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RESEARCH ARTICLE

Exclusion of Ring-billed Gulls (*Larus delawarensis*) from recreational beaches using canid harassment

Dustin W. Jordan, Michelle E. Kane, Thomas M. Gehring,* Rebeccah L. Sokol, and Elizabeth W. Alm

Department of Biology, Institute for Great Lakes Research, Central Michigan University, Mount Pleasant, Michigan, USA
* Corresponding author: gehri1tm@cmich.edu

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ABSTRACT

Ring-billed Gull (*Larus delawarensis*) populations have dramatically increased throughout their geographic range with the largest concentrations in the Great Lakes region of Canada and the United States. Large populations of gulls cause conflict with humans at recreational beaches, where their effects on human health and safety include bacteria contamination from gull feces. We used border collies to harass and exclude gulls from beaches in summer 2012 and 2013, then measured gull numbers and *Escherichia coli*. Dogs were effective at reducing gull numbers by 56–76% during continuous and noncontinuous dog treatment periods. Levels of *E. coli* were lower on dog-treated beaches, but only during the first half of the summer. Mixed modeling analysis showed presence of dogs was a strong predictor of gull numbers and *E. coli* levels, with variation among dogs, possibly related to age. Noncontinuous use of dogs, applied within an integrated beach management framework, can provide a nonlethal method for reducing gull use and *E. coli* levels at recreational beaches.

Keywords: dog, *Escherichia coli*, Great Lakes, gull exclusion, nonlethal management, recreational beach, Ring-billed Gull, wildlife–human conflict

Exclusión de *Larus delawarensis* de playas recreativas mediante hostigamiento con perros

RESUMEN

Las poblaciones de *Larus delawarensis* han aumentado dramáticamente a lo largo de su rango geográfico, con las mayores concentraciones en la región de los Grandes Lagos de Canadá y Estados Unidos. Las grandes poblaciones de gaviotas causan conflictos con los humanos en las payas recreativas, donde sus efectos en la salud humana y la seguridad incluyen contaminación con bacterias proveniente de las heces de las gaviotas. Usamos perros de la raza border collie para hostigar y excluir a las gaviotas de las playas en los veranos de 2012 y 2013, y luego medimos las cantidades de gaviotas y los niveles de *Escherichia coli*. Los perros fueron efectivos para reducir los números de gaviotas en un 56–76% durante períodos de tratamiento continuos y no continuos con perros. Los niveles de *E. coli* fueron menores en las playas con el tratamiento de perros, pero solo durante la primera mitad del verano. Un análisis de modelos mixtos mostró que la presencia de perros fue un fuerte predictor del número de gaviotas y de los niveles de *E. coli*, con variaciones entre perros, posiblemente debido a la edad. El uso no continuo de perros, aplicado adentro de un marco integrado de manejo de la playa, puede representar un método no letal para reducir el uso por parte de las gaviotas y los niveles de *E. coli* en las playas recreativas.

Palabras clave: conflicto vida silvestre–humanos, *Escherichia coli*, exclusión de gaviotas, Grandes Lagos, *Larus delawarensis*, manejo no letal, perro, playas recreativas

INTRODUCTION

Beach recreation is an important component of the economies of coastal communities (Vaccaro et al. 2009, Song et al. 2010). During the summer season large numbers of people visit beaches for sunbathing, swimming, and other water-related activities. Recreational activities generate substantial revenue for local businesses as well as fishing, boating, and other permit sales for county and state agencies. As the abundance of some native gull species has increased, managers have observed an increase in human–gull conflicts. Ring-billed Gull (*Larus delawarensis*) populations have increased dramatically following their near demise in the mid-1800s and early 1900s (Pollet et al. 2012). The Ring-billed Gull is classified as a migratory bird species and is thus protected by federal law under the Migratory Bird Treaty Act of 1918. Since 1993, Ring-billed Gull populations have been growing at a median rate of 2.08% per year (Sauer et al. 2017). Giroux et al. (2016) reported that the Great Lakes Region supported the largest

Ring-billed Gull concentrations, where it has become the most abundant waterbird (Solman 1994, Greenlaw and Sheehan 2003, Morris et al. 2011, Norwood 2011).

