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Use of short-rotation coppice willow crops by birds and small mammals in central New York

Steven P. Campbell [a,*], Jacqueline L. Frair [a], James P. Gibbs [a], Timothy A. Volk [b]

[a] Department of Environmental and Forest Biology, SUNY College of Environmental Science and Forestry, Syracuse, NY 13210, USA
[b] Department of Forest and Natural Resources Management, SUNY College of Environmental Science and Forestry, Syracuse, NY 13210, USA

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ABSTRACT

As the use of short-rotation coppice willow crops increases, this vegetation type will comprise a greater extent of the landscape, yet its attendant effects on biodiversity remain poorly understood. In this study we characterized the avian and small mammal communities of willow crops that were established for phytoremediation and biomass production in industrial settling basins and compared these communities to those of surrounding areas of naturally-established perennial herbaceous-woody vegetation. Overall, we observed 33 bird species and five small mammal species in five focal sites (i.e., areas consisting of willow crops and adjacent vegetation) and 20 bird species and four small mammal species in two reference sites (i.e., areas of the settling basins without willow crops). For birds and small mammals, focal sites supported slightly greater average species richness and average abundances of all species combined than reference sites. Within focal sites, willow crops supported fewer species and similar combined abundances compared to adjacent areas. Importantly, community and individual species responses varied with the duration of time since coppicing. More small mammal species and individuals used willow crops in the year following coppicing because of their herbaceous undergrowth, while more birds tended to use older willow crops. Collectively, these results indicate that willow crops located within areas of perennial herbaceous-woody vegetation provide some benefits to bird and small mammal populations and that promoting a herbaceous layer in willow crops and maintaining multiple age classes of willows in the landscape simultaneously are likely to enhance the value of willow crops for biodiversity.

1. Introduction

Short-rotation woody crops are increasingly being used to address a range of environmental problems. They provide a carbon-neutral source of biomass for energy production [1–3]; convert wastes (e.g., wood ash and municipal waste water and sludge) into woody biomass [4,5]; are utilized for phytoremediation to remove heavy metals from soil, break down organic compounds, or contain contaminated soils via evapotranspirative reduction in the volume of leachate [4,6–9]; control soil and wind erosion; and act as living snow fences and riparian buffers [1,10]. In northern temperate areas, woody crop production has focused on willows (*Salix* spp.) [2,11]. The basic characteristic of willow production involves genetically improved plant material that is grown on open or fallow agricultural land and cultivated under a short-rotation coppice system [10]. Under this system sites are intensively prepared to control weeds and willows are planted

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* *Corresponding author*. Albany Pine Bush Preserve Commission, 195 New Karner Road, Suite 1, Albany, NY 12205, USA. Tel.: +1 518 456 0655; fax: +1 518 456 8198.
E-mail address: scampbell@albanypinebush.org (S.P. Campbell).

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in double rows as unrooted cuttings at a density of about 15,000 ha^{-1}, coppiced after the first growing season to initiate re-sprouting of multiple stems from the remaining stools, and then harvested by coppicing every 3–4 years [2,12,13]. During each rotation, the vegetation structure of the willow crops changes rapidly; within their first growing season after coppicing they change from an essentially open field to an open-canopy shrub community and by their third year they form a closed-canopy, forest-like stand with stems approaching 10-m in height.

Given that vegetation structure is an important determinant of animal distribution [e.g., [14–18]], the rapidly changing vegetation structure of willow crops as well as its novelty and increasing extent in the landscape will likely have important consequences for the structure of animal communities at local and landscape scales. Nevertheless, few studies have examined the ecological effects of this newly emerging and dynamic land-use. Of the studies that have been conducted, most have examined birds. For example, in farmland landscapes in the UK and Sweden, a diverse suite of bird species used willow crops, but only a few species showed strong preference for this vegetation type [19–24]. Further, willow crops were found to increase the abundance and diversity of birds in an area when they replaced other arable crops or improved grasslands, but not when they replaced scrub or broad-leaved vegetation types, semi-natural grasslands, or wetlands [20,22,24]. Likewise, Dhondt et al. [25,26], observed that bird species richness, nesting density, and reproductive success in willow crops in central New York State were similar to other early-successional vegetation types in the region (e.g., farmland, abandoned fields, clear cuts, and shrublands). The few studies that have investigated other taxa found that willow crops support a diverse insect community [23,27,28], provide browse for large herbivores [29], but are poor habitat for most small mammals species unless a herbaceous layer is allowed to develop [21,28,30].

The potential for willow crops to affect biodiversity suggests that their establishment in the landscape for utilitarian purposes such as biomass production could also accommodate management goals associated with biodiversity conservation. Integrating these land management goals will require knowing which species are using willow crops, how the vegetation structure of willow crops affects these species, and how the species assemblages using these systems compare to those in the vegetation types that are being replaced. To this end, we characterized the vegetation structure and avian and small mammal communities of different-aged willow crops and compared them to those of the surrounding vegetation types. Our study focused on willow crops that were planted for the dual purpose of evapotranspiration cover and biomass production on settling basins formerly used by an industrial soda ash production operation. We expected that willow crops would increase or have a negligible effect on avian and small mammal biodiversity compared to the perennial herbaceous-woody-plant communities that dominates the settling basins and that older willow crops would have greater structural complexity and thus provide greater niche differentiation and higher biodiversity.

2. Methods

2.1. Study site

The Solvay settling basins encompass about 240 ha adjacent to Onondaga Lake in the town of Camillus in Syracuse, NY (43.072 N, 76.255 W; Appendix A). From 1881 to 1986, these areas were used as the primary disposal site for the waste by-products (calcium chloride and other salts) of the production of soda ash (sodium carbonate). Following the termination of their use, successional processes have converted much of the settling basins into perennial herbaceous-woody-plant communities [31] in which *Populus deltoides* was the dominant tree and shrub. Between 2004 and 2008, five areas of the settling basins ranging in size from 0.4 to 1.8 ha were planted with fast-growing shrub willows to assess the effectiveness of this system as an evapotranspiration cap that reduces or eliminates the leaching of salts into the lake and to determine the growth rate of different willow varieties for biomass production (Table 1, Appendix A). The soils in these areas were amended with biosolids and crops were established using 25-cm long cuttings of willow from 10 clonal varieties. Plants were arranged in a double-row configuration at

Table 1 – Distribution of sampling effort among five focal sites (FS) and two reference sites (RS) in the Solvay settling basins, Syracuse, NY, 2009. Sampling within focal sites was divided among willow crops (W), adjacent control areas (C), and intervening edges (E). Reference sites were composed entirely of control areas.

