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Rehabilitation and Continuing Management of an Urban Lake Shoreline in Southeastern Minnesota, USA

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Abstract: Lake Winona is a 129-hectare urban lake which occupies part of an old side channel of the Mississippi River and has been modified significantly over the past 125 years. The entire shoreline (>8 km) is publicly owned, with current shorelines created mostly during two periods of lake dredging and filling of fringe wetlands 70 and 110 years ago, respectively. Since then, some sections were allowed to revegetate naturally with trees and shrubs, some were armored with riprap, and others have been maintained mostly as turfgrass parklands. Shoreline vegetation assessments and tree stand surveys were completed prior to beginning targeted shoreline rehabilitation in 2017. These rehabilitation activities (encompassing the majority of shoreline) include the following: (1) repeated removal and chemical treatment of woody invasive shrubs/trees (primarily common buckthorn *Rhamnus cathartica* and nonnative bush honeysuckles *Lonicera* spp.) by contractors and volunteers; (2) chemical spraying and hand pulling of nonnative invasive ornamental grasses (*Miscanthus* spp.) and forbs (Japanese hops *Humulus japonica*; leafy spurge *Euphorbia esula*) annually or as needed; (3) killing of turfgrass and overseeding with native prairie species; (4) shrub and sapling plantings and overseeding with native species in both wooded and turfgrass sections; (5) installation of wave barriers (using cut woody invasives) and planting of emergent aquatic macrophytes; (6) prescribed burns of prairie plantings; (7) establishment of fixed photo reference points to document changes; and (8) altered park mowing practices to maintain a shoreline buffer of vegetation. These ongoing management activities aim to replace more turfgrass with native prairie, plant more shrubs and trees on shorelines, suppress nonnative invasives, and encourage the development of aquatic macrophyte beds to reduce, or eliminate shoreline erosion. Future management activities will continue to emphasize invasive species control, turfgrass conversion to native vegetation, and shoreline erosion reduction.

Keywords: restoration of lake shorelines; shoreline reclamation; invasive shrubs; plant inventory; urban lake; common buckthorn

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1. Introduction

Lakeshore restoration has been practiced in many regions of the world for several decades [1–4]. Restoration is needed because shorelines have been degraded by human activities such as recreation and residential development [1,4–8], causing losses of valuable onshore and in-lake habitats and their associated biological communities [9,10]. The field of lakeshore restoration science has advanced dramatically, benefiting from new methodologies [2,7,10–14], intensive and informed assessments of past efforts [6,8,15,16], and analyses of society's attitudes to and perceived benefits from restoration [4,17]. Consequently, rehabilitation of altered lake shorelines has allowed for improvements and/or recovery of both upland and aquatic plant and animal communities [3,6,10,15,16].

Lakeshore restoration usually attempts to rehabilitate portions of degraded shorelines so that they resemble (in appearance and functionality) what they were naturally prior to disturbance, e.g., fringe wetlands, unshaded habitats dominated by grasses and forbs, or

various types of forests [1,6,7,10,11]. Although many lakeshore rehabilitation projects have been successful [10,11,15,16], many others have produced poor results due to revegetation failures [15]. Failures have been attributed to inappropriate species selection, continued invasions of non-native plants, high recreational traffic, wildlife interference, high wave action, lack of ongoing maintenance efforts, and other stressors [15,16]. Developing strategies and techniques to adequately counter these problems is the primary goal of lakeshore restoration planners and installers [15].

Beginning in 2015, we initiated efforts to rehabilitate the shorelines of an urban lake in southeastern Minnesota, USA. With shorelines completely under public ownership and with a history of disturbances from numerous human activities spanning over a century, we set out to manage non-native and invasive species and re-establish native vegetation on those shorelines. Working on multiple different projects simultaneously, and using a mix of volunteer and professional labor, we hoped to gradually convert most shoreline habitats into more natural forms stabilized with native terrestrial and aquatic vegetation. This paper reports on the successes and problems encountered during the first 10 years of our lakeshore rehabilitation efforts and summarizes plans for future management efforts.

2. Study Site History

Lake Winona is a 129-ha urban lake located in Winona, Minnesota, USA (44°02′19.54″ N, 91°38′37.24″ W; 197 m above sea level). It lies within the natural floodplain of the upper Mississippi River, and is surrounded entirely by public property, mostly city parklands. In 1973, the lake was rehabilitated to create a recreational sport fishery for young and elderly anglers, and others who cannot safely access the fishery of the nearby Mississippi River [18]. The lake currently has three boat ramps, four fishing piers, and >8 km of accessible shoreline, that, combined, provide easy access to the game fishery.