As the number of Ring-billed Gulls ("gulls" hereafter) has increased, managers have been challenged with addressing general nuisance issues and potential human health and safety concerns linked to gulls (Hartmann et al. 2009). These effects are readily observed at recreational beaches where high numbers of gulls and people are found together. High numbers of gulls may be considered aesthetically displeasing, and their frequent defecation can lead to property damage, reduced recreational enjoyment, and increased health risks (Hartmann et al. 2009). Gull fecal matter has been found to carry bacteria such as *Escherichia coli*, *Salmonella* spp., and *Campylobacter* spp., which may contribute to the contamination of recreational waters (Lévesque et al. 2000) and lead to high *E. coli* levels in beach water (Edge and Hill 2007). Alm et al. (2018) found that Ring-billed Gulls had the potential to disperse human-associated microbes between human waste sites and beaches based in part on the presence of the human-associated marker, HF183, in gull feces. The human health hazards can lead to swim bans and beach closings linked to bird fecal contamination (McLellan and Salmore 2003). Beach closings have the potential to result in significant economic losses to coastal communities. Rabinovici et al. (2004) estimated a Lake Michigan beach closing could lead to a net economic loss of up to $35,000 per day. Song et al. (2010) estimated a seasonal closure of one beach site may result in an economic loss of $130,000 to $24 million, while closing all Lake Michigan sites has been estimated as high as $1 billion. These values illustrate the substantial economic importance of the Great Lakes public beaches.

Implementing a gull deterrent that effectively reduces the number of gulls using a beach may mitigate health hazards and potential economic losses associated with beach closings. There are many lethal and nonlethal methods proposed for deterring gulls. Lethal methods include active culling as well as egg oiling techniques that prevent successful nesting. However, special permitting is required for lethal control of birds covered by the Migratory Bird Treaty Act. In addition, Reiter et al. (1999) found that the U.S. public favors nonlethal management methods, compared to lethal control, when dealing with wildlife–human conflicts. Nonlethal methods to deter nuisance bird species include disruptive-stimulus and aversive-stimulus tools (Shivik 2006). Disruptive-stimulus techniques, such as propane cannons, pyrotechnics, lasers, and other repellents, disrupt and frighten wildlife from a site without long-term modification of behavior (Blackwell et al. 2002; Gilsdorf et al. 2002). Aversive-stimulus tools, such as overhead monofilament wire fencing (Blokpoel and Tessier 1984), ultimately lead to modification in wildlife behavior via conditioning (Shivik 2006). However, most of these methods are undesirable or not feasible on a public beach.

Properly raised and trained dogs have already proven to be an effective nonlethal management tool in human–wildlife conflicts concerning livestock depredation and disease transmission (Andelt 1992, VerCauteren et al. 2008, Gehring et al. 2010, VerCauteren et al. 2014) and may be viewed as both a disruptive- and aversive-stimulus tool (Gehring et al. 2010). Conflicts caused by Canada Geese (*Branta canadensis*) on golf courses and airport runways have been safely alleviated using dogs as a harassment tool (Castelli and Sleggs 2000). Burger et al. (2007) found disturbances in the form of cars, planes, people, and dogs had effects on gull and shorebird behavior at beaches, but did not examine continuous exposure to these disturbances. In addition to being a highly intelligent breed of dog, the border collie possesses an excellent herding instinct. This behavior is important for wildlife harassment as it encourages the dog to chase and displace animals without attacking or harming them (Koski and Kinzelman 2010). Koski and Kinzelman (2010) used border collies for waterfowl and gull harassment on beaches, but noted that continuous treatment was necessary to maintain desired exclusion levels. Dorfman and Rosselot (2011) suggested border collies were effective tools for improving beach quality at one beach in Chicago, Illinois; however, this effectiveness was not quantified. Border collies have been used in recent years for gull harassment on Chicago beaches with mixed success, often reducing gull numbers during harassment (Hartmann et al. 2012). Converse et al. (2012) conducted a study in Racine, Wisconsin, that indicated up to a 98% reduction in gull visitation at one beach site after one week of border collie harassment. This decrease in gull numbers was correlated with a decrease in fecal indicator bacteria in swim water. However, gull harassment was implemented for only 16 days (Converse et al. 2012).

