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RESEARCH ARTICLE

Impacts of colonial waterbirds on vegetation and potential restoration of island habitats

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Colonial waterbirds have impacted forested island ecosystems throughout their breeding range, changing vegetation, and soil characteristics and bird communities. Our objectives were to (1) determine effects of three levels of colonial waterbird exclusion on overall vegetation diversity and growth, and survival of a candidate restoration species (black elderberry; *Sambucus nigra canadensis*); (2) investigate effects of different planting techniques on survival and growth of black elderberry; and (3) determine effects of waterbird colonization on soil chemistry. In 2012, we investigated effects of three levels of waterbird exclusion (none control plots [CON]; partial, which excluded waterbirds larger than gulls [PEX]; and full which excluded all waterbirds [FEX]) on bird use, existing vegetation growth and diversity, and survival of planted black elderberry on three islands in Door County, WI, Lake Michigan. In 2013, we evaluated survival of black elderberry established with four planting treatments within three waterbird exclusion treatments on two islands in 2013. We also compared soil chemistry characteristics between islands with and without nesting waterbirds for 2 years. Overall plant growth was greater in exclosures, but elderberry survival was similar among treatments. Soil replacement and weed suppression planting treatments did not affect survival, but generally increased overall elderberry biomass. Soil from nesting islands was more acidic and had greater nutrient concentrations than reference islands. Exclusion or removal of colonial nesting waterbirds from islands may improve overall vegetation growth, but successful restoration of woody vegetation may require significant soil manipulation and planting.

Key words: double-crested cormorant, Great Lakes, *Phalacrocorax auritus*, soil, woody plants

Implications for Practice

- Exclusion of waterbirds increases non-woody plant growth but may not allow regeneration of woody vegetation if viable propagules of woody plants are not present in the soil or if soil conditions do not allow germination.
- If planting of woody vegetation is necessary for restoration, exclusion, or removal of colonial nesting waterbirds from islands and planting larger plants can improve plant survival.
- Soil with low pH or an altered nutrient chemistry from colonial waterbird nesting may need to be augmented for restoration of some plant species.

Introduction

The increase in the Great Lakes population of double-crested Cormorants (*Phalacrocorax auritus*; cormorants) in recent decades (Hatch & Weseloh 1999) has been associated with damage to forested island habitats (Taylor & Dorr 2003; Dorr & Somers 2012). The Great Lakes islands provide important habitats for a variety of nesting birds; some of which are species of special concern (WIDNR 2014). Cormorants, which nest in trees or on the ground, are known to cause damage to forest vegetation because of guano deposition and physical destruction to vegetation, resulting in abandonment of habitats by co-nesting species that require woody vegetation for nesting (Hebert et al. 2005; Boutin et al. 2011). Cormorant destruction of woody vegetation allows open areas to develop, which then attracts obligate ground nesting colonial waterbirds such as gulls (*Larus* spp.) and American White Pelicans (*Pelecanus erythrorhynchos*; pelicans), consequently altering bird and plant communities (Weseloh & Ewins 1994; Quinn et al. 1996; Koh et al. 2012). Gulls and pelicans subsequently nesting in these open areas can add to and perpetuate soil damage and

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suppression of woody vegetation growth by further guano deposition and soil chemistry changes and physical damage of vegetation (Weseloh & Ewins 1994; Quinn et al. 1996; Hebert et al. 2005). Damage to vegetation, alteration of bird communities, and other issues with natural resources occur throughout the Double-Crested Cormorant's breeding range and have led to extensive management of cormorants particularly in the Great Lakes region of North America (Dorr & Somers 2012).

The first objective of this study was to determine vegetation response, and survival of a native woody perennial (*Sambucus nigra canadensis*; hereafter black elderberry) under three levels of disturbance by colonial nesting waterbirds: ambient (control), reduced (partial bird exclusion), and low (full bird exclusion). We selected elderberry as a restoration candidate species because it is native to the area, has a small tree growth form used by many co-nesting species impacted by cormorants (e.g. Black-crowned Night Herons [*Nycticorax nycticorax*]), and produces forage and cover for many wildlife species (Weidinger 2008). Elderberry is also persistent on some test islands (e.g. Jack Island) and may be more tolerant of soil conditions associated with nesting waterbirds than other woody plant species. We predicted that exclusion of waterbirds would promote diversity and biomass of plants at the end of a nesting season and increase survival of black elderberry because of reduction in physical damage and reduced inputs of guano to soil by nesting and loafing birds. The second objective was to evaluate four black elderberry planting treatments within exclusion treatments to determine effects of a weed barrier and soil replacement on restoration plant survival. We predicted that disturbance by ground nesting waterbirds would negatively impact restoration (growth and survival) and that weed barriers and soil replacement will improve plant survival. The third objective was to compare soils from islands with and without annual colonial waterbird nesting colonies. We predicted that soils on islands without colonial waterbirds would contain less N, P, and metals, and have higher pH because of less accumulation of guano. Phosphorous can become toxic in high concentrations and levels above 330 ppm require remediation to support future growth of many plant species (Provin & Pitt 2002). Understanding effects of ground nesting waterbirds on vegetation, soil chemistry, plant survival, and possible mitigation measures will inform predictions of plant community response to vegetation restoration efforts.