Historically, the lake was formed from an old, cut-off side channel of the Mississippi River and was bordered completely by wetlands prior to 1910 [18]. The lake has been dredged multiple times beginning in 1910–1913, with various projects aimed at filling the fringe wetlands to create useable lands, creating a road causeway across the lake, and removing sand to fill additional lands nearby for commercial property development (while also deepening the lake to extend its life expectancy). During dredging in the 1950s, defined lake shorelines were established along both northern and southern shores by elevated retaining dikes constructed originally to facilitate the filling of wetlands behind them [18]. Additional retaining dikes constructed perpendicular to the shorelines separated the fill area into multiple cells to better manage the dredging and filling process.

After the 1950s dredging, filled wetlands along the northern lakeshore were developed into turfgrass parklands containing scattered shade trees, whereas the southern lake shorelines revegetated naturally and remained largely undeveloped and "wild" until 1978 (Figure 1). In that year, a multi-use asphalt pathway was completed along the lake's entire shoreline, mostly following the tops of the dredging-period retaining dikes [18]. Established trees and other "wild" vegetation remained on both sides of the pathway along the southern shore, with only 1 to 2 m of vegetation mowed periodically on either side to keep the pathway clear (Figure 1). The width of the wooded habitat between the lake and the southern-shore pathway varies from 3 to 20 m. The pathway on the northern shore typically is further from shore, meandering through mowed turfgrass.

Today, some 70 years after the current Lake Winona shorelines were established, the northern shorelines typically are a narrow fringe of grasses, forbs, and occasional trees bordering turfgrass, whereas the southern shoreline habitat remains largely wooded. Eastern cottonwoods (*Populus deltoides)*, likely established soon after the shoreline, today tower over the paved pathway beneath them, sharing the lakeshore habitat with a variety of other native and non-native trees, shrubs, grasses, and forbs. In addition to cottonwood, other native floodplain trees present include river birch (*Betula nigra*), American elm (*Ulmus americana*), black willow (*Salix nigra*), and green ash (*Fraxinus pennsylvanica*). Non-native and/or invasive trees and shrubs present include common buckthorn (*Rhamnus cathartica*),

glossy buckthorn (*Frangula alnus*), various bush honeysuckles (*Lonicera* spp.), Siberian elm (*Ulmus pumila*), black locust (*Robinia pseudoacacia*), white mulberry (*Morus alba*), round leaf bittersweet (*Celastrus orbiculatus*), and box elder (*Acer negundo*).

Figure 1. The wooded southern shoreline of the eastern basin of Lake Winona as viewed from the lake (**top panel**), the paved multi-use pathway along that same shoreline (**middle panel**), and a section of shoreline overrun with invasive buckthorn and honeysuckle (**bottom panel**).

The dredged material used to fill the wetlands behind the southern shoreline/retaining dikes had a high organic content. Consequently, as the organic matter in this fill material gradually decomposed, what had been flat land level with the retaining dikes immediately

after dredging began to subside. Eventually, these areas subsided to the level of the water table (and lake surface) and below, shifting much of the habitat back into shallow wetlands. Trees that had grown in these areas after dredging ultimately died, resulting in some standing dead snags and toppled submerged logs scattered throughout an otherwise open wetland largely dominated by broadleaf cattail (*Typha latifolia*), common rush (*Juncus effusus*), and purple loosestrife (*Lythrum salicaria*). The perimeter of the wetlands and the old retaining dikes oriented perpendicular to the shoreline are still covered in trees (mostly buckthorn, box elder, black locust, black willow).

Over the years, many areas of shorelines on both basins have been armored (or riprapped) with rock (locally quarried limestone) or fragmented concrete to protect against erosion from wave action. Shoreline sections dominated by riprap include both sides of the causeway separating the two basins (sections 1–2 and 3W), most of sections 15–33 along the northern and eastern portions of the eastern basin, the western half of the southern shoreline (sections 5W and 6W) of the western basin, and several portions of the western basin's northern shoreline (section 2W; see Figure 1).

3. Shoreline Vegetation Assessments and Tree Surveys

Prior to beginning shoreline management actions, the shorelines of each basin were assessed qualitatively to document the vegetation present (Table 1). Shorelines were delineated into sections (37 sections on the eastern basin, 9 sections on the western basin; Figure 2) based on the vegetation communities present, and both dominant and invasive species in each section were noted. Several sections (all along the eastern basin) were assigned as "special focus areas" (Figure 2) due to severe erosion problems, designation as lakeshore protection demonstration sites by the Minnesota Department of Natural Resources, or other specific conditions needing protection or immediate attention. Additionally, shoreline areas protected from erosion by the placement of rock or concrete riprap were noted (Figure 2) for potential future removal and replacement by a more esthetically pleasing and ecologically functional shoreline erosion control measure (e.g., planting of onshore and/or emergent vegetation).

Table 1. Example notes made during walking vegetation and shoreline condition survey of the eastern basin of Lake Winona, November 2015. See Figure 2 for section locations.