More rigorous, experimental field research is required to establish the effectiveness of dogs as an efficient, nonlethal management tool for human–avian conflicts. The goal of this study was to evaluate the cost and effectiveness of trained border collies as a tool for gull removal on recreational beaches. Varying intensities of exclusion efforts were explored in order to further determine a minimum effective application of dog harassment. A reduction of beach *E. coli* levels, and therefore an increase in beach quality, was the desired result of gull exclusion efforts.

METHODS

Study Area

Beach sites were located along 17 km of Lake Michigan shoreline in Ottawa County, Michigan, USA (Figure 1). Ottawa County features ~40 km of Lake

FIGURE 1. Beach sites and treatment years. (**A**) North Beach Park (2012–2013), (**B**) Grand Haven Beach Association (2012), (**C**) Izzo's Private Beach (2013), (**D**) Grand Haven City Beach (2013), (**E**) Rosy Mound Park Beach (2012), (**F**) Kirk Park Beach (2012–2013).

Michigan coastline with numerous state, county, township park, and private beaches dotted along the shore. Study sites included a mixture of public and private properties across 2 sampling seasons (first and second half of summer) during 2012 and 2013. Four beach sites, separated from each other by at least 750 m, were used during each season. Known or potential Piping Plover (*Charadrius melodus*) nesting areas were excluded from the study. Public beach sites consisted of properties owned and operated by the Ottawa County Parks and Recreation Commission with the exception of the Grand Haven City Beach, which was owned and operated by the city of Grand Haven. Private beach properties were interspersed with public sites. County and city beach administrators granted a special-use permit to allow the use of dogs on their properties for this study.

Study Dogs

Four different border collies were leased (FlyAway Farm & Kennels, Chadbourn, North Carolina, USA) for gull harassment, with 2 dogs used each field season. All dogs were female and ranged in age from 18 mo to 7 yr. Dogs were bred from herding stock and professionally trained specifically for avian harassment, most often having worked excluding geese from military airbase runways. All dogs were delivered with instruction manuals and handlers received hands-on training from the kennel owner prior to starting treatment periods. All dogs were veterinarian-checked for health prior to use and maintained on appropriate parasite prevention medication throughout the study. All fecal matter deposited on beach sites by study dogs was immediately picked up, bagged, and disposed of in waste receptacles by the dog handler. Dogs were deployed on treatment beaches for gull harassment accompanied at all times by a trained dog handler using voice commands to direct dogs from a centralized station.

Experimental Design

Beach sites were 200 m in length, determined using a combination of satellite imagery and handheld GPS receivers (Figure 2). Sites 750–15,300 m apart were grouped into adjacent pairs with one beach randomly assigned as control and the other to receive canid harassment. Each season began in mid-May and ended mid-August for roughly a 3-mo sampling period. Seasons were separated into 2 trial periods that consisted of 38 days each with a 10-day rest period between trials. Upon completion of trial period one, a crossover design was used where all control beaches became treatment beaches and vice versa (VerCauteren et al. 2008). This crossover design was used due to having only 2 dogs available each field season and to control for site biases that may have resulted from differences in physical attributes or gull visitation between beaches. Using this crossover design, each season produced 4 control beaches and 4 treatment beaches. Gull counts were conducted on all beaches throughout all trial periods. During 2012, beaches were monitored or treated 7 days per week from 0800 to 2000 hr, which we considered continuous intensity of dog harassment. The intensity of treatments was reduced (i.e. noncontinuous intensity of dog harassment) for the 2013 field season. The reduced intensity harassment targeted times of the day when dogs could be most effective at excluding gulls while avoiding conflict with beach visitors, and was also a more effective use of personnel resources. During noncontinuous use of dogs in the 2013 season, beaches were monitored or treated 5 days per week for 4 hr following sunrise and again for 4 hr prior to sunset. Control beaches had no gull harassment, but were still monitored for gull visitation by an observer. All observation sessions consisted of gull counts at 15-min intervals from fixed positions within the beach sections. Only gulls physically on the beach were counted; this did not include gulls offshore, sitting on swim buoys, or flying over the beach during count intervals.