Site	Last Coppiced	Age of Willows	Area (ha)		Number of vegetation plots		Number of small mammal traps				Mist net hours			
			W	C	W	C	W	E	C	Total	W	E	C	Total
FS1	2006	3	0.43	0.61	3	3	29	20	51	100	58.65	58.65	58.65	175.95
FS2	2007	2	0.44	0.46	3	3	20	25	55	100	41.17	41.17	40.33	122.67
FS3	2006	3	0.65	0.59	3	3	32	18	50	100	33.33	42.33	35.33	110.99
FS4	2009	1	1.33	1.45	3	3	31	12	57	100	36.42	36.42	36.42	109.26
FS5	2009	1	1.79	2.66	3	3	25	10	65	100	47.55	47.55	47.55	142.65
RS1	–	–	–	1.48	–	3	–	–	100	100	–	–	141.58	141.58
RS2	–	–	–	3.13	–	3	–	–	100	100	–	–	105.45	105.45

planting densities of 15,300 ha^{-1} and the different varieties were grouped into blocks [11]. Willows were planted before June, coppiced below 10 cm in height during their first winter, and allowed to grow for up to 4 years. We report the age of willows as the time since last coppicing (e.g., the first growing season following coppicing was year 1 and successive growing seasons were numbered consecutively). For this study, we used two 1-year, one 2-year, and two 3-year old willow crops (Table 1).

Each willow crop along with an adjacent control area of naturally-established vegetation and an intervening edge comprised a focal site (Appendix B). We examined the effects of willow crops on bird and small mammals by comparing the communities among the three areas within focal sites. Because the willow crops may have had an effect on animal communities in the adjacent control areas, we also compared the bird and small mammal communities of the five focal sites to two more distant reference sites. These sites were 400–500 m from the nearest willow crop and had vegetation representative of the perennial herbaceous-woody-plant communities that had established naturally in the settling basins (Appendix A).

2.2. *Vegetation structure*

We characterized the vegetation structure of each site in early October 2009 using 6 m × 6 m plots. At each focal site, three plots were randomly located in the willow crop and three in the adjacent control area (Appendix B). Three vegetation plots were also randomly located within each reference site. Within each plot, we recorded the species, frequency, diameter at breast height (dbh), and height of all trees (dbh $\geq$ 5.08 cm), from which we derived basal area, average height, and standard deviation of height (a measure of vertical structural diversity) of trees for each plot. The density of shrubs (woody stems with a dbh $<$ 5.08 cm) was estimated using two 1.7-m wide transects spanning each plot. We visually estimated overstory percent canopy cover and percent ground cover at 13 points located systematically throughout each plot. In the willow crops, we also measured the height of the willows at each of these 13 locations. Finally, we quantified vertical vegetation structure as the percent coverage of plants in six strata: $<$0.25 m, 0.25–1 m, 1–3 m, 3–5 m, 5–10 m, and $>$10 m, with percent coverage in each stratum classified as: 0%, 1–5%, 5–25%, 25–50%, 50–75%, and 75–100%.

2.3. *Bird and small mammal communities*

We used nine 9-m long mist nets (i.e., low-visibility mesh nets hung between two poles [32]) to capture birds at each focal site: three nets in the willow crop, three in the control area, and three within 1 m of the crop's outer edge (Appendix B). Nine nets were also deployed at each reference site. Weather permitting, mist nets were opened between 05:00 and 13:00 for three days at each site from 18 May and 20 July 2009. When a bird was captured we recorded species, sex, and age and affixed them with uniquely-numbered aluminum bands from the USGS Bird Banding Laboratory.

We sampled the small mammal community twice daily (dawn and dusk) for three consecutive days at each of the seven sites between 27 July and 8 September 2009 using 100 Sherman live traps (8 × 9 × 23 cm) arranged at 10 m intervals in a 10 × 10 grid. At focal sites the grid was positioned such that there were approximately 40 traps in the willow crop, 50 in the control area, and 10 within 5 m of the crop's edge (Table 1, Appendix B). Traps were baited with rolled oats and peanut butter [33]. We identified each captured animal to species, except for the White-footed Mouse (*Peromyscus leucopus*) and Deer Mouse (*Peromyscus maniculatus*), which we grouped together as *Peromyscus* spp. All individuals were marked with uniquely-numbered ear tags, except for the Short-tailed Shrew (*Blarina brevicauda*) which lacks an external ear.

2.4. *Data analysis*

Sampling effort for birds ranged from 33 to 59 net hours (number of nets × number of hours) per area within focal sites and from 105 to 175 net hours per focal and reference site (Table 1). To adjust for differences in effort, we standardized bird abundance to the number of unique individuals caught per 100 net hours and we limited species richness to birds captured within the minimum number of net hours for a given comparison (i.e., 33 net hours for comparisons among areas within focal sites and 100 total net hours for comparisons between focal and reference sites). Similarly, the number of traps deployed within the willow, edge, and control areas varied by site (Table 1), so we expressed relative abundance as the number of unique individuals captures per 100 traps. We did not adjust mammal species richness because there were so few species. For both richness and abundance metrics we excluded juvenile birds because of differences in the timing of sampling among sites (i.e., some sites were sampled pre-fledging and some post-fledging). In general, this exclusion made little difference for richness because juveniles of a species rarely occurred at sites where adults were not also present. We did not exclude juvenile small mammals from these metrics because reproduction was occurring at all of the sites at the time of sampling.

We compared species richness and abundance of birds and mammals between the focal and reference sites using the Wilcoxon-Mann-Whitney U statistic, and among the willow, adjacent control, and edge areas using Kruskal–Wallis tests. Pair-wise associations among richness and abundance of all species combined, age of the willow crop, and vegetation structure variables were evaluated using Pearson's correlation coefficients.

3. Results

3.1. *Vegetation structure*

At the start of the study in May 2009, the 1-year old willow crops (i.e., willows at FS4 and FS5; Table 2) had just been coppiced and were beginning to regrow so they were nearly devoid of vegetation. By October 2009, these willows averaged 2.6–3.2 m in height, but did not attain canopy closure. During this time, weedy herbaceous vegetation was pulled and the spaces between willow rows were mowed in late June and early July to minimize competition with the willows. Despite

Table 2 – Vegetation characteristics of focal sites (FS) and reference sites (RS) in the Solvay settling basins, Syracuse, NY, 2009. In each focal site, vegetation is described for willow crops (W) and adjacent control areas (C), while reference sites are comprised entirely of control areas. Values in the table represent the average (standard deviation) for each variable measured within three 6 m × 6 m plots.