Section	Description
1	Wooded shoreline east of Visitors' Center: riprap present; control invasive species (buckthorn and honeysuckle).
2	Highly disturbed shoreline area (cutting and pulling); retain some red-osier dogwood; plant river birch; remove black locust. Plant grassy area between ropes with short prairie. Maintain short native vegetation in riprap area at parking lot. Maintain wooded area on shore near fishing pier. Riprap present. At sidewalk embankment: redo landscape timbers; suggest state-of-the-art sandbags; enlist Master Gardeners.
3	Wooded shoreline north of fishing pier; riprap present but shoreline is eroding; a major problem; need protective matting and/or wave barrier coir rolls; tree removal has resulted in erosion.
4	Open shoreline to edge of DNR planting. Good diversity; widen non-mowed area and plant prairie from shoreline to base of slope at sidewalk; plant emergent vegetation (bulrush, bur reed); allow sandbar willow to expand along shoreline. This will discourage Canada geese from accessing area from the lake and loafing on shore.
5	DNR Demonstration Area—this is a Focus Area. Expand area to tree line next to the bike trail; this would be a good area for WSU classes to adopt and maintain.
6	Protect aquatic plants with wave barrier coir rolls; control invasives; has seed bank of desirable plants for pollinators and birds. Expand no-mow area to 15 feet from shoreline; plant emergent vegetation at culvert area.

Combined between the two basins, 124 species of trees, forbs, grasses, and sedges were documented along Lake Winona's shorelines during simple walking surveys (i.e., qualitative only) conducted between July and early October 2015. Conservatively, 10% to 15% of the species detected were considered non-native and/or invasive and potentially worthy of some level of targeted management. In addition to those invasive or non-native trees and shrubs listed above (see 2. Study Site History above), shoreline plant species identified for some degree of future management included leafy spurge (*Euphorbia*

esula), silvergrass (*Miscanthus* spp.), yellow iris (*Iris pseudacorus*), reed canarygrass (*Philaris arundinacea*), and purple loosestrife (*Lythrum salicaria*).

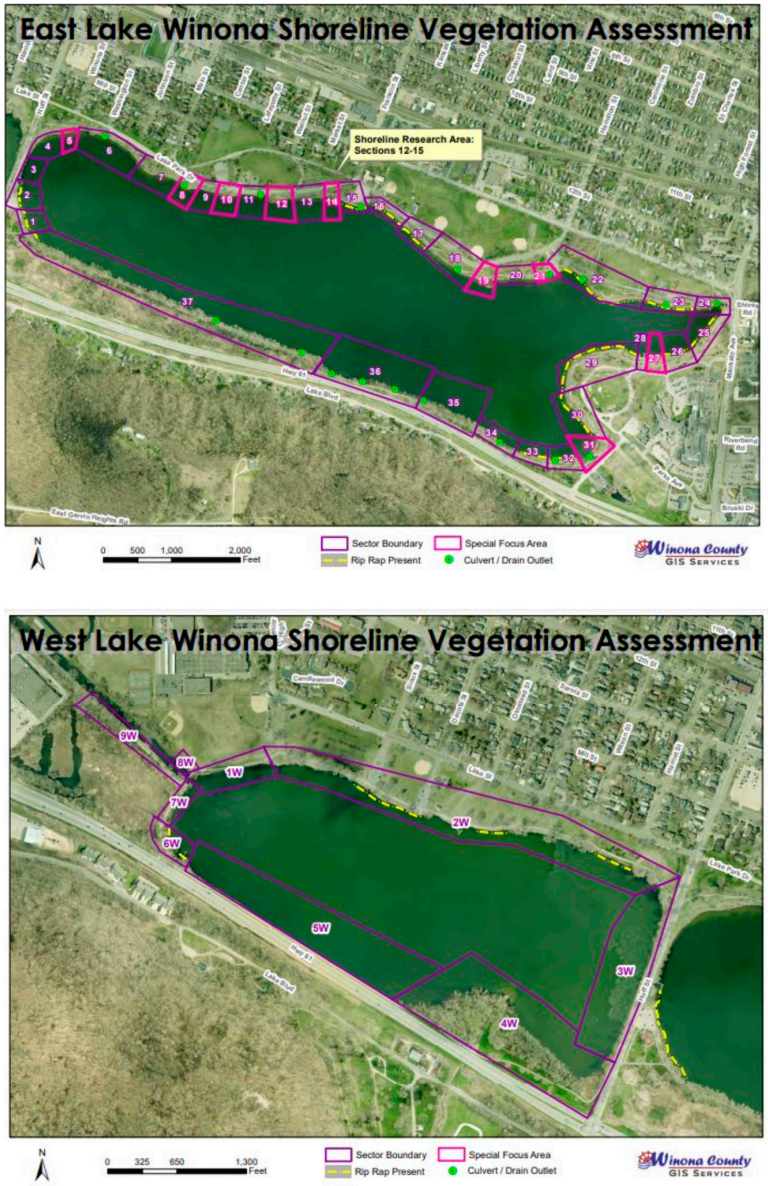

Figure 2. Designated shoreline sections of the eastern (**top panel**) and western (**bottom panel**) basins of Lake Winona, based on qualitative surveys of vegetation and other shoreline features. Please note that panels are shown at different scales.