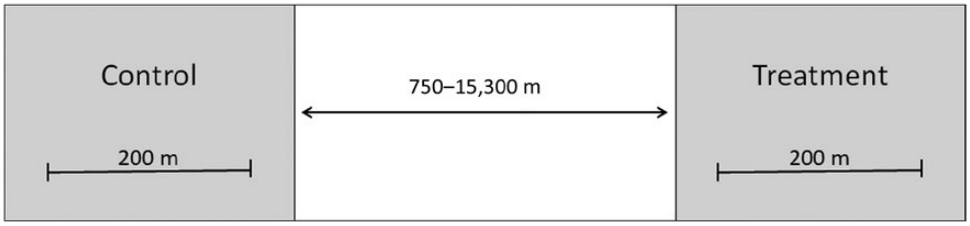

FIGURE 2. Study design including beach size, pairing, and distance from other sites. A crossover design switched treatment and control beaches during separate trial periods.

Water and Sand Sampling for *E. coli* Enumeration

Water and sand samples were collected at treatment and control beaches in the morning once per week during May–August 2012 and 2013. Three 300-mL water samples were collected within 5 m of shore and ~1 m below the surface from the middle, north end, and south end of each beach section. Water samples were collected into pre-labeled, sterile, Whirlpak bags on the end of a 2-m collection pole and placed on ice in a cooler for transport back to the lab. In the lab, composite water samples were created by mixing the 3 water samples together in a sterile beaker. Three 100-mL composite water samples were withdrawn and processed in triplicate to enumerate *E. coli* using membrane filtration over 0.45-µm Millipore HAWP grid filters and incubation at 35°C for 2 hr followed by 44.5°C for 22 hr on membrane Thermotolerant *E. coli* (mTEC) Agar (United States Environmental Protection Agency 2000).

Three sand samples each of approximately 30–40 g were collected at the middle, north end, and south end of each beach section, including both wet foreshore sand and dry backshore sand, using a sterile metal scoop. Sand samples were placed into pre-labeled, sterile, 50-mL polypropylene tubes and placed on ice in a cooler for transport back to the lab. In the lab, sand samples were combined into a composite sample by placing samples from each beach section into a sterile beaker and mixing. Three 5–10 g composite sand samples were withdrawn and stirred with Nanopure water to create a sand slurry (Alm et al. 2003) and processed in triplicate to enumerate *E. coli* using membrane filtration and incubation as described above. All samples were processed within 8 hr of collection.

For each sample processing date, we conducted a field blank control of 100 mL of Nanopure water that was prepared in the lab, transported to the beach sites and back on ice, and processed in the lab along with the field samples. We also prepared an *E. coli* positive control using dilutions of *E. coli* ATCC 25922.

Statistical Analysis

Gull count data were converted to an index (i.e. total gulls per unit effort) by totaling gull counts over an entire 38-day trial period and dividing by number of 15-min count intervals that occurred on the beach over that period of time. A Wilcoxon signed-rank test was used to compare gull use on dog-treated beaches to control beaches without gull harassment. We compared *E. coli* levels in water and sand to (1) the maximum gull count observed 0800–2000 hr prior to collecting *E. coli* samples, and (2) the average number of gulls observed within the week prior to sample collection using a Pearson's correlation analysis. These data were log-transformed to normalize them. A Wilcoxon signed-rank test was also used to compare the reduction in beach *E. coli* levels as a result of gull exclusion. A significance level of 0.10 was used to reduce the chance of committing a Type II error (Underwood and Chapman 2003). These statistical analyses were performed using program R 3.5.0 (R Core Team 2018).

We performed mixed modeling analysis in SAS 9.4 with PROC GLIMMIX (SAS Institute, Cary, North Carolina, USA) using a normal distribution, identity link, and laplace method. Before modeling took place, variables were compared using a Pearson's correlation analysis to verify variable independence ($r \leq 0.50$). For each year, the paired difference between treatment beaches and control beaches was the response variable and included (1) average number of gulls per week (ΔGull), (2) average *E. coli* level in water (ΔWater), and (3) average *E. coli* level in sand (ΔSand). Site was used as a random effect in every model to account for variation between individual sites. Explanatory variables used in these models were treatment order (first or second half of summer), age of the dog (which was an individual identifier for each dog), age of the dog nested in site (to account for individual dogs performing differently on different sites), and average number of gulls per week (only for *E. coli* models). For ΔGull, treatment order assessed any residual effect of dog use in our crossover design. We also developed intercept-only models for the gull and *E. coli* levels to isolate dogs as a main effect. Our most complex models included 2 variables (i.e. intercept + explanatory variable) because we wanted to avoid overfitting the data. An information theoretic approach corrected for small sample bias (AIC_c) was used to evaluate the models generated. Models with ΔAIC_c values ≤2 and high AIC weights (w_i) were considered to have strong empirical support (Burnham and Anderson 2002). Potentially competing models were evaluated by examining 95% confidence intervals on covariates to determine if they included zero, indicating that the covariate was uninformative (Arnold 2010).