Site	Tree density (ha^{-1})		Tree basal area (m^2 ha^{-1})		Mean tree height (m)		Std. Dev. tree height (m)		Shrub stem density (ha^{-1})		Canopy cover (%)		Herbaceous ground cover (%)		Mean willow height (m)	
	W	C	W	C	W	C	W	C	W	C	W	C	W	C	W	C
FS1	–[a]	1111.11 (277.78)	–	17.77 (14.24)	–	10.05 (1.88)	–	1.58 (1.11)	62222.22 (7742.98)	4259.26 (1785.86)	81.92 (3.85)	27.44 (13.46)	2.22 (1.92)	92.59 (11.88)	8.11 (0.63)	–
FS2	–	1666.67 (277.78)	–	43.34 (31.03)	–	14.88 (5.21)	–	5.22 (0.67)	64074.07 (19325.70)	277.78 (0.00)	72.82 (30.48)	36.92 (8.66)	5.19 (6.58)	100.00 (0.00)	5.38 (0.89)	–
FS3	–	462.96 (424.31)	–	8.46 (8.17)	–	10.82 (4.13)	–	6.66 (8.51)	63240.74 (9591.72)	462.96 (578.24)	79.62 (9.71)	16.67 (16.18)	0.00 (0.00)	99.07 (1.60)	6.72 (0.84)	–
FS4	–	2685.19 (2009.49)	–	17.57 (8.78)	–	10.17 (1.00)	–	1.78 (1.34)	17962.96 (3941.44)	2222.22 (1944.44)	1.79 (1.60)	51.92 (10.83)	80.74 (11.47)	80.19 (11.79)	2.58 (0.44)	–
FS5	–	925.93 (578.24)	–	8.15 (6.24)	–	7.38 (0.81)	–	2.62 (0.36)	31759.26 (28115.08)	4074.07 (5459.82)	12.18 (14.14)	16.15 (11.56)	34.07 (34.23)	84.63 (26.62)	3.20 (0.51)	–
RS1	–	1018.52 (801.88)	–	18.88 (15.31)	–	11.27 (5.47)	–	2.84 (1.90)	–	1018.52 (578.24)	–	35.77 (31.77)	–	72.31 (45.55)	–	–
RS2	–	648.15 (1122.63)	–	8.09 (.)[b]	–	9.99 (.)	–	2.85 (.)	–	277.78 (481.13)	–	14.87 (25.76)	–	77.56 (38.86)	–	–

a – indicates that a vegetation structure (e.g., trees) or plots did not exist at that site.
b (.) indicates that trees only existed at one of three plots.

these efforts herbaceous vegetation covered 34–81% of the ground (Table 2).

In the 2 and 3-year old willow crops (i.e., willows at FS1-FS3), willow stem densities were 2–3.6 times greater than in 1-year old crops (see shrub stem density in Table 2). The willows averaged 5.4–8.1 m in height and formed a dense canopy. However, there were some patches in which certain willow varieties failed to persist or attain canopy closure; within these patches dense stands of burdock (*Arctium* sp.) and other weedy species became dominant.

When the willow crops were examined collectively, the vegetation structure of the crops reflected the age of the willows (Fig. 1). Willow height, shrub stem density, and canopy cover were positively associated with age ($r \geq 0.93$, $P < 0.01$; Table 3), whereas ground cover tended to decline with age ($r = -0.86$, $P = 0.06$). Most of the structural changes in the vegetation occurred in the first two years of growth, as the majority of the foliar biomass shifted from the ground to the willow canopy (Fig. 1). Between the second and third growth years, the willows grew 1–3 m taller but the gross vegetation

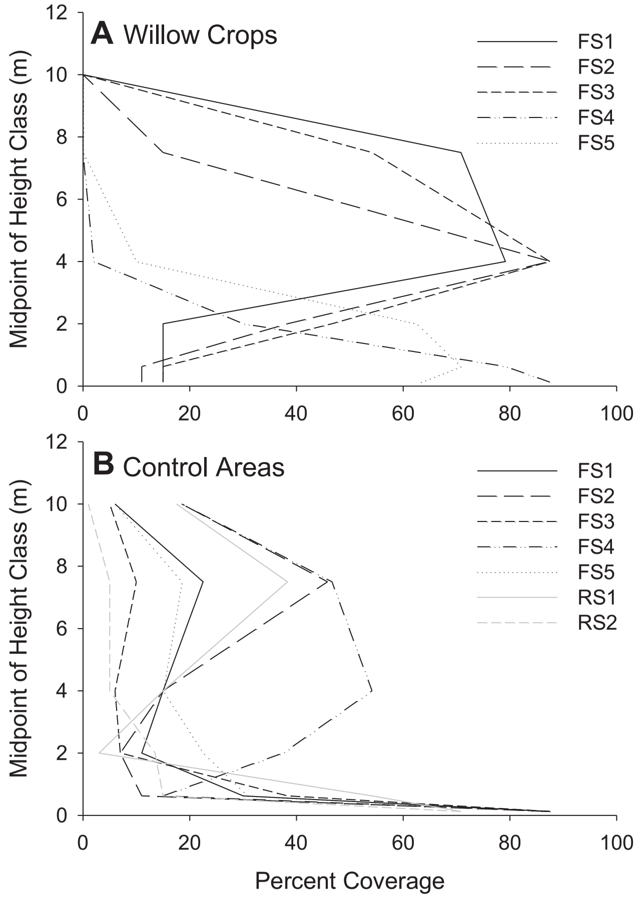

Fig. 1 – Average percent cover of different vegetation strata in the willow crop (A) of each of the focal sites (FS1–FS5) and of the control areas (B) adjacent to the willow crops (FS1–FS5) and in the more distant reference sites (RS1 and RS2) at the Solvay settling basins, Syracuse, NY, 2009. Strata are < 0.25 m, 0.25–1 m, 1–3 m, 3–5 m, 5–10 m, and > 10 m.

Table 3 – Pearson's pair-wise correlation coefficients among the site, vegetation structure, and animal community metrics for willow crops in the Solvay settling basins, Syracuse, NY, 2009. Statistical significance is indicated as * where $P < 0.10$ and ** where $P < 0.05$.

	Area	Average willow height	Shrub stem density	Canopy cover	Ground cover	Bird richness	Bird abundance	Mammal richness	Mammal abundance
Age of willow crops	−0.93**	0.97**	0.93**	0.98**	−0.86*	−0.15	0.55	−0.67	−0.80
Area		−0.88**	−0.93**	−0.96**	0.80	−0.20	−0.59	0.76	0.78
Average willow height			0.89**	0.94**	−0.85*	−0.27	0.34	−0.48	−0.69
Shrub stem density				0.98**	−0.96**	0.03	0.65	−0.66	−0.92**
Canopy cover					−0.92**	−0.01	0.61	−0.69	−0.87*
Ground cover						0.14	−0.55	0.46	0.92**
Bird richness							0.37	−0.47	−0.06
Bird abundance								−0.89**	−0.84*
Mammal richness									0.70

structure of the crops, i.e., open understory with a dense canopy, remained the same.

In contrast to the willow crops, the adjacent control areas and the reference sites included largely open meadows (15–52% canopy closure) with a dense grassy ground cover (72–100% ground cover) and low densities of small trees (density: 463–2685 ha^{-1}; basal area: 8–43 m^2 ha^{-1}) and shrubs (278–4259 stems ha^{-1}) (Fig. 1, Table 2).