Quantitative tree surveys initially were undertaken along various sections of the wooded southern shoreline of the eastern basin between October 2016 and 2018 before sections of woody invasives were removed (Section 4.1 below). Follow-up surveys were conducted in September 2020 and 2024 after woody invasive management to assess re-growth of invasives and the need for additional removal/treatment. Each year, surveys were conducted using multiple plots (10 to 20 plots per year, each plot 20 m long with variable widths based on changing distances between shore and the paved multi-use pathway). Different plots were surveyed in 2016 and 2018, whereas plots surveyed in2020 and 2024 were in the same general area of shoreline as plots surveyed in 2016. All trees and woody shrubs within each plot were identified, counted, and measured (cm in diameter at breast height, DBH). Within each survey year, total area surveyed by all plots was determined and tree densities (number/100 m^2), frequencies (presence in individual plots), and coverages

(basal area based on DBH measurements) were calculated to permit determination of each species' importance value (importance value = sum of relative density, relative frequency, and relative coverage [19]).

Pre-management surveys (2016 and 2018) indicated that native eastern cottonwood, American elm, river birch, green ash, and slippery elm were among the native species of highest importance along various portions of the southern shoreline of the eastern basin (Figure 2). However, in some locations, buckthorn (common and glossy), honeysuckle, Siberian elm, and black locust displayed higher importance than many native species. After targeted management of buckthorn and honeysuckle (see Section 4.1 below), community importance values shifted in favor of eastern cottonwood and American elm (Figure 3, 2020), but honeysuckle and buckthorn became more important by 2024 after a period of regrowth (sprouting) and germination from the seedbank (Figure 3).

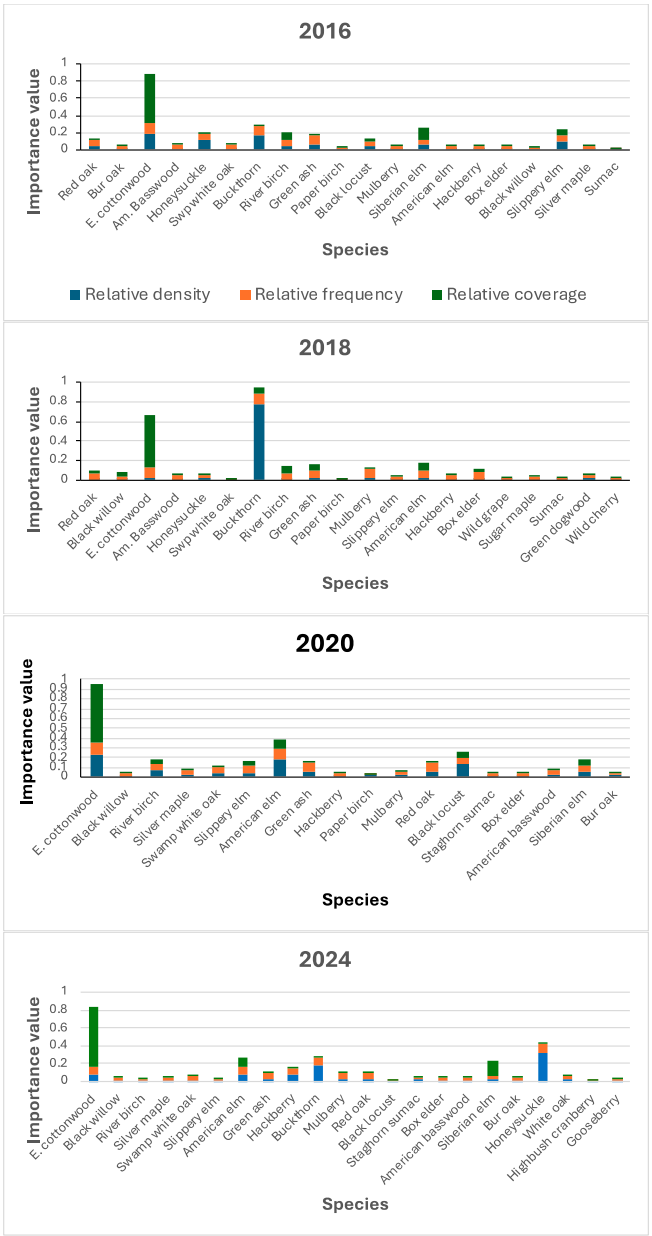

Figure 3. Relative importance values (sum of relative density, relative frequency, and relative coverage) of trees and shrubs along the southern shoreline of the eastern basin of Lake Winona. Data from 2016 and 2018 were collected prior to woody invasive removal in different shoreline sections. Data from 2020 and 2024 were collected after woody invasive management was initiated.