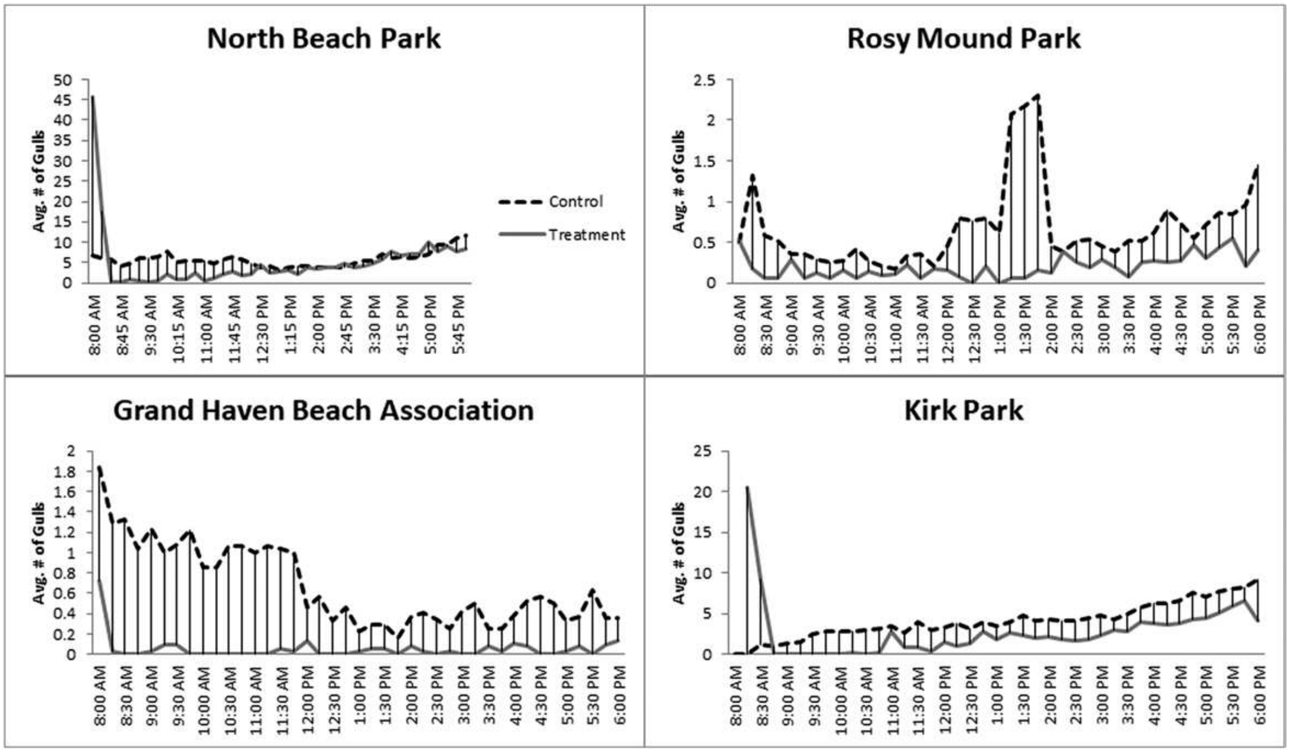

FIGURE 3. Average number of Ring-billed Gulls (*Larus delawarensis*) on beaches during each count interval throughout summer 2012.