Methods

Site Characteristics

We conducted this study on five islands in Green Bay and Lake Michigan in Door County, Wisconsin (Figure 1). Cormorants nested on islands in this area in the 1940s and 1950s and possibly earlier, declined sharply by the early 1960s, then after over a decade of absence, cormorant nests in Green Bay increased from fewer than 10 in 1974 to 17,945 in 2009 (Anderson & Hamerstrom 1967; Matteson et al. 1999; Jones & Lovell 2009). Jack and Hat Islands are privately owned and located on the bay-side of the peninsula. Cormorants have nested continuously on both islands since the early 1980s (Matteson et al. 1999). Jack and Hat Islands have supported up to 3,730 (2006) and 3,324 (2007) breeding pairs, but by 2013 breeding pairs and nests were reduced to 416 and 764, respectively (Table 1). The land areas of Jack and Hat Islands are 3.12 and 2.84 ha, respectively, and cormorant nesting areas in 2013 were 0.045 and 0.184 ha, respectively. Breeding cormorant densities on Jack and Hat Islands were 267 and 538 birds/ha, respectively. Spider Island, part of the United States Fish and Wildlife Service (USFWS) Gravel Island National Wildlife Refuge, is a 9.2 ha island located on the east side of the peninsula and is not managed to restrict breeding bird numbers. Cormorants began renesting there in the late 1970s (Matteson et al. 1999) and in 2013 there were 2,135 nests recorded with an island-wide breeding-cormorant density of 464 birds/ha (Table 1). All islands have large numbers of co-nesting gulls and Hat Island also has co-nesting pelicans (Table 1). All three of these islands once supported mature woody vegetation (i.e. shrubs and trees), which has died in correlation with increases in cormorant nesting numbers over the past few decades (Judziewicz 2001). Cormorants nest only on the ground of all these islands. We used Adventure and Plum Islands as controls for comparing soil samples (Fig. 1) because these two islands have the same soil series as the bird-colony islands (USDA-NRCS 2011), support healthy communities of woody vegetation, and have no record of nesting colonial waterbirds. There are no significant mammal populations that use these islands to our knowledge.

2012 Exclosure Experiment

We used a random block design to examine effects of nesting colonial waterbirds on all vegetation island-wide using three levels of exclusion as the treatment factor. We designed full exclusion (FEX) to prevent any access by waterbirds (i.e. cormorants, pelicans, gulls, Canada Geese [*Branta canadensis*; geese]). Partial exclusion (PEX) was designed to allow access by gulls, but exclude larger waterbirds, to simulate absence of cormorants. Control plots (CON) did not exclude any species. Exclusion of birds was intended to prevent physical damage to vegetation by birds and also greatly reduce the amount of guano deposited inside exclosures. On 11–13 April 2012, prior to egg-laying by cormorants, we set up five replicates of FEX, PEX, and CON plots each of Hat, Jack, and Spider Islands (i.e. $n = 15$ plots per island, 45 total). We placed treatments in randomly selected 10×10 m cells (ESRI® ArcMap 10.1, Esri Inc., Redlands, CA, U.S.A.) of a grid placed over an aerial image of each entire island. The GPS coordinated center of selected cells was used to establish centers of plots. Active cormorant nesting areas were avoided because disturbance of active nests may displace birds from the islands, thus eliminating presence of birds necessary for our experiment.

Each plot was comprised of a 3.2 m^2 area. Full exclosures consisted of 4–1.8×1.3 m panels (L × H) of 10×10 cm galvanized wire mesh with a chicken wire apron at the bottom to prevent entry by chicks. Partial exclosures consisted of four panels of 20×15 cm (W × H) galvanized wire mesh. We strung high visibility lines across approximately 10 cm above the top