3.2. *Bird communities*

Across all seven sites there were 605 captures that represented 36 species and at least 404 adult individuals. The most abundant species overall were the American Goldfinch (*Spinus tristis*) and Song Sparrow (*Melospiza melodia*), accounting for 25% and 12% of all individuals captured, respectively (Table 4). Most species were rare (<5 individuals), with 21 species representing only 11% of all individuals captured. In the five focal sites, we captured 33 bird species, 16 of which were not captured in the reference sites. By comparison, we captured 20 species in the two reference sites, of which only three species were found exclusively in these sites (Table 4). Notably, six species (Killdeer [*Charadrius vociferus*], Spotted Sandpiper [*Actitis macularia*], American Kestrel [*Falco sparverius*], Swainson's Thrush [*Catharus ustulatus*], Northern Waterthrush [*Parkesia noveboracensis*], and Wilson's Warbler [*Cardellina pusilla*]) were found exclusively in the willows at the focal sites, which translates to a 20% increase in avian species richness (from 30 to 36) due to the presence of the willows. Nevertheless, these species were represented by single captures. Despite these differences in aggregate species richness, the number of species at individual focal and reference sites were not different (focal: $\bar{x} = 16.4 \pm 3.2$ SD, reference: $\bar{x} = 14.0 \pm 1.4$ SD, $P = 0.43$; Fig. 2A). Average abundance of all bird species combined, however, was twice as high in focal sites compared to reference sites, but variation among focal sites was high ($P = 0.33$; Fig. 2B; Table 4). Of the 17 species in common to focal sites and reference sites, 14 tended to be more abundant in the focal sites, but the difference was only notable for the Song Sparrow and American Robin (*Turdus migratorius*) (Table 4).

Within the focal sites, control and edge areas supported more species (control: $\bar{x} = 10.4 \pm 4.4$ SD, edge: $\bar{x} = 8.6 \pm 0.9$ SD; $P = 0.044$) than the willow crops ($\bar{x} = 6.4 \pm 1.5$ SD), but the total numbers of individuals of all bird species combined were not different among areas ($P = 0.179$; Table 4). When species were examined individually, the Willow Flycatcher (*Empidonax traillii*) was more abundant in the willows, the Field Sparrow (*Spizella pusilla*) and Eastern Bluebird (*Sialia sialis*) were more abundant in the adjacent control areas, and the Song Sparrow was more abundant in the edges (Table 4). There was also a tendency for the Baltimore Oriole (*Icterus galbula*) and Brown-headed Cowbird (*Molothrus ater*) to be more abundant in control and edge areas and for the Yellow Warbler (*Setophaga petechia*) to be more abundant in the willow crops and edge areas.

Within the willow crops, bird species richness and total bird abundance was unrelated to the age and the structural characteristics of the willow crops (Table 3). We did, however, observe twice as many total birds in 2–3 year-old willow crops ($\bar{x} = 30.3 \pm 13.0$ SD) compared to 1-year old crops ($\bar{x} = 15.6 \pm 1.2$ SD) (Table 5; Fig. 2B). Of the few species commonly captured in willow crops, the Red-winged Blackbird (*Agelaius phoeniceus*) was observed only in 1–2 year-old willows while the Gray Catbird (*Dumetella carolinensis*) and Downy Woodpecker (*Picoides pubescens*) were observed only in 2–3 year-old willows (Table 5). The Willow Flycatcher, Yellow Warbler, and American Goldfinch were the only species to occur in willow crops of all ages; the Song Sparrow occurred in 1-year old and 3-year old crops and so probably also occurred in intermediate-aged crops.

At focal sites where we captured juveniles, 83% were captured in the edges and willows compared to 63% of adult birds in these same areas (Fig. 3). Song Sparrow and American Robin were the most common juvenile birds in our sample, representing 79% and 8% of all juvenile birds captured ($n = 182$). Over half of the juvenile American Robins were captured in the willows compared to only 9% of adults; a similar pattern existed for the Song Sparrow (Fig. 3).

3.3. *Small mammal communities*

In total, there were 612 captures of small mammals represented by at least 414 individuals from five species: Long-tailed Weasel (*Mustela frenata*), Meadow Jumping Mouse (*Zapus hudsonius*), Meadow Vole (*Microtus pennsylvanicus*), *Peromyscus* spp., and Short-tailed Shrew. Meadow voles comprised the majority of the individuals (56%) followed by

Table 4 – Species composition and mean abundance (with standard deviation) of birds at two reference sites and five focal sites in the Solvay settling basins, Syracuse, NY, 2009. Within focal sites, abundances are divided by willow crops, edges, and adjacent control areas. All abundances are standardized to individuals per 100 net hours. Statistical significance is indicated by * where $P < 0.10$ and ** where $P < 0.05$ according to Wilcoxon Mann–Whitney U tests for comparisons between reference and focal sites and Kruskal–Wallis tests for comparisons among areas within focal sites. Also shown is the percent of individuals based on the total number of adult birds captured at all seven sites.