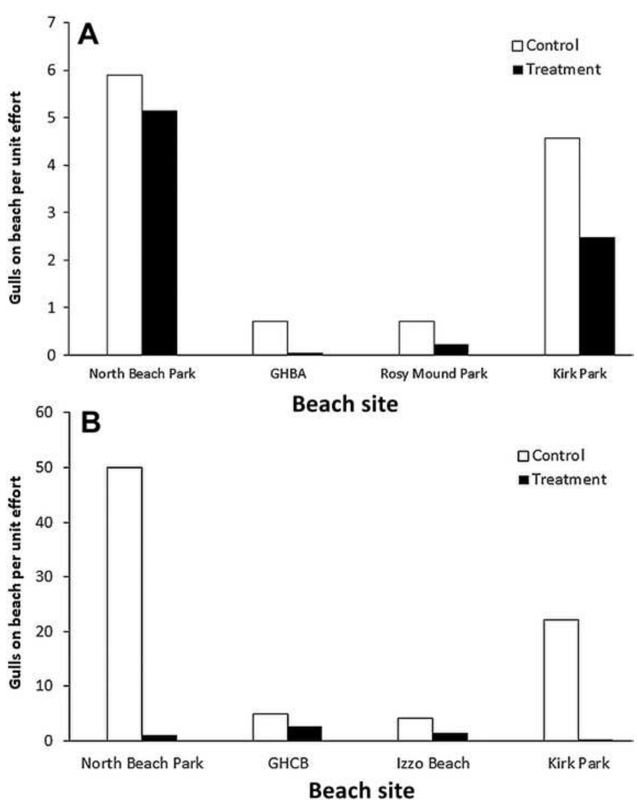

FIGURE 4. (**A**) Ring-billed Gulls per unit effort counted on beaches during summer 2012 (i.e. continuous canid harassment). (**B**) Ring-billed Gulls per unit effort counted on beaches during summer 2013 (i.e. noncontinuous canid harassment).

RESULTS

Gull Counts

During the 2012 season, we observed an average of 3.4 ± 0.9 (SE) gulls per 15-min observation period during the control periods. During dog treatment periods, 2.5 ± 0.7 gulls were observed per 15-min observation period. During the 2012 season, higher gull numbers were observed during the morning and evening hours compared to mid-day hours (except at Rosy Mound Park; Figure 3). This prompted a shift in time and reduction in treatment intensity for the 2013 season in order to better target gulls for more efficient exclusion. During the 2013 season, 20.1 ± 6.2 gulls per 15-min observation period were found during control periods, with 1.2 ± 0.3 gulls during treatment periods

Continuous use of dogs to haze gulls during 2012 led to fewer gulls on dog-treated beaches compared to control beaches ($W = 10$, $P = 0.062$; Figure 4a). We observed 56% (SE = 17%; range: 13–94%) gull reduction on treated beaches during 2012. Noncontinuous use of dogs during 2013 reduced gulls by 76% (SE = 13%; range: 45–99%; $W = 10$, $P = 0.062$; Figure 4b).

E. coli Counts

E. coli in beach water collected in this study exceeded Michigan Water Quality Standards (P323.1062) as a daily geometric mean only once during the study, at North Beach on May 21, 2012. Water quality monitoring was also performed by Ottawa County Health Department using Colilert 18 hr at a frequency of 4 times per week in 2012 and once per week in 2013. The County recorded exceedances in 2012 at North Beach on July 9, at Rosy Mound on July 24, and at Kirk Park on July 3, and in 2013 at Grand Haven City Beach and Kirk Park on June 13. High levels of *E. coli* were detected much more frequently in beach sand, with 18 of 48 samples (37.5%) above 300 CFU per 100 g sand in 2012 and 22 of 48 samples (45.8%) above 300 CFU per 100 g sand in 2013. A higher percentage of sand samples had elevated *E. coli* levels during the second half of the summer (54.2% in 2012 and 75% in 2013) than during the first half of the summer (20.8% in 2012 and 16.7% in 2013). Correlations between maximum gull counts observed during 0800–2000 hr prior to collecting samples and *E. coli* in sand and water samples, and between average number of gulls observed within the week prior to sample collection and *E. coli* in sand and water samples, were low to moderate (range of $r = -0.031$ to 0.350). A positive correlation between *E. coli* in water existed during the second half of the summer season (i.e. after dog treatment) with maximum gull counts ($r = 0.562$, $P = 0.004$) and with average number of gulls within the week prior ($r = 0.413$, $P = 0.045$). During the first half of the summer seasons the exclusion of gulls using dogs resulted in reduced *E. coli* counts measured in sand when compared to sand of control beaches with no gull exclusion ($W = 661.5$, $P = 0.002$; Figure 5). When gull exclusion by dogs occurred during the 2nd half of the summer, even though gull numbers were reduced, treatment and control beaches did not differ in overall *E. coli* burdens in sand ($W = 743.5$, $P = 0.120$; Figure 5).