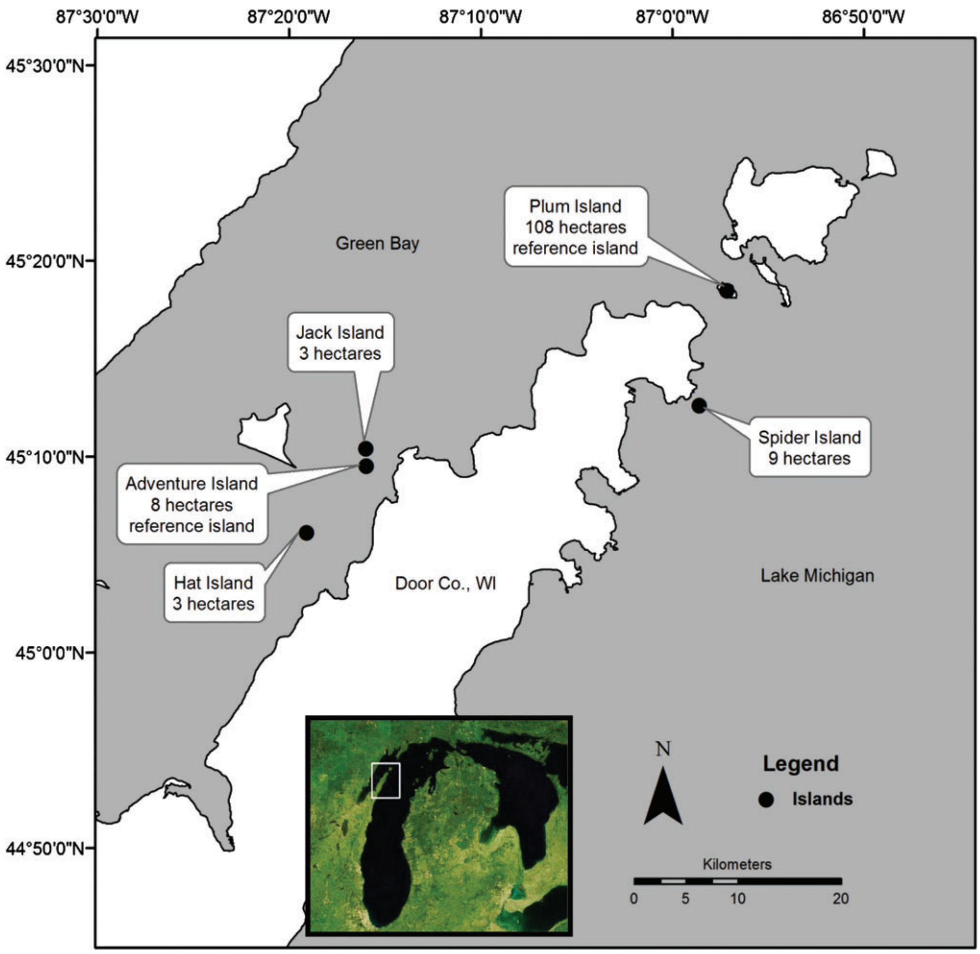

Figure 1. Map of study area including three islands with cormorant nesting colonies (Hat, Jack, and Spider) used for bird exclusion studies and two reference islands (Adventure and Plum) used to compare soil samples to bird breeding islands, all located in Door County, Wisconsin, U.S.A.

Table 1. Recorded numbers of Double-crested Cormorant (DCCO), American White Pelican (AWPE), and Herring Gull (HERG) nests on Hat, Jack, and Spider Islands, Door County, Wisconsin from 1997 to 2013. Counted by Wisconsin USDA-WS, USFWS, University of Wisconsin, and University of Minnesota. Dashes represent that count was not available.

Island	*Species*	*1997*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
Jack	DCCO	1154[a]	3429[a]	3730[a]	3459[a]	2756[a]	2462[a]	1571[a]	1188[a]	197[a]	416[a]
	AWPE	—	—	—	—	0[b]	0[b]	0[b]	0[b]	0[b]	0[b]
	HERG	—	—	—	—	1471[b]	981[b]	599[b]	1437[b]	1053[b]	1640[b]
Hat	DCCO	1457[a]	2106[a]	—	3324[a]	2102[a]	1973[a]	1472[a]	1397[a]	747[a]	764[a]
	AWPE	—	—	—	—	—	227[b]	559[b]	161[b]	739[a]	253[a]
	HERG	—	—	—	—	—	1050[b]	1237[b]	3020[b]	2140[b]	2233[b]
Spider	DCCO	3865[b]	1985[b]	—	2132[b]	2466[b]	2503[b]	1808[b]	4055[b]	3440[b]	2135[b]
	AWPE	—	—	—	—	0[b]	0[b]	15[b]	0[b]	0[b]	2[b]
	HERG	—	—	—	—	3983[b]	3266[b]	2330[b]	4558[b]	2211[b]	2416[b]

[a]Counts done from the ground.
[b]Counts done from aerial photography.

edge of each exclosure at 20 cm intervals to prevent entry from above (Amling 1980; Laidlaw et al. 1984). We tied fluorescent flagging tape on each line to increase visibility and deterrence. CON consisted of four 0.5 m wooden stakes placed at each plot corner. We planted a black elderberry seedling (approximately 25 cm tall) contained in 4 L of potting soil in the center of each plot. We used RECONYX PC85 motion sensitive cameras (RECONYX, Inc., Holmen, WI, U.S.A.) placed on 2.4 m metal T-posts to photograph birds in two randomly selected plots, of each treatment ($n = 6$) on each island. We reviewed all photos to estimate bird species, number, and age class (adult or pre-fledged chick) of birds present within a plot. The number

of bird-photos (i.e. the number of birds in each photo) of each species, on each plot, on each day provided a standardized measure of plot use.

On 7–8 August 2012, we measured percent cover and biomass of vegetation, survival of elderberry plants (alive or dead), and identified every plant species in each plot. We harvested and weighed above-ground biomass of each species from within one randomly selected 1 × 1 m quadrat of each plot. We photographed and pressed voucher specimens of species we were unable to positively identify in the field for later identification. We took overhead photos of each quadrant of each plot and used a 100-square grid on each photo to estimate percent cover. Existing vegetation before experimental set-up was not measured as ground in all plots was largely devoid of vegetation during set-up.