Bird species[a]	% of all individuals ($n = 404$)	Between site comparisons		Within focal site comparisons		
		Reference sites ($n = 2$)	Focal sites ($n = 5$)	Control	Edge	Willow
Species observed only in focal sites						
Killdeer (*Charadrius vociferus*)	Tr[b]	–	Tr	–	–	Tr
Black-capped Chickadee (*Poecile atricapillus*)	Tr	–	Tr	Tr	Tr	–
Spotted Sandpiper (*Actitis macularia*)	0.3	–	0.4 (0.9)	–	–	0.4 (0.9)
American Kestrel (*Falco sparverius*)	0.3	–	0.5 (1.2)	–	–	0.5 (1.2)
Swainson's Thrush (*Catharus ustulatus*)	0.3	–	0.5 (1.1)	–	–	0.5 (1.1)
Northern Waterthrush (*Parkesia noveboracensis*)	0.3	–	0.5 (1.1)	–	–	0.5 (1.1)
Wilson's Warbler (*Cardellina pusilla*)	0.3	–	0.5 (1.1)	–	–	0.5 (1.1)
Yellow-billed Cuckoo (*Coccyzus americanus*)	0.3	–	0.4 (0.9)	0.4 (0.9)	–	–
Red-bellied woodpecker (*Melanerpes carolinus*)	0.3	–	0.4 (0.9)	0.4 (0.9)	–	–
Brown Thrasher (*Toxostoma rufum*)	0.5	–	0.8 (1.1)	0.3 (0.8)	0.5 (1.1)	–
Common Grackle (*Quiscalus quiscula*)	0.5	–	1.1 (2.5)	0.5 (1.2)	0.5 (1.2)	–
Cedar Waxwing (*Bombycilla cedrorum*)	0.7	–	1.2 (1.7)	0.5 (1.2)	0.7 (1.5)	–
Eastern Kingbird (*Tyrannus tyrannus*)	0.7	–	1.3 (2.8)	0.4 (0.9)	0.8 (1.9)	–
Northern Cardinal (*Cardinalis cardinalis*)	0.7	–	1.4 (1.3)	0.4 (0.9)	–	0.9 (1.4)
Eastern Bluebird (*Sialia sialis*)	1.0	–	1.7 (1.8)	1.7 (1.8)**	Tr	Tr
Warbling Vireo (*Vireo gilvus*)	1.5	–	2.9 (3.2)	1.0 (1.4)	1.9 (3.2)	–
Species observed only in reference sites						
Blue Jay (*Cyanocitta cristata*)	0.3	0.4 (0.5)	–	–	–	–
Eastern Meadowlark (*Sturnella magna*)	0.3	0.5 (0.7)	–	–	–	–
Wood Thrush (*Hylocichla mustelina*)	0.5	0.7 (1.0)	–	–	–	–
Species observed in reference and focal sites						
Tree Swallow (*Tachycineta bicolor*)	0.3	Tr	0.4 (0.9)	0.4 (0.9)	–	–
Hairy Woodpecker (*Picoides villosus*)	0.5	0.4 (0.5)	0.4 (0.9)	0.4 (0.9)	–	–
House Wren (*Troglodytes aedon*)	0.7	0.4 (0.5)	0.8 (1.1)	0.8 (1.1)	Tr	–
Willow Flycatcher (*Empidonax traillii*)	1.0	0.4 (0.5)	1.4 (1.3)	–	–	1.4 (1.3)**
Indigo Bunting (*Passerina cyanea*)	1.2	0.7 (1.0)	1.5 (2.2)	Tr	1.0 (2.2)	0.5 (1.2)
Downy Woodpecker (*Picoides pubescens*)	2.2	1.7 (0.3)	2.3 (1.8)	0.4 (0.9)	0.8 (1.2)	1.1 (1.5)
Least Flycatcher (*Empidonax minimus*)	2.5	1.3 (0.8)	2.9 (2.6)	2.2 (2.3)	0.7 (1.5)	–
Unknown Flycatcher[c]	2.7	2.6 (1.7)	2.2 (1.8)	0.4 (0.9)	0.8 (1.1)	1.0 (2.2)
Common Yellowthroat (*Geothylpis trichas*)	3.0	2.4 (0.7)	2.9 (3.2)	0.5 (1.2)	2.4 (2.9)	–
Baltimore Oriole (*Icterus galbula*)	3.0	0.7 (1.0)	4.3 (4.0)	1.4 (1.3)*	2.9 (2.7)*	–
American Robin (*Turdus migratorius*)	4.0	0.5 (0.7)*	6.6 (4.0)*	3.2 (2.7)	2.7 (3.5)	0.6 (1.3)
Field Sparrow (*Spizella pusilla*)	5.5	2.8 (4.0)	7.2 (7.4)	6.6 (7.9)**	0.5 (1.2)**	–
Gray Catbird (*Dumetella carolinensis*)	6.9	2.2 (1.8)	10.2 (8.3)	1.3 (1.9)	2.7 (3.2)	6.2 (6.3)
Brown-headed Cowbird (*Molothrus ater*)	6.9	2.6 (2.3)	9.6 (8.4)	4.9 (4.3)*	4.8 (5.9)*	Tr
Red-winged Blackbird (*Agelaius phoeniceus*)	7.4	8.8 (10.4)	4.7 (5.8)	2.8 (4.6)	0.8 (1.0)	1.0 (1.4)
Yellow Warbler (*Setophaga petechia*)	7.7	7.8 (5.1)	6.3 (5.2)	–	4.2 (4.0)*	2.1 (2.9)*
Song Sparrow (*Melospiza melodia*)	11.6	7.3 (0.4)*	12.7 (2.72)*	3.0 (2.1)**	8.0 (3.2)**	1.7 (1.6)**
American Goldfinch (*Spinus tristis*)	24.5	9.0 (7.3)	35.3 (28.4)	11.2 (9.2)	18.6 (18.6)	5.5 (5.4)
Total	100	52.9 (1.1)	125.4 (58.9)	45.4 (28.8)	55.6 (31.7)	24.4 (12.2)

[a] Species are ordered by their relative frequency in the overall sample.

[b] Trace presence (only juveniles were captured or abundance could not be ascertained because individuals were captured but not banded).

[c] Unknown Flycatchers are either Least or Willow Flycatchers; they are not included in species richness measures.

Peromyscus spp. (25%), Short-tailed Shrews (10%), Meadow Jumping Mice (8%), and Long-tailed Weasels (1%). All species occurred in both types of sites except for the Long-tailed Weasel, which occurred only in the focal sites (Table 6). Consequently, species richness of each type of site was nearly equal (focal: $\overline{x} = 3.8 \pm 0.7$ SD, reference: $\overline{x} = 3.5 \pm 0.8$ SD; $P = 0.83$; Fig. 4A). In contrast, the abundance of all small mammal species combined was 2.5 times higher at the focal sites than in the reference sites ($P = 0.08$; Table 6), with the focal sites with the youngest willow crops contributing most to this difference (Fig. 4B).

Across all focal sites, control and edge areas supported a slightly higher number of species ($\overline{x} = 3.4 \pm 0.9$ SD and $\overline{x} = 2.2 \pm 0.8$ SD, respectively) than willow crops ($\overline{x} = 1.8 \pm 0.8$ SD; $P = 0.05$). However, at focal sites with younger willow crops, the numbers of species captured in the three areas were nearly equal (Fig. 4A). Similarly, the combined abundance of mammal species was on average 1.3 and 1.8 times higher in

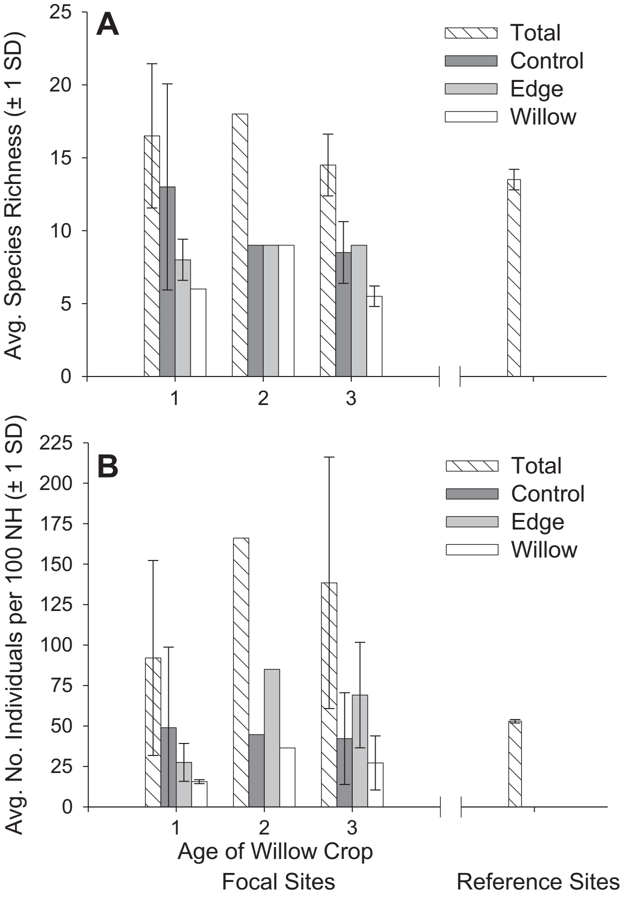

Fig. 2 – Mean bird species richness (A) and relative abundance (B) in focal sites containing variably-aged willow crops and reference sites at the Solvay settling basins, Syracuse, NY, 2009. Within focal sites, richness and abundance are divided into willow crops, adjacent control areas, and edges. Abundances are standardized to individuals per 100 net-hours (NH) and species richness measures are based on birds captured within the number of net-hours from the area with the lowest capture effort (see Section 2.4 Data Analysis).