4. Management Actions

4.1. Removal and Chemical Treatment of Woody Invasive Shrubs/Trees

Rehabilitation of Lake Winona's northern and southern shorelines on the eastern basin began in 2017 with a series of efforts aimed at cutting Siberian elm, buckthorn, and honeysuckle along the shoreline, with activities in different areas variously conducted in partnership between the City of Winona and Winona County, the Winona County Soil and Water Conservation District (SWCD), students from two local universities (St. Mary's University of Minnesota, Winona State University), a local landscape restoration company, and Healthy Lake Winona, a citizen group focused on improving the Lake Winona environment (http://healthylakewinona.weebly.com, accessed on 18 December 2024).

Woody invasive removal efforts along the eastern basin's northern shore were conducted in March 2017 in six shoreline sections (10–15; Figure 2) previously designated as research areas, i.e., shorelines where various methodologies would first be tested prior to use elsewhere around the lake. These sections consisted of both wooded and turfgrass areas, with Siberian elm, buckthorn, and honeysuckle present along the shore in both habitats. After cutting, cut stump herbicide treatments were used to prevent regrowth.

Along the southern shore of the eastern basin, buckthorn and other woody invasives were first cut and treated in August 2017. Large buckthorns along one section were cut by a youth crew from the Conservation Corps of Minnesota and Iowa. Stumps were treated to prevent regrowth, and the cut brush was transported by City of Winona staff to another portion of the lake, where it was used in another shoreline project (see Section 4.5 below). More extensive buckthorn removal and treatment efforts by adult crews of the Conservation Corps of Minnesota and Iowa occurred along most of the southern shore (nearly 2 km) from July 2019 to January 2020, and again in August 2020. The removal focused on both the lake and wetland sides of the paved pathway, primarily to remove large berry-and-seed producing buckthorn. The retreatment of the southern shoreline and initial removal around the southeastern bay (sections 30–33) took place in June and September/October 2021 and September/October 2022, working section by section to target new plants germinating from the seedbank plus any stump resprouts. This removal and treatment process will continue along the southern shoreline until the buckthorn seedbank becomes depleted (Figure 1).

Management activities on the western basin took place in November 2018 and January 2019. Woody invasives (primarily buckthorn) were removed and stumps chemically treated along sections of the northern and southern/southeastern shorelines. As with the eastern basin, continued cutting and treatment will be needed until the buckthorn seedbank depletes.

4.2. Spraying, Pulling, Digging, and Burning of Non-Native Invasive Grasses and Forbs

In May 2014, 2015, and 2017, volunteers representing Healthy Lake Winona and several classes of Winona Middle School students and their teachers removed invasive non-native leafy spurge from several shoreline sites along Lake Winona. Plants were pulled by hand to reduce impacts to native shoreline plants, and all plants were bagged and disposed of offsite.

Beginning in 2017 and continuing annually (except in 2024 when no plants were observed), invasive yellow iris plants were removed from five to six areas along the northern shoreline of the eastern basin, spearheaded by the Winona County SWCD. Management efforts consisted of hand digging with shovels to remove all tubers, bagging, and subsequent disposal offsite.

A targeted removal of Japanese hops (*Humulus japonica*) has occurred annually from 2018 to the present in section 2W along the western basin's northern shore and sections 29 and 30 along the eastern end of the eastern basin (Figure 2). Plants were pulled by hand to limit impact to native plants and bagged for off-site disposal.

Beginning in March 2024, invasive silvergrass in patches along the northern (9 m^2) and southern (316 m^2) shorelines of the western basin were chemically treated with broad-spectrum herbicide. The northern patch was 95% eradicated, with future chemical treatment to follow. The larger southern patch suffered <10% kill, so will require more intensive treatment efforts.

4.3. Killing Turfgrass and Overseeding with Native Prairie Species

During early July 2017, two sections of turfgrass (approximately 0.1 ha total area) within the "research area" along the eastern basin's northern shoreline (Figure 2, sections 12–15; Figure 4) were killed via two glyphosate herbicide applications. Based on soil characteristics, different sections were then overseeded during early November 2017 with five different, site-specific seed mixes (prairie mix, sand prairie mix, wet meadow mix, understory mix, and riprap mix; Figure 4). Plots were surrounded by temporary fencing to exclude waterfowl and to delineate areas from adjacent mowed turfgrass.