2013 Exclosure and Elderberry Restoration Experiment

We conducted a second exclusion study in 2013. We used a random block design with elderberry planting technique as a factor nested within exclusion treatment. We constructed larger exclosures on two islands in 2013 (Spider Island on 24 April and Hat Island on 8 May) to test exclosures and elderberry planting techniques closer to current nesting areas. Plots measured 3.6 × 12.6 × 1.3 m (W × L × H). We affixed 5 cm-mesh chicken wire across FEX 10 cm below the top to prevent bird entry as gulls were observed entering FEX in 2012. We strung wire, marked with flagging tape, across the top of FEX at 10 cm intervals, and a single strand 10 cm above the top of the exclosure perimeter to deter perching. We altered PEX to make entry easier for gulls in 2013 by enlarging mesh cells to 20 × 30 cm and placing flagged strands of wire across the top at wider 40 cm intervals. We placed wooden stakes at 1.8 m intervals to outline a 3.6 × 12.6 m CON area.

We tested four planting treatments for effects on survival of dormant, bare root elderberry plants approximately 1 m tall. We used bare root elderberry plants to test survival of taller, dormant plants. We planted 56 plants within each plot, divided equally among four treatments: (1) 4 L of organic topsoil replacement, (2) a 0.51 m^2 burlap weed protection apron around the base of the plant, (3) soil replacement and burlap apron, or (4) neither soil replacement nor burlap apron (i.e. control). We randomly placed the four treatments within groups of four plants (i.e. 2 × 2 groups) and placed plants in each plot in a 4 × 14 plant grid with 1 m between plants and 0.5 m from plot edges to nearest plant to maintain independence between elderberry planting treatments (Appendix S1, Supporting Information). We placed a motion sensor camera at each end of all plots to monitor bird activity. We compared the number of photos/bird species/day among plot treatments and between islands.

Colonial Nesting Waterbird Effects on Soil

In April 2012, we took soil cores (9 cm diameter × 20 cm deep) from the center of each plot ($n = 15$ for each island). In April and May 2013, we took soil cores (9 cm diameter × 20 cm deep) from 7 of the 14 soil replacement treatment locations within each plot (Appendix S1). We distributed soil sample locations across plots by randomly selecting one of the two soil replacement locations from adjacent sets of four plant-treatment types (Appendix S1). We thoroughly mixed and removed stones from each sample, and soils were sieved, and ground at the soil testing lab. This assured we would collect samples from a variety of distances from active nesting areas. We also collected 15 samples each from Adventure and Plum Islands in 2013 for comparisons to colony islands. We selected an area of each control island of the same soil series and collected soil cores (9 cm diameter × 20 cm deep) every 10 m along a 150 m transect. All samples were stored in dry room-temperature conditions in cardstock collection boxes provided by the analyzing laboratory until approximately 50 mL subsamples were transferred to Whirl-pak bags for transport to the analyzing laboratory. All soil samples were analyzed for NO_3-N, available P (hereafter P), K, Mg, Zn, and pH at the Mississippi State University Extension Service Soils Testing Laboratory (Mississippi State, MS, U.S.A.). All samples were passed through a size 20 (0.841 mm) mesh sieve and a Dynacrush soil grinder before analyses. Soil P, K, Mg, and Zn were determined using the Lancaster method (Cox 2001). Nitrate-nitrogen was measured using a nitrate electrode using calcium sulfate solution (Johnson 1992). Soil samples were analyzed for exchangeable Al by Spectrum Analytic Inc. (Washington Court House, OH, U.S.A.) by extracting Al from 2 g of soil with 10 mL of 1 M KCl, then measuring any extracted Al in this solution using a Thermo 6500 ICAP spectrometer (Thermo Scientific, Waltham, Massachusetts, U.S.A.) (Soil and Plant Analysis Council 2000). All nutrient concentrations were measured in $\mu g\ g^{-1}$ of dry mass of soil.

Statistical Analyses

For 2012, we used the MIXED procedure in SAS 9.3 (SAS®, Cary, NC, U.S.A.) to determine bird exclusion (i.e. FEX, PEX, CON) effect on vegetation biomass, percent cover, total number of plant species, and total number of native plant species. We used the GLIMMIX procedure in SAS 9.3 (SAS®) to determine bird exclusion treatment effects on survival of planted elderberry. We included island as a random independent variable in all models. We examined differences in least squares means between treatments if the type III test of fixed effects was significant ($\alpha = 0.05$). We used the Sidak adjustment for multiple comparisons to determine significant between-treatment differences (Moran 2003).

We used the MIXED procedure in SAS 9.3 to determine plot treatment effects on bird use (sum of photos/bird species/day) for cormorants, pelicans, gulls, geese, other species combined, and all species combined (six models total). We only observed pelicans on Hat Island, so we only included the six plots from Hat in the model for effect of treatment on pelican use. We included island as a random independent variable in all models.

For 2013, we used the GENMOD procedure in SAS 9.3 with a zero inflated negative binomial distribution to determine bird exclusion and elderberry planting treatment effects on above-ground biomass growth of elderberry. Biomass growth on the two islands was significantly different so we tested factor

Table 2. Mean number of bird photos per day (with standard deviations in parentheses) in three levels of exclusion of waterbirds: no exclusion (CON), exclusion of all waterbirds other than gulls (PEX), and full exclusion of waterbirds (FEX) from 45 3.2 m^2 plots on three islands (six camera plots per island, two of each treatment) in Door County, Wisconsin in 2012. Superscript letters represent significantly different groups among treatments using Sidak adjusted P-values and $\alpha = 0.05$. Species abbreviations include American White Pelican (AWPE), Canada Goose (CANG), and Double-crested Cormorant (DCCO).