Model Results

In 2012, the best model included the intercept only ($w_i = 0.63$), indicating the effectiveness of dogs in reducing gull use on beaches (Table 1). All potentially competing models had ΔGull estimates with confidence intervals that included zero. Continuous intensity of dog use reduced gulls by 0.91 gulls per week (ΔGull 95% C.I.: −1.80, −0.03). In 2013, with noncontinuous intensity of dog harassment, the best model was age nested within site ($w_i = 0.93$), indicating that dog effectiveness varied based on the age of dogs. Older dogs reduced gulls by 45.34 gulls per week compared to younger dogs (ΔGull 95% C.I.: −54.42, −36.27). In 2012, the best model to explain the reduction in *E. coli* levels in the water was the number of gulls week^{-1} ($w_i = 0.49$), whereas the potential competing intercept-only model had a confidence interval that included zero (Table 2). *E. coli* levels were reduced by 16.94 CFU per 100 g on beaches with fewer gulls (ΔWater 95% C.I.: −30.10, −0.78). *E coli* in the sand was best explained by the order of treatment ($w_i = 0.84$, Table 3). In 2012, when dogs were applied first, *E. coli* levels in sand were reduced by 2,788.07 CFU per 100 g compared to control beaches (ΔSand 95% C.I.: −4,867.75, −708.39). In 2013, the intercept-only model (effectiveness of dogs) included zero in the confidence interval, with the next best model being age nested with site ($w_i = 0.37$), indicating that dog effectiveness varied based on the age of dogs at assigned sites (Table 2). Older dogs reduced *E. coli* levels in the water at treated beaches by 25.64 CFU per 100 g compared to younger dogs (ΔWater 95% C.I.: −37.77, −13.51). *E. coli* in the sand was best explained by the order of treatment ($w_i = 0.64$, Table 3). The intercept-only model was a potential competing model, however it included zero in the confidence interval. In 2013, when dogs were applied first, *E. coli* levels in sand were reduced by 1,907.24 CFU per 100 g compared to control beaches (ΔSand 95% C.I.: −3,542.88, −271.60).

Costs of Dog Use

The cost of operations for achieving an overall reduction in gull numbers and early summer sand *E. coli* levels was \$3,000 for dog leasing (\$1,500/dog), approximately \$500 in dog equipment, food, and medical care, and labor for dog handlers at \$8–10 per hour. For one summer of continuous gull exclusion (i.e. 10 hr per day, 7 days per week) on one 200-m beach section the total cost would be \$9,200–11,000 depending on labor costs. Noncontinuous use of dogs for gull exclusion (i.e. 8 hr per day, 5 days per week) cost \$6,160–7,200 depending on labor costs.

DISCUSSION

Border collies have been deployed to exclude gulls from beaches in several large cities (e.g., Chicago, Illinois; Milwaukee, Wisconsin; and Toronto, Ontario; Koski and Kinzelman 2010). Canine harassment has been employed at Chicago area beaches since 2006, with Chicago 63rd Street Beach receiving dawn-to-dusk harassment during summers of 2010–2013 (Beckerman et al. 2010, Hartmann et al. 2013). It was reported that harassment was highly effective, but reductions in gull numbers were not quantified (Beckerman et al. 2010, Dorfman and Rosselot 2011, Hartmann et al. 2013). Only one study has used an experimental design to test the effectiveness of canid harassment. Converse et al. (2012) conducted a study that focused on the improvement of water quality, as indicated by *E. coli* reductions, in response to bird harassment using dogs. They found that by the end of one week of canine harassment average bird numbers had been reduced by 98%. As a result of a 50% bird population reduction, they observed a 29% decrease in *E. coli* counts (Converse et al. 2012). While their study is currently the only experimental study focusing on gull harassment using dogs and resulting in reductions in gull numbers and *E. coli* levels, their study was limited to 16 days of dog treatment at a single beach.

In the current study, border collies were shown to be an effective tool for managing gulls on public beaches with a