the edges than in the willows and control areas, respectively ($P = 0.08$; Table 6), but in sites with younger willows the average abundance in the edges and willows were equal and more than twice that of the control areas (Fig. 4B). For individual species, *Peromyscus* spp. was 1.7 and 5 times more abundant in the edges than in the willows and control areas, respectively ($P = 0.01$), while the Short-tailed Shrew was 3.1 times more abundant in the control area than the edges and was absent from the willows ($P = 0.05$; Table 6).

Within the willow crops, both species richness and overall abundance of small mammals tended to decline with the age of the willows (Table 3). Small mammal abundance was positively correlated with herbaceous ground cover ($r = 0.92$, $P = 0.03$) and negatively related to shrub density ($r = -0.92$, $P = 0.03$) and overstory canopy closure ($r = -0.87$, $P = 0.06$; Table 3). Meadow voles and *Peromyscus* spp. were the two most common species and they showed contrasting patterns with respect to the age of the willows. Specifically, Meadow Voles were captured exclusively in 1-year old willows ($\bar{x} = 79.2 \pm 15.8$ SD), whereas *Peromyscus* spp. were three times more abundant in 2- and 3-year old willows ($\bar{x} = 35.7 \pm 17.4$ SD) compared to 1-year old willows ($\bar{x} = 11.7 \pm 10.9$ SD).

Table 5 – Occurrence and average abundance (with standard deviation) of bird species captured in willow crops of different ages in the Solvay settling basins, Syracuse, NY, 2009. Abundances are standardized to individuals per 100 net hours.

Bird species[a]	Age of willow crop		
	1 ($n = 2$)	2 ($n = 1$)	3 ($n = 2$)
Killdeer	Tr[b]	–	–
Eastern Bluebird	Tr	–	–
Brown-headed Cowbird	Tr	–	–
Spotted Sandpiper	1.1 (1.5)	–	–
American Kestrel	1.4 (1.9)	–	–
Indigo Bunting	1.4 (1.9)	–	–
Red-winged Blackbird	1.4 (1.9)	2.4	–
Swainson's Thrush	–	2.4	–
Northern Waterthrush	–	2.4	–
Wilson's Warbler	–	2.4	–
Northern Cardinal	–	–	2.4 (0.9)
Downy Woodpecker	–	2.4	1.5 (2.1)
Gray Catbird	–	7.3	11.8 (4.6)
American Robin	Tr	–	1.5 (2.1)
Song Sparrow	2.4 (0.5)	–	1.7 (2.4)
Willow Flycatcher	1.1 (1.5)	4.9	2.4 (0.9)
Yellow Warbler	2.7 (3.9)	4.9	Tr
American Goldfinch	4.2 (5.9)	7.3	6.0 (8.5)
Total	15.6 (1.2)	36.4	27.2 (16.7)

a Species are ordered by their occurrence and relative abundance across the willow age classes.

b Trace presence (only juveniles were captured or abundance could not be ascertained because individuals were captured but not banded).

4. Discussion

4.1. Birds

Bird community composition of willow crops is influenced by at least three factors. First, the vegetation structure of the willows is important because more bird species have been shown to be associated with taller (i.e., older) willow plants, higher planting density, and increased weediness of the understory [19,20,22,26]. In our study, however, we found no relationship of avian species richness with the age or height of the willows (Table 3), possibly because one year-old crops were more structurally diverse than 2-3 year-old crops. One-year old willow crops did not attain canopy closure, but they had two strata: a dense herbaceous ground cover and a shrub layer composed of willow stems exceeding 4 m in height (FS4 and FS5 in Fig. 1A). In contrast, the vegetation biomass of older crops occurred primarily in a single canopy layer (FS1-FS3 in Fig. 1A).

A second factor influencing bird community composition is the size of the area planted with willow. Dhondt et al. [26] found that larger areas of crops (>3 ha) supported more

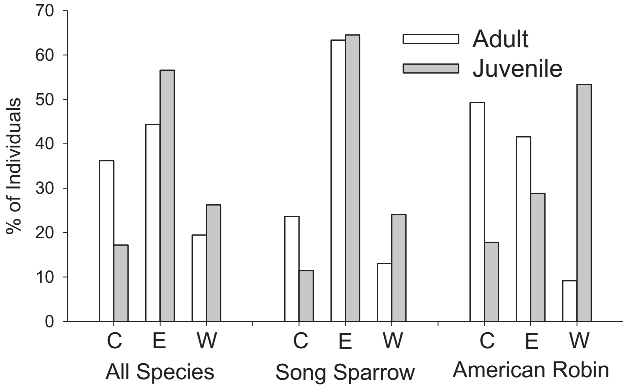

Fig. 3 – Percentage of adult and juvenile birds of all bird species and of the Song Sparrow and American Robin that were captured in willow crops (W), adjacent control areas (C), and edges (E) of the focal sites at the Solvay settling basins, Syracuse, NY, 2009.

species than smaller (<3 ha) areas for all but the youngest crops and attracted more species as the willows aged than smaller areas of crops. However, Sage et al. [24] found more birds within 50 m of the boundaries of 2–3 year-old willow crops than in the interiors (>50 m from edge), suggesting that small areas of willows support a greater density of birds because of their higher edge to interior ratios. Similarly, Sage and Robertson [20] suggest that large areas of willows will have a limited benefit for birds nesting in adjacent habitat, because they are unlikely to access more than the edges of the willow crops. In our study, species richness per willow crop (5-9 species) was within the range observed by Dhondt et al. [26] for small (<3 ha) areas of willows, but we found no relationship between species richness and crop area. This lack of relationship may be because of the relatively small range of areas, small sample size, or the strong, but spurious, negative relationship between age and area of the willow crop (Table 3). We also found more birds in the edges of the crops than in the interiors, especially in the 2-3 year-old crops where the edges are more distinct from the surrounding vegetation (Fig. 2B).

