00	0.33
Cyperaceae	SCHTAB	*Schoenoplectus tabernaemontani*	0.50	0.25	0.00	0.25
Equisetaceae	EQULAE	*Equisetum laevigatum*	0.00	1.00	0.00	0.33
Fabaceae	AMOFRU	*Amorpha fruticosa*	0.00	0.50	0.00	0.17
Juncaceae	JUNCUS	*Juncus* spp.	0.00	0.00	0.75	0.25
Lamiaceae	LYCOPUS	*Lycopus* spp.	1.25	1.50	0.75	1.17
Lamiaceae	MENARV	*Mentha arvensis*	0.25	0.00	0.00	0.08
Lythraceae	LYTSAL	*Lythrum salicaria*	63.25	19.75	35.00	39.33
Lythraceae	AMMROB	*Ammannia robusta*	0.00	0.25	0.00	0.08
Poaceae	LEEORY	*Leersia oryzoides*	0.75	0.50	1.50	0.92
Poaceae	CALSTR	*Calamagrostis stricta*	0.00	0.00	1.00	0.33
Poaceae	MUHRAC	*Muhlenbergia racemosa*	0.00	1.00	0.00	0.33
Poaceae	ECHMUR	*Echinochloa muricata*	0.00	0.50	0.00	0.17
Poaceae	SPAPEC	*Spartina pectinata*	0.50	0.00	0.00	0.17
Polygonaceae	POLPUN	*Polygonum punctatum* [*Persicaria punctata*]	25.50	8.50	12.25	15.42
Polygonaceae	POLCOC	*Polygonum coccineum*	0.00	6.25	2.00	2.75
Polygonaceae	POLPER	*Polygonum persicaria* [*Persicaria maculosa*]	6.25	1.00	0.00	2.42
Polygonaceae	POLCON	*Polygonum* [*Fallopia*] *convolvulus*	0.00	1.50	0.00	0.50
Salicaceae	SALEXI	*Salix exigua*	1.00	0.00	0.00	0.33
Typhaceae	SPAREUR	*Sparganium eurycarpum*	2.00	0.00	0.00	0.67
Typhaceae	TYPANG	*Typha angustifolia*	1.25	0.00	0.00	0.42
Violaceae	VIOSOR	*Viola sororia*	0.00	0.00	0.50	0.17