	All	*AWPE*[*]	*CANG*	*DCCO*	*Gull*	*Other*
CON	22.97 (25.45)^{a}	19.93 (10.76)^{a}	0.50 (0.57)^{a}	0.25 (0.37)^{a}	15.53 (14.24)^{a}	0.04 (0.05)^{ab}
PEX	0.48 (0.65)^{b}	0.00 (0.00)^{b}	0.00 (0.00)^{b}	0.00 (0.00)^{b}	0.14 (0.15)^{b}	0.34 (0.53)^{b}
FEX	4.12 (4.11)^{b}	0.00 (0.00)^{b}	0.00 (0.00)^{b}	0.00 (0.00)^{b}	4.09 (4.09)^{b}	0.03 (0.04)^{a}

[*]Means for American white pelicans were calculated from one island only because pelicans were not observed on other islands.

effects separately for each island. We used least squares means to determine differences between treatments; P-values were adjusted using the Sidak equation for multiple comparisons (Moran 2003). We examined differences in least squares means between elderberry planting treatments only within plot type to reduce confounding effects of levels of bird use or soil, between plots. We used the GENMOD procedure with a binomial distribution to determine bird exclusion and elderberry planting effects on elderberry survival for both islands combined. Similar to 2012, we used the MIXED procedure in SAS 9.3 to determine effect of bird exclusion and elderberry planting on bird use of plots. An α of 0.05 was used for all significance tests. We compared soil differences in pH, P, K, NO_3-N, Mg, Zn, and exchangeable Al between breeding colony islands and reference islands using the GLM procedure in SAS 9.2.

Results

2012 Exclosure Experiment

Photos were taken between 29 and 118 days (mean = 94 days) over the 118 day test period (11 April–8 August 2012). Bird use overall in 2012 was dependent on plot treatment ($P < 0.001$) with CON being used >22-fold more than PEX ($\beta = 8.66$, SE = 1.11, $P < 0.001$; Table 2) and 5-fold more than FEX ($\beta = 7.37$, SE = 1.23, $P < 0.001$). Cormorant use in CON was more than in PEX ($\beta = 0.61$, SE = 0.10, $P < 0.001$) or FEX ($\beta = 0.60$, SE = 0.11, $P < 0.001$). Pelican use in CON was also greater than in PEX ($\beta = 30.55$, SE = 10.37, $P = 0.010$) or FEX ($\beta = 30.55$, SE = 12.07, $P = 0.035$). Goose use was greater in CON than PEX ($\beta = 1.11$, SE = 0.21, $P < 0.001$) or FEX ($\beta = 1.24$, SE = 0.23, $P < 0.001$). Gull use in CON was 16 times greater than in PEX ($\beta = 17.14$, SE = 2.18, $P < 0.001$) and almost four times greater than FEX ($\beta = 13.30$, SE = 2.39, $P < 0.001$). Gull use was greater in FEX because 16 gulls spent an extended amount of time trapped in FEX plots.

Vegetation biomass in CON was less than half of PEX ($\beta = 1137.97$, SE = 453.39, $P = 0.048$). Biomass in the FEX was intermediate between the PEX and CON and not statistically different from either. Mean vegetation biomass in CON was 843 g (SD = 494), in PEX was 1981 g (SD = 1471), and in FEX was 1777 g (SD = 1552). Vegetation cover was similar among exclusion treatments ($P = 0.135$) and averaged 85%. The total number of plant species and number of native plant species was similar among all exclusion treatments across islands. We found an average of three native plant species, and six total species in each plot. We identified a total of 41 plant species in the experimental plots, including 24 (59%) non-native plants and 17 (41%) native plants (Appendix S2B). Survival of elderberry plants was similar in all treatments ($P = 0.192$). Only six of 45 elderberry plants survived, with four surviving in PEX and one in each of control and FEX.

2013 Exclosure and Elderberry Planting Experiment

On both islands in 2013, birds overall used CON more than exclosures ($P < 0.001$; Table 3). Pelicans were only observed in CON, yet did not differ overall among plot treatments, although they approached significance ($P = 0.055$). Geese only used CON and use differed from PEX ($\beta = 8.04$, SE = 1.72, $P < 0.001$) and FEX ($\beta = 8.04$, SE = 1.44, $P < 0.001$). Cormorant use in CON was greater than PEX ($\beta = 1.02$, SE = 0.22, $P < 0.001$) and FEX ($\beta = 0.98$, SE = 0.19, $P < 0.001$) although use of CON by cormorants was low relative to all other species (Table 3). Gulls used all levels of exclusion more than any other species (Table 3) using CON more than PEX ($\beta = 52.71$, SE = 4.81, $P < 0.001$) and FEX ($\beta = 56.20$, SE = 4.46, $P < 0.001$). Small passerines (e.g. Red-winged Blackbirds [*Agelaius phoeniceus*]) were able to enter FEX, but larger species were only observed briefly perching on FEX. Use of PEX and FEX did not differ significantly for any species.