Figure 4. Replacement of sections of shoreline turfgrass with native prairie plantings, northern shoreline of eastern basin of Lake Winona. (**Top panel**): Turfgrass section of shoreline. (**Middle panel**): Prescribed burn of native prairie planting after third growing season. (**Bottom panel**): Native prairie planting after several growing seasons.

During May 2021, established prairie plants were transplanted from a prairie planting on the campus of Saint Mary's University of Minnesota (slated for removal to make way for a construction project) into the "research area" prairies. Transplanted species included prairie dropseed (*Sporobolus heterolepis*), golden alexander (*Zizia aurea*), nodding onion (*Allium cernuum***)**, Pennsylvania sedge (*Carex pennsylvanica*), hairy mountain mint

(*Pycnanthemum pilosum*), wild bergamot (*Monarda fistulosa*), columbine (*Aquilegia canadensis*), and rattlesnake master (*Eryngium yuccifolium*).

4.4. Shrub/Sapling Plantings and Overseeding

After the buckthorn removal along the east basin's southern shoreline (Figure 1), several efforts were directed at planting native shrubs, tree saplings, and native woodland seeds (forbs and grasses). Shrubs and trees were planted during the spring of 2020 and 2021, including the American elm, eastern cottonwood, river birch, and peachleaf willow (*Salix amygdaloides*). Additional plantings of these species occurred along the eastern bays (sections 20–31; Figure 2) of the eastern basin during spring 2022. Over 1900 seedlings and 100 trees 1.2 m or taller have been planted along shorelines of the eastern basin.

Trees and shrubs also were planted in 2019, 2021, and 2022 along the western and southeastern shores of the western basin. Most plantings were of eastern cottonwood to replace aging and dying trees of that species, plus ironwood (*Ostrya virginiana*) and buttonbush (*Cephalanthus occidentalis*).

The overseeding of the southern shoreline (eastern basin) took place during spring 2020. A wet woodland seed mix containing 48 species of native forbs (e.g., Virginia waterleaf [*Hydrophyllum virginianum*], purple prairie clover [*Dalea purpurea*], early sunflower [*Heliopsis helianthoides*], sweet cicely [*Osmorhiza claytonii*], golden alexanders [*Zizia aurea*]), grasses (e.g., side-oats grama [*Bouteloua curtipendula*], bottlebrush grass [*Elymus hystrix*], Virginia wild rye [*Elymus virginicus*], little bluestem [*Schyzachyrium scoparium*]), and sedges (e.g., bristly cattail sedge [*Carex frankii*], common bur sedge [*Carex grayi*], narrow-leaved oval sedge [*Carex tenera*]) was spread along the wooded shoreline between the lake and the paved pathway, covering approximately 0.8 hectares.

4.5. Wave Barrier Installation and Planting Emergent Macrophytes

The large buckthorn and honeysuckle cut from the southern lake shoreline was used to create wave barriers in 2017 for installation along a portion of the northern shoreline where wave action was causing severe erosion of the sandy shore. Quantities of the cut woody invasives were wrapped in mesh coir fabric to create brush bundles (approximately 0.75 m in diameter, 4.5 m long) onshore adjacent to the shorelines. Bundles were secured with jute rope, rolled into the water and placed 3 to 4 m from the shore, and anchored to the lake bottom with 1.5 m-long wooden stakes. Barriers extended from the lake bottom to approximately 30 cm above lake level. A total of 16 barrier units (10 in one group, six in another) were placed end-to-end parallel to the shoreline, with end barriers angled toward shore to protect two areas of eroding shoreline, separated by about 15 m (Figure 5). Wave barriers were intended for only short-term use (approximately 2 years), allowing time for the planted macrophytes to become established and for shorelines to stabilize.

After wave barriers were in place, a variety of native emergent aquatic macrophytes (396 plants total) purchased from a regional supplier were planted along the shorelines within the two protected areas (Figure 5). Species planted included woolgrass (*Scirpus cyperinus*), river bulrush (*Scirpus fluviatilis*), softstem (*Scirpus validus*), sweet flag (*Acornus calamus*), blue flag iris (*Iris versicolor*), bur-reed (*Sparganium eurycarpum*), and arrowhead (*Sagittaria latifolia*). In addition, arrowhead plants growing on nearby city-owned property under development were "rescued" and planted along the shoreline within the barrier-protected areas. Finally, seeds gathered from local populations of floating-leaf American lotus (*Nelumbo lutea*) were collected and dried before being physically scarified with a hand-held rotary cutting tool. Some scarified seeds were allowed to germinate before planting in lake sediments within and outside of wave barriers, whereas others were planted without first being germinated. Numerous lotus beds have now become established, most notably along the northern shoreline of the eastern basin (Figure 6), where wave action had been causing significant bank erosion. With several beds now extending out into water as deep as 3 m, wave action against adjacent shorelines is now virtually non-existent once plants reach the lake surface each growing season.