A third factor is the position of the willow crop in the landscape. At larger spatial scales, the inclusion of willow crops in landscapes dominated by arable crops or fallow lands will attract bird species not otherwise found in the landscape, but the replacement of natural grasslands or forests with willow crops will likely lead to a loss of bird diversity [20,22,24]. At more local scales, adjacent habitats can strongly influence the bird community composition in willow crops and may even be more important than the structure of the willows themselves [22]. In our study, the willow crops occurred within a matrix of perennial herbaceous-woody vegetation that had naturally-established after use of the settling basins was terminated and the suite of bird species using the willow crops was largely a subset of the bird species occurring within this surrounding vegetation type (Table 4). Although there were six bird species that were unique to the willow crops, they were each represented by a single observation (i.e., they were either rare or transient), suggesting that no bird species were simultaneously abundant and exclusive in their use of the willow crops.

Among bird species found in the willow crops, the extent of their use of the willows remains poorly understood. Sage and Tucker [28] found that only two of 22 species always incorporated willow crops in their territories, three species were never recorded in the willows and the remaining species occasionally included willow crops in their territories. In our study, the high degree of movement between the willow crops and the surrounding areas (unpublished data) clearly indicates that birds are using the willows to some extent, but suggests that they likely need two or more habitats to meet their requirements [34]. The need for other habitats is probably a combination of the willow crops on our sites being too small to accommodate the entire territory of some species and the inability of the willows to provide the full suite of habitat requirements (e.g., nesting, foraging, and cover from predators) for all species.

The purposes for which birds are using the willows are also poorly known. Willows may represent good foraging habitat for many insectivorous bird species, because willows support more insect species than most other tree species [35] and willow crops, in particular, have been found to support insects

Table 6 – Species composition and mean abundance (with standard deviation) of small mammals captured at the two reference sites and five focal sites in the Solvay settling basins, Syracuse, NY, 2009. Within focal sites, abundances are divided by willow crops, edges, and adjacent control areas. All abundances are standardized to individuals per 100 traps. Statistical significance is indicated by * when $P < 0.10$ and ** when $P < 0.05$ based on Wilcoxon Mann–Whitney U tests for comparisons between reference and focal sites and Kruskal–Wallis tests for comparisons among areas within focal sites. Also shown is the percent of individuals based on the total number of small mammals captured at all seven sites.

Mammal species	% of individuals ($n = 414$)	Between site comparisons		Within focal site comparisons		
		Reference sites ($n = 2$)	Focal sites ($n = 5$)	Control	Edge	Willow
Long-tailed Weasel (*Mustela frenata*)	0.7	–	1.9 (1.9)	0.4 (0.9)	–	1.5 (2.0)
Meadow Jumping Mouse (*Zapus hudsonius*)	7.7	0.5 (0.7)	17.0 (34.9)	6.6 (11.8)	10.4 (23.3)	–
Short-tailed Shrew (*Blarina brevicauda*)	10.1	12.0 (14.1)	7.8 (5.7)	5.9 (4.6)**	1.9 (2.67)**	–
White-footed Mouse and Deer Mouse (*Peromyscus* spp.)	25.2	3.5 (2.1)*	79.0 (39.2)*	8.8 (5.9)**	44.1 (20.0)**	26.1 (18.8)**
Meadow Vole (*Microtus pennsylvanicus*)	56.3	57.0 (55.2)	76.5 (81.3)	21.3 (14.0)	23.4 (31.3)	31.7 (44.1)
Total	100.0	73.0 (38.2)*	182.2 (51.7)*	43.1 (16.7)*	79.9 (14.1)*	59.2 (35.6)*

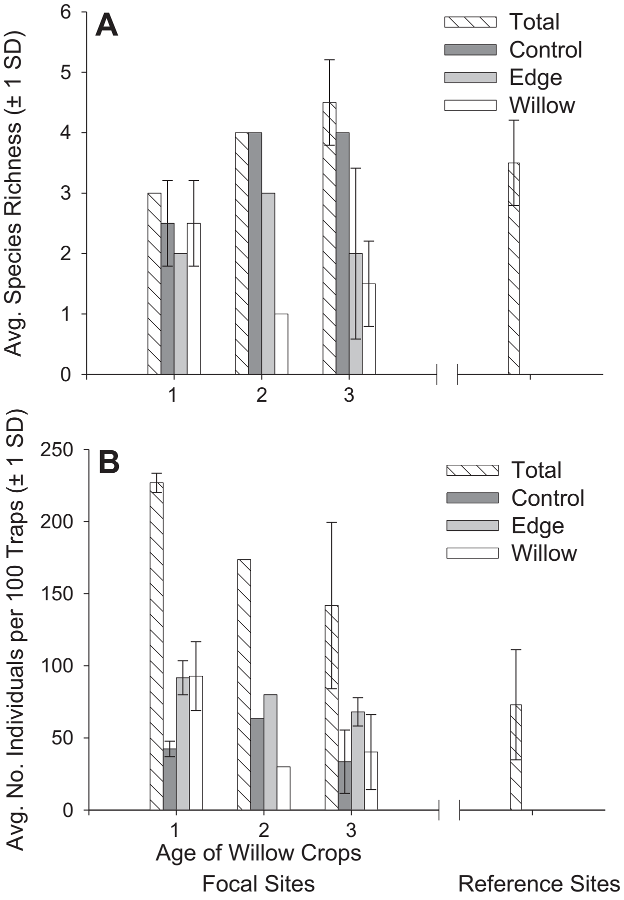

Fig. 4 – Mean small mammal species richness (A) and relative abundance (B) in focal sites containing variably-aged willow crops and reference sites at the Solvay settling basins, Syracuse, NY, 2009. Within focal sites, richness and abundance are divided into willow crops, adjacent control, and edge areas. Abundances are standardized to individuals per 100 traps but species richness measures are not adjusted for differences in trapping effort (see Section 2.4 Data Analysis).

from 38 groups [27]. Willow crops have been shown to provide nesting habitat for 27 bird species in New York [26]. Birds may also be using the willows as resting areas and cover from predators, because of their greater structural density compared to surrounding vegetation. For example, the greater abundance of juveniles of some species in the willows than adults (Fig. 3) suggests that juveniles may move into areas of dense vegetation in late summer because they afford better cover from predators [36].

4.2. *Small mammals*

The abundance and richness of small mammals were highest where there was abundant understory vegetation. For example, at sites with older willows, fewer species and individuals were captured in the willows than in the adjacent control and edge areas (Fig. 4), likely because of the lack of ground cover under the canopy of the older willow crops (Fig. 1) and the low amounts of internal heterogeneity in the willows relative to the edge and control areas. In contrast, the numbers of small mammal species captured in the youngest willow crops, the adjacent controls, and the intervening edge were nearly equal (Fig. 4A), likely because the vegetation structure was more similar between the willow crops and their surrounding controls (e.g., both contained thick ground cover and a low shrub layer; Fig. 1). Additionally, the abundance of all small mammal species combined was higher in the young willow crops and their edges than in all the other areas sampled (Fig. 4B), further suggesting that the young willows appeared to provide the best habitat for small mammals in general.