Elderberry growth differed among exclusion treatments on both islands in 2013, but did not consistently support our hypothesis of greater growth with greater colony-nesting bird exclusion. On Hat Island, biomass in exclosures was significantly greater than CON; but on Spider Island, mass growth in CON was significantly greater than PEX and all other comparisons were non-significant (Table 4). Planting treatment had a significant effect on biomass on both Hat and Spider ($P = 0.021$ and 0.012, respectively). Eight of 36 within-plot comparisons between planting treatment effects on biomass were significant in 2013 (Table 4), and all comparisons supported burlap and soil mitigation improving biomass. CON contained the fewest plants with at least some biomass growth (33%) and FEX had the most (70%). Control planting treatments had the fewest plants with at least some biomass growth (50%) and soil-replacement only plants had the most (63%). Elderberry plants had greater survival when protected from birds by exclosures ($P < 0.001$; Table 5); planting treatment effects approached significant effects on elderberry survival ($P = 0.063$). The fewest plants survived in CON (57%), while the greatest percentage of elderberry survived in FEX (96%; Table 5). Control and burlap only

Table 3. Mean number of bird observations per day (with standard deviation) in three levels of exclusion of waterbirds: no exclusion (CON), exclusion of all waterbirds other than gulls (PEX), and full exclusion of waterbirds (FEX) in six 49 m^2 plots on Hat and Spider Islands in Door County, Wisconsin in 2013. Superscript letters represent significantly different groups among treatments using Sidak adjusted P-values and $\alpha = 0.05$. Species abbreviations include American White Pelican (AWPE), Canada Goose (CANG), and Double-crested Cormorant (DCCO).

	All	*AWPE**	*CANG*	*DCCO*	*Gull*	*Other*
CON	52.35 (16.13)^{a}	2.34 (0.613)^{a}	0.88 (0.06)^{a}	0.12 (0.13)^{a}	49.90 (15.70)^{a}	0.28 (0.28)^{a}
PEX	3.19 (2.98)^{b}	0 (0)^{a}	0 (0)^{b}	0.01 (0.01)^{b}	3.44 (3.01)^{b}	0.06 (0.06)^{ab}
FEX	0.26 (0.09)^{b}	0 (0)^{a}	0 (0)^{b}	0.01 (0.02)^{b}	0.20 (0.04)^{b}	0.36 (0.06)^{b}

*Means for American white pelicans were calculated from Hat Island only because pelicans were not observed on Spider and overall P-value was 0.055.

Table 4. Means and model results of bird exclusion and elderberry planting treatment, respectively, on biomass of 56 restoration plants (Black elderberry [*Sambucus nigra canadensis*]) in each of six plots on Hat and Spider islands used by nesting waterbirds in Door County, Wisconsin in 2013. Superscript letters represent significantly different plot treatments using Sidak adjusted P-values for multiple comparisons. There were six within-plot planting treatment comparisons. Only significant comparisons are included.

Hat	*Exclusion Treatment**	*Mean (g)*	*SD*	*Spider*	*Exclusion Treatment†*	*Mean (g)*	*SD*		
	CON	0.56^{a}	1.52		CON	19.80^{a}	41.36		
	PEX	10.05^{b}	17.88		PEX	12.54^{b}	23.34		
	FEX	12.41^{b}	13.86		FEX	14.75^{ab}	22.56		
Hat	Exclusion planting combinations[2]	β	SE	P-value	Spider	Exclusion planting combinations†	β	SE	P-value
	CON-B > CON-C	4.78	1.44	0.006		PEX-BS > PEX-C	2.08	0.61	0.033
	CON-BS > CON-C	4.74	1.44	0.006		PEX-S > PEX-C	2.16	0.59	0.013
	FEX-BS > FEX-B	0.85	0.29	0.018					
	FEX-S > FEX-B	0.81	0.28	0.022					
	FEX-BS > FEX-C	1.03	0.3	0.003					
	FEX-S > FEX-C	0.99	0.29	0.004					

*Plot treatments included no exclusion (CON), full exclusion of waterbirds (FEX), and partial exclusion of waterbirds to allow entry by gulls (PEX).
†Plant treatments included a burlap weed barrier (B), soil replacement (S), burlap, and soil (BS), and a control planting directly into present conditions (C).

Table 5. Survival of planted black elderberry (*Sambucus nigra canadensis*) in 49 m^2 plots on two islands used by nesting waterbirds in Door County, Wisconsin in 2013. Effects of island and elderberry planting treatment on plant survival were not significant. Plot treatments included no exclusion (CON), partial exclusion of waterbirds to allow entry by gulls (PEX), and full exclusion of waterbirds (FEX). Superscripts represent significantly different groups using Sidak adjusted P-values at $\alpha = 0.05$.

Plot Treatment	*Survival*	*Percent Alive*
CON	64/112^{a}	57
PEX	92/112^{b}	82
FEX	108/112^{c}	96
Plant treatment	Survival	Percent alive
Burlap	62/84	74
Soil	68/84	81
Burlap and soil	72/84	86
Control	62/84	74

elderberry planting treatments had the fewest plants survive (74%), and burlap and soil combined treatments had the most plants survive (86%; Table 6).