Figure 5. Brush bundle wave barriers (buckthorn wrapped in coir fabric) in place along the northern shore of the eastern basin of Lake Winona, anchored in place with wooden stakes (stakes were shortened later). Volunteers are shown planting emergent aquatic macrophytes to stabilize the shoreline.

Figure 6. Bed of American lotus (*Nelumbo lutea*) established along the northern shore of Lake Winona's eastern basin.

With wave barriers installed, wave action against the shoreline ceased and sand began accumulating along many areas along and outside of the wave barriers, especially the ends of each protected area, where new shoreline was added. This new shoreline and other accumulated sediments became stabilized by the planted emergent macrophytes and other natural vegetative cover that self-established.

4.6. Prescribed Burns

As the native prairie plantings that replaced turfgrass became established along the northern shore, prescribed burns were conducted to enhance growth and to inhibit establishment of unwanted invasive saplings and forbs. The first burn was conducted in March 2021 after the third growing season post-seeding, utilizing volunteers from the Minnesota Driftless Chapter of The Prairie Enthusiasts (Figure 4). As anticipated, the plantings responded by growing vigorously that spring and summer. A second burn was conducted three years later in March 2024. This burn purposefully only targeted half of the prairie area to retain refugia for invertebrates and small animals. Because these burns took place in an urban park setting, public notices were needed to alert residents and other park users of the burn activities.

4.7. Photo Reference Points

A series of fixed photographic reference points (20 in total) were established during May 2024 along the lake's eastern basin shorelines to aid in documenting shoreline conditions both in areas where work was being conducted and in areas where no management actions have been taken. In general, these reference points coincided with locations where stormwater culverts enter the lake. Reference points for the western basin shoreline will be established during spring 2025, similarly using stormwater culverts as fixed locations.

4.8. Altered Mowing Practices

Historically, the City of Winona managed the lakeshore as an extension of the turfgrass parklands surrounding it along the northern and eastern shorelines of the eastern basin. This meant the shorelands were mowed to the edge of the water, or as close as possible, to maintain a "manicured" esthetic. An undesirable effect of this practice was shoreline erosion as turfgrasses have limited roots to hold sediment in place. Once erosion began, the sandy nature of the subsoil led to continued erosion. Beginning in 2015, the Healthy Lake Winona group coordinated with the City to amend their practices and retain at least a 0.5 to 1.0 m buffer of native vegetation around the lakeshore. The buffer in many areas is now 2 to 3 m. This proved to be helpful in areas where erosion was limited, but inadequate to stabilize highly eroding areas. The City of Winona still mows the buffer areas annually with a brush mower arm attachment to control woody vegetation and allay some residents' concerns of losing lake views.

5. Future Management

A few Lake Winona projects need to begin soon pending funding availability, whereas others will require continued effort. New projects include the following:

- Riprap reductions or removal. Extensive shoreline reaches need to have riprap removed and banks protected with alternative measures to make the banks more esthetically pleasing and ecologically functional [16,20].
- Protection/stabilization of eroding banks. Several bank failures need immediate attention to stop ongoing erosion and shoreline losses. We may attempt to protect some shorelines by planting fresh-cut willow (*Salix* spp.) stakes harvested from other areas of shoreline where they are abundant. Willow stakes can root quickly to stabilize eroding banks [20,21].
- Removal of large Siberian elm and black locust trees along the southern shoreline of the eastern basin. Continuing seed production by these mature trees needs to be stopped. Additionally, felling these large trees into the lake will create long-lasting submerged wood for fish habitat and basking areas for turtles.
- Rehabilitation of the western basin's forested southeastern shoreline (section 4W; Figure 2). Extensive recent die-offs of ash trees (*Fraxinus pennsylvanica*) due to emerald ash borer (*Agrilus planipennis*) infestation have left this area filled with dead trees, and long-term runoff of eroding soils from nearby blufflands through this section have created an unstable, muddy delta extending into the lake. Soil inputs have diminished with the

construction of multiple interceptor basins within the blufflands, but the previously eroded soils still remain at the lakeshore.

Work will continue on several fronts along the shorelines of both basins on projects already underway. Most notable among these are the following:

- Continuing cutting and chemical treatment of shoreline woody invasives. The seedbank for common buckthorn, honeysuckle, Siberian elm, and black locust appears to be robust, requiring a multi-year effort to remove young invasives as they appear. We anticipated that we could cut and treat specific shoreline sections on a 2- or 3-year rotation, but that has not always been realized. Consequently, some buckthorns have been able to mature and produce berries/seeds before being re-treated. More regular, scheduled re-treatment will be necessary to make significant inroads toward eliminating the invasive seedbank.
- Replacing turfgrass with native plantings. Wherever possible, little-used mowed turfgrass areas will be targeted for transition to native grasses and forbs that will require much less maintenance. Additional areas along the southeastern part of the eastern basin are slated for turfgrass conversion in 2025–2026.
- Pulling invasive forbs, treating/burning invasive grasses. Efforts will be directed annually at eliminating patches of invasive forbs and grasses as they appear. Whenever possible, hand-pulling will be used to cause the least disturbance to shoreland soils and native plant communities. Chemical treatment and burning will be utilized only when patches are too large for hand-pulling to be an efficient procedure.
- Wave barrier creation and installation, emergent macrophyte planting. Several additional sections of lakeshore could benefit from wave barrier protection and emergent macrophyte establishment. Although highly effective, wave barriers created from bundles of wrapped buckthorn were labor intensive to produce and install. Alternative barrier forms may be considered for future sites needing temporary protection while emergent macrophytes become established.

6. Lessons Learned and Synthesis

Shoreline rehabilitation activities around Lake Winona benefited from previous lakeshore restoration work within the Minnesota and Wisconsin regions [3,5,10–17]. The methods and procedures we used have proven successful numerous times previously, so we were able to avoid much of the time and expense of trial-and-error experimentation that can hamper similar rehabilitation projects [15,16]. Although most of the projects described above were undertaken and accomplished by citizen volunteers, our projects benefited from the skills and knowledge of the Conservation Corps of MN and IA, local and regional natural resource agency personnel, and a local professional landscape restoration specialist.

Woody invasives such as buckthorn and honeysuckle have proven extremely difficult to manage, due to their high densities and reproductive potential. Management of these invasives within the Winona area has required continued effort and a variety of management strategies [22]. For example, the initial removal of large buckthorn was straightforward and efficient, but the subsequent management of the young plants germinating and growing from the seedbank has been much more difficult. Densities of these younger plants are many times greater than for the older plants, requiring chemical treatment of many more and much smaller cut stems (and increasing the possibility of failing to treat some), slowing the process considerably and requiring more volunteer hours to cut and treat the same area. Going forward, the continued management of woody invasives along the eastern basin's southern shore will be a time-consuming but necessary task every year for the foreseeable future.

The brush bundle wave barriers (also referred to previously as brush mattresses [20]) created from large buckthorn and honeysuckle proved very effective in eliminating wave action against shorelines with newly planted emergent macrophytes. Brush bundles also accumulated sand being carried along shore by wave action, helping to build a new shoreline for most of their 2-year lifespan. These types of wave barriers would prove useful when placed along several other sections of Lake Winona's shoreline, especially in the

more windswept eastern basin. However, much of the large buckthorn and honeysuckle have already been removed from the lakeshore, leaving only smaller regrowth stems and saplings that would be less useful in wave barrier construction. Cutting large buckthorn from other areas and transporting it to the lake for bundling or creating the brush bundles at the site of cutting and transporting finished bundles to the lake are possibilities, as buckthorn is plentiful at other locations within the city. However, both approaches come with added transportation needs and costs. Other wave barrier designs (e.g., V-shaped wave breaks constructed from fabric silt barriers and PVC pipe) [15] may be simpler to install, more cost effective, and require less labor.

Relying heavily on volunteer labor to perform much of the shoreline rehabilitation has proven effective with this project. Hundreds of volunteers have contributed their time and effort to accomplish much of the work for the shoreline rehabilitation to date. Initial enthusiasm and participation for this project were very good, with community members, school groups, and other local organizations and businesses willing to contribute labor to accomplish specific goals. Previous projects involving Lake Winona also relied heavily on volunteer labor to accomplish many different tasks [18]. Now at the 10-year mark in this effort, volunteers are becoming scarcer and even the citizen group Healthy Lake Winona, with its primary focus directed toward improving the lake environs, has had reduced participation during recent projects. This is not surprising, as maintaining momentum and enthusiasm among volunteers for any project can be difficult over many years [18]. Greater volunteer recruitment likely will be required, retaining as many previous volunteers as possible while bringing in new people to keep volunteer hours at a level appropriate to continue the rehabilitation efforts.

Overall, we are pleased with the success of the many efforts undertaken to reclaim Lake Winona's shorelines during the past 10 years. We have changed many areas for the better and received compliments from many in the community who have noticed the changes. Although the lakeshore reclamation process for a lake of this size is a significant undertaking, working on small segments and projects has allowed us to make improvements and produce positive results repeatedly. We hope to continue our success to date in obtaining small local and regional grants to fund our efforts. With the continued support of our many volunteers, we look forward to the next decade of improvements to Lake Winona's shorelines.

7. Conclusions

Rehabilitation efforts along Lake Winona's shorelines have been largely successful, although much work remains as invasive species continue to reappear, more turfgrass needs to be converted to native vegetation to reduce mowing needs in under-utilized park land, and additional shoreline sections need to be protected from continued erosion. Funding and volunteer involvement will be key to achieving these future goals.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on reasonable request.

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