Only the White-footed Mouse and Deer Mouse occurred in all age classes of willows (Table 6). Both of these species are well-documented habitat generalists as demonstrated by their high degree of plasticity in habitat selection in this and other studies [37–40]. These species also inhabited the adjacent control areas, but they were less abundant than in the willows possibly because of competition with old-field species such as the Meadow Vole [41,42]. The Long-Tailed Weasel is also a habitat generalist that is primarily limited by prey availability [43]. It was captured in a control area and a 1-year-old and 3-year-old willow crop (Table 6). Its lack of capture in other sites was likely a result of its rarity and the short interval for which we sampled each site.

The other members of the small mammal communities tended to be more stenotopic in their habitat use (Table 6). The Meadow Vole was found in the control areas of the focal sites, the reference sites, and in only the youngest willow crops, all of which had a dense herbaceous layer. The Meadow Jumping Mouse is an old-field species that was found in the reference sites and only the control and edge areas of the focal sites. Short-tailed Shrews were also absent from willow crops. The absence of these species from the willow crops may have resulted from the lack of ground cover, leaf litter, and coarse woody debris, which trap moisture and increase local humidity for small mammals, and the lack of tree and shrub diversity which influences food availability [38,40,44–46].

The few other studies to examine small mammals in willow crops have found similar patterns. Bodnor [30] found that willow crops in England provided inappropriate food and cover for small mammals unless the crops were allowed to become weedy. Small mammal use of willow crops included wood mouse (*Apodemus sylvaticus*), common shrew (*Sorex araneus*) and field vole (*Microtus agrestis*), but only the generalist wood mouse was common in large weed-free crops. Coates and Say [21] also found the willow crops to be poorer habitat than hedgerow and scrub land. However, in contrast to our results they found older willow crops to be most attractive to small mammals.

4.3. *Management recommendations*

Biodiversity conservation is typically only one of many environmental considerations when developing and managing willow crops and it is always of secondary importance to the utilitarian value of the willows. Nevertheless, actions can be taken that can improve the biodiversity of these systems without compromising the higher priority considerations for which the willows were established.

First and foremost, we recommend establishing willow crops in landscapes in which they are a structurally distinct vegetation type because the willows will be more likely to attract a suite of species that is distinct from the surrounding habitat (i.e., biodiversity will be enhanced). For example, willow crops will likely have their greatest benefit for biodiversity when they replace or are located among arable lands and pastures [22]. However, willow crops are unlikely to enhance biodiversity if they are replacing scrub-shrub or forest habitats ([20,24], this study). Similarly, we also suggest establishing willow crops next to different habitat types (e.g., some next to forests and others next to fields), because adjacent habitats can strongly influence community composition in the willow crops [22]. These types of juxtapositions are especially important for taxa with low vagility such as small mammals and amphibians, but less so for more mobile taxa such as birds. Despite these recommendations, the decision of where to establish willows at both local and regional scales will likely be constrained by practical considerations. For example, the local placement of the willow crops in this study was dictated by the locations of the phytoremediation sites within the Solvay settling basins. Similarly, at regional scales willow crops must remain within 90 km of a power plant to remain profitable and maximize net energy ratios [47,48].

Many structural features of the willow crops themselves are relevant for biodiversity and can be managed for accordingly. Most notably, the age of the willow crops can act as a surrogate for many of the structural features of the vegetation; it affects willow height, canopy cover, and ground cover (Table 3), all of which determine the structural complexity of a willow crop and its contrast with the surrounding vegetation types. Because different-aged willow crops support communities of plants and animals that range from open-habitat species to woodland species, biodiversity is likely to benefit most if willows are managed so that multiple age classes are present in the landscape simultaneously. The weedy herbaceous layer is another particularly important vegetation component for biodiversity. Most current management practices aggressively control weeds during the establishment phase of the willow crop, even though the economic threshold for weed populations is likely high enough to increase plant diversity without compromising the primary function of the willows [49]. While further studies are needed to determine this threshold, we suggest that willow crops be actively managed to maintain some amount of herbaceous layer or that at a minimum the presence of other plants in the understory of willows be tolerated. Biodiversity in the willows can also be enhanced by planting and managing a diverse mixture of herbaceous plants in the headlands and pathways that immediately surround and allow access to the willow crops.

Finally, the variety of willows and planting density can be managed to enhance biodiversity. Mixtures of willows can enhance structural and functional diversity and reduce the impact of pests and diseases [50,51]. Nesting habitat can be improved by including varieties of willow in which birds preferentially nest [25] and greater planting density can have a positive effect on bird populations [20]. While current recommendations call for planting 4–6 different varieties of willow in blocks across the landscape, work conducted in Northern Ireland suggest that intimate mixtures of willow may also be effective [50,51]. Furthermore, opportunities exist to adjust initial planting densities, because the productive function of willows can be maintained across a fairly broad range of planting densities. In fact, matching planting density with crown architecture can help attain the production potential of the crop [10]. Further work is needed to examine how the interaction between planting density and willow variety affects biodiversity.

5. Conclusions

The addition of shrub willow crops to the perennial herbaceous-woody vegetation of the Solvay settling basins did not have overwhelmingly positive or negative effects on the area's bird and small mammal communities. The combination of willows and adjacent areas of perennial herbaceous-woody vegetation tended to support slightly more bird and small mammal species and greater abundances of all species combined than other areas of the settling basins without willow crops. Nevertheless, the willow crops *per se* supported fewer species and similar combined abundances compared to adjacent areas. Thus, the willow crops are not necessarily enhancing biodiversity at the settling basins by attracting species that would not otherwise occur in the landscape, but they may augment local populations of some species by increasing the complexity of the area's vegetation.

As willow crops are increasingly used for purposes such as phytoremediation and biomass production, this vegetation type will comprise a greater extent of the landscape and consequently have a greater potential to influence biodiversity. Thus, it will become progressively more important for willow crop management to explicitly include biodiversity conservation as an objective. While this and other studies have identified age and structure of the willow crop, surrounding vegetation types, presence of a herbaceous layer, and planting mixtures and densities as factors that influence biodiversity in willow crops, only general management recommendations can be made with regard to these factors (e.g., maintaining multiple age class in the landscape simultaneously, and promoting a herbaceous layer within the willow crop). A more mechanistic understanding of how these factors influence biodiversity will be necessary to develop effective management strategies. In particular, further study is needed to elucidate how changes in these factors not only affect biodiversity but also the primary functions of the willows, as these two goals will not always be mutually compatible. A better understanding of these types of relationships will help managers to integrate biodiversity conservation into willow crop management without detracting from the purposes for which the willows were planted.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.biombioe.2012.09.026.

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