Colonial Nesting Waterbird Effects on Soil

Island-wide soil chemistry differed between breeding colony and reference islands in 2012 for nutrients, metals, and pH (Table 6). The soil from breeding bird islands was more acidic than reference islands. Nitrate-nitrogen, phosphorus, potassium, zinc, magnesium, and exchangeable aluminum were all significantly greater in soil samples from breeding bird compared to reference islands (Table 6). Mean pH of samples from near colonies in 2013 was less than reference islands and island-wide estimates in 2012 (Table 6). Nitrate-nitrogen and phosphorous from near colonies were greater than island wide estimates in 2012 and 4 to 26 times greater, respectively than reference islands (Table 6). Potassium and zinc were greater than reference islands while magnesium on breeding islands averaged, about 68% that of reference islands (Table 6). Exchangeable aluminum averaged 2.24 ppm on breeding islands, nearly three times greater than reference islands.

Discussion

Excluding cormorants, pelicans and gulls increased vegetation growth. Many (41%) of plants responding to exclusion of birds were native species and sometimes dominated cover and biomass. However, there were many non-natives (59%) and no woody plant species response. Bird exclusion significantly increased survival of our restoration plant species in 2013, but results were mixed for plant growth. Use of larger dormant bare root plants likely contributed to increased survival in 2013 compared to 2012. Bird exclusion greatly decreased bird use relative to CON and may serve as a non-lethal restoration tool to prevent ground-nesting waterbirds from damaging growing woody vegetation. Weed barriers and soil replacement may improve growth of planted woody vegetation. Once woody plants have

Table 6. Means (±SD) pH and concentrations (µg/g) of nutrients in dry soil from three islands supporting colonies of breeding waterbirds to nearby reference islands absent of breeding colonies in Door County, Wisconsin in 2012 and 2013.

Island[a]	*pH*	P	*NO_3-N*	*K*	*Mg*	*Zn*	*eAl*
Reference	7.7 (0.2)	176 (171)	89.0 (106.3)	160.4 (62.3)	2681 (976)	16.6 (12.9)	0.8 (0.77)
Jack (2012)	6.6 (0.6)[b]	4360 (2613)[b]	72.4 (68.6)	188.2 (67.3)	936 (444)[b]	11.1 (3.1)	3.4 (1.56)[b]
Hat (2012)	6.4 (0.6)[b]	3662 (2803)[b]	241.3 (159.4)[b]	326.9 (135.8)[b]	811 (328)[b]	12.8 (5.2)	3.0 (1.68)[b]
Spider (2012)	6.1 (1.0)[b]	1856 (2093)[b]	57.9 (62.8)	92.5 (47.7)[b]	321 (147)[b]	11.8 (5.5)	2.6 (1.06)[b]
Hat (2013)	6.9 (0.3)[b, c]	3701 (861)[b]	450.5 (353.0)[b, c]	696.4 (259.6)[b, c]	3077 (392)[c]	18.7 (3.9)[c]	2.3 (0.78)[b]
Spider (2013)	5.5 (0.5)[b, c]	5425 (4084)[b, c]	277.5 (281.3)[b, c]	223.9 (69.8)[b, c]	586 (347)[b, c]	34.8 (15.3)[b, c]	2.2 (1.06)[b]

[a]Breeding islands included Hat, Jack, and Spider, and reference islands included Plum and Adventure. Breeding islands were sampled randomly, island-wide in 2012 ($n = 15$), and within 18 m of the nesting area in 2013 ($n = 21$). Reference islands were sampled in 2013, every 10 m along a transect beginning at least 10 m from shore ($n = 15$).
[b]Represents significant difference from reference islands in both years.
[c]Represents significantly different *P*-value from island-wide sample from the same island in 2012 ($\alpha = 0.05$).

been reestablished they should still be protected through harassment or deterrence of nesting waterbirds.

Both PEX and FEX were effective in limiting bird use, although observed use of CON by cormorants in 2013 was low and may not have been biologically significant. We did not expect low use by cormorants, as they have been observed collecting nesting material island-wide at other colony locations (Brian Dorr, USDA-APHIS, unpublished data). Low use of open space on the islands by cormorants, yet little regeneration in woody vegetation growth suggests that once cormorants have altered habitat, use by other colonial waterbird species may maintain or exacerbate vegetation impacts. This is supported by our photo data of other colonial waterbirds using non-exclosure plots island-wide. The low cormorant use of CON in 2013 may be because of lack of nesting material in the interior portions of the islands or neophobia associated with stakes, elderberry plants, or burlap. Elderberry survival was greater in exclosures, indicating that damage caused by co-nesting waterbirds may play an important role in the potential restoration of island vegetation. Partial exclosures were designed to allow entry by gulls; however gulls were deterred. Similar biomass growth between CON and full exclosures in 2012 was likely due to some trapped gulls within FEX for an extended period. Gulls were able to enter despite making deterrent grids more restrictive than those used in other studies (Amling 1980; Laidlaw et al. 1984). Although most gulls escaped, mortality of 16 gulls occurred. Entry of gulls may have occurred because the sheer numbers of gulls present (2,106–6,880) and subsequent use overwhelmed traditional deterrent designs. Modified full exclosures with a covering of smaller mesh openings eliminated entry by gulls in 2013. One clear result from exclosure testing is that even a partial barrier of wire placed at relatively wide (1 m) intervals over the top of the exclosures eliminated almost all use by pelicans and cormorants and most gull use. This result suggests that a relatively simple barrier could be used as a non-lethal means of reducing use and improving potential success of restoring island vegetation. This might be a particularly effective method where cormorants have been removed but other ground nesting colonial waterbirds are still present.

The lack of woody plants in any plots suggests that viable propagules of woody plants may not have been present in the seed bank or conditions may not have been favorable for germination, limiting potential for these species to naturally recolonize impacted areas. Boutin et al. (2011) found that cormorant colonies appeared to have little effect on the seed bank of their study site; however, their study site still had large woody vegetation present as a seed source. Given this, supplemental planting of older bare-root woody vegetation for community restoration may be necessary. Current management goals for the islands in this study are to allow all waterbirds to nest on the islands, although Hat and Jack are limited to 500 nesting pairs of cormorants each (Jones & Lovell 2009). In the absence of other management such as exclusion, continued nesting of cormorants may limit establishment, and regrowth of woody forest vegetation because cormorants would likely roost or nest in new shrubs, leading to destruction of the plants (Hebert et al. 2005). This study suggests that waterbirds and particularly pelicans may perpetuate vegetation damage, further preventing natural succession of the plant community.

When compared to reference islands, we found acidic soils and higher accumulations of nutrients associated with nesting waterbirds, which can have deleterious effects on plant growth, especially native plant species adapted to alkaline soils. Mean levels of *P* were nearly 10 times that considered toxic for some plant species (Provin & Pitt 2002) and pH was >10 times more acidic than on reference islands. Phosphorous can be toxic in high concentrations and limit a plant's ability to absorb micronutrients such as zinc and iron (Provin & Pitt 2002), requiring soil remediation to support growth of many plant species. Acidic soils can lead to other soil nutrients becoming toxic or deficient depending on their reactivity at low pH (Ashman & Puri 2002). For example, aluminum can become soluble in soils with pH ≤4 and cause poor development of plants due to stunted roots and reduced availability of other nutrients. Other nutrients such as calcium, potassium, and magnesium can also become deficient in acidic soils.

With nesting waterbirds, high soil P and lower soil pH occurred island-wide, not just adjacent to nesting areas. Island-wide effects may have resulted from nesting areas shifting annually, leaching and blowing of material, and/or contribution of bird feces to the soil from birds moving around the island. Gulls and pelicans, which only nest on the ground, would contribute to this but they would likely not be present in current numbers if cormorant-caused vegetation changes did

not increase island habitats favorable for these birds. If soil remediation or replacement is not feasible it may take several years for pH and *P* to return to normal levels (Wiese 1977; Ishida 1996).

A potential limitation to restoring woody vegetation is competition from other plants. Boutin et al. (2011) examined the species in the seed bank on an island in Ontario colonized by cormorants. They concluded that exotic plants made up the majority of plant species and some had potential to outcompete native species, especially in eutrophic soils. Boutin et al. (2011) also described how chemical deforestation and creation of open areas reduces soil moisture. Ishida (1997) showed both direct and indirect negative effects of cormorant feces accumulation on the growth and survival of woody plants as seeds, seedlings, and saplings. To our knowledge, this study is the first to document plant response at various levels of bird use.

We observed poor survival rates of elderberry in 2012 possibly because of substantial competition from native and non-native herbaceous plants (average cover 85%), soil conditions, and the use of smaller plants versus larger dormant bare-root plants. We observed much greater survival rates in 2013 even in CON when we planted larger, bare-root elderberry plants. This finding suggests that planting larger bare root woody plants can facilitate survival and restoration efforts. We observed some improvement in growth with the additional treatments of burlap weed protection and soil replacement, indicating that competition from surrounding, fast-growing plants, and poor soil conditions can still hinder growth and possibly establishment of woody vegetation even when using larger plants.

This study indicates that restoration of plant communities on islands in the Great Lakes can be facilitated, at least in part, by removal or exclusion of ground-nesting waterbirds (e.g. cormorants, pelicans, and to a lesser extent, gulls). These findings may not be limited to cormorants in North America, as vegetation and soil impacts by cormorant species in Europe and Japan have been documented as well (Ishida 1997; Breuning-Madsen et al. 2010). Colonial waterbird species can transform island plant communities to open herbaceous landscapes over an extended period (Cuthbert et al. 2002; Boutin et al. 2011). Even with management and remediation it will probably take years for these islands to return to forested habitats that can support avian communities that once existed there. Colonial waterbird colonization that impacts plant communities, causing succession in the avian community is a natural process (Wires & Cuthbert 2006) and may be acceptable under specific conservation and management goals. If colonial waterbird removal or exclusion is conducted, it should be in the context of this natural process to achieve sustainable ecological outcomes on these island habitats.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Example schematic of design of six 49 m^2 plots (three per island) and four elderberry planting treatments for determining effects on growth and survival of black elderberry (*Sambucus nigra canadensis*) planted adjacent to Double-crested Cormorant (*Phalacrocorax auritus*) nesting colonies on Spider and Hat Islands in Door County, Wisconsin, USA, April–May 2013. S, soil replacement, B, 0.51 m^2 burlap weed barrier, BS, both soil replacement and burlap weed barrier, C, control (plants placed in present soil); **S**, soil sample collected for analyses.

Table S2. List of plant species found in 2012 in sample plots on three islands where Double-crested Cormorants breed in Door County, Wisconsin, USA. N, native, I, non-native Invasive, A, annual, B, biannual, and P, perennial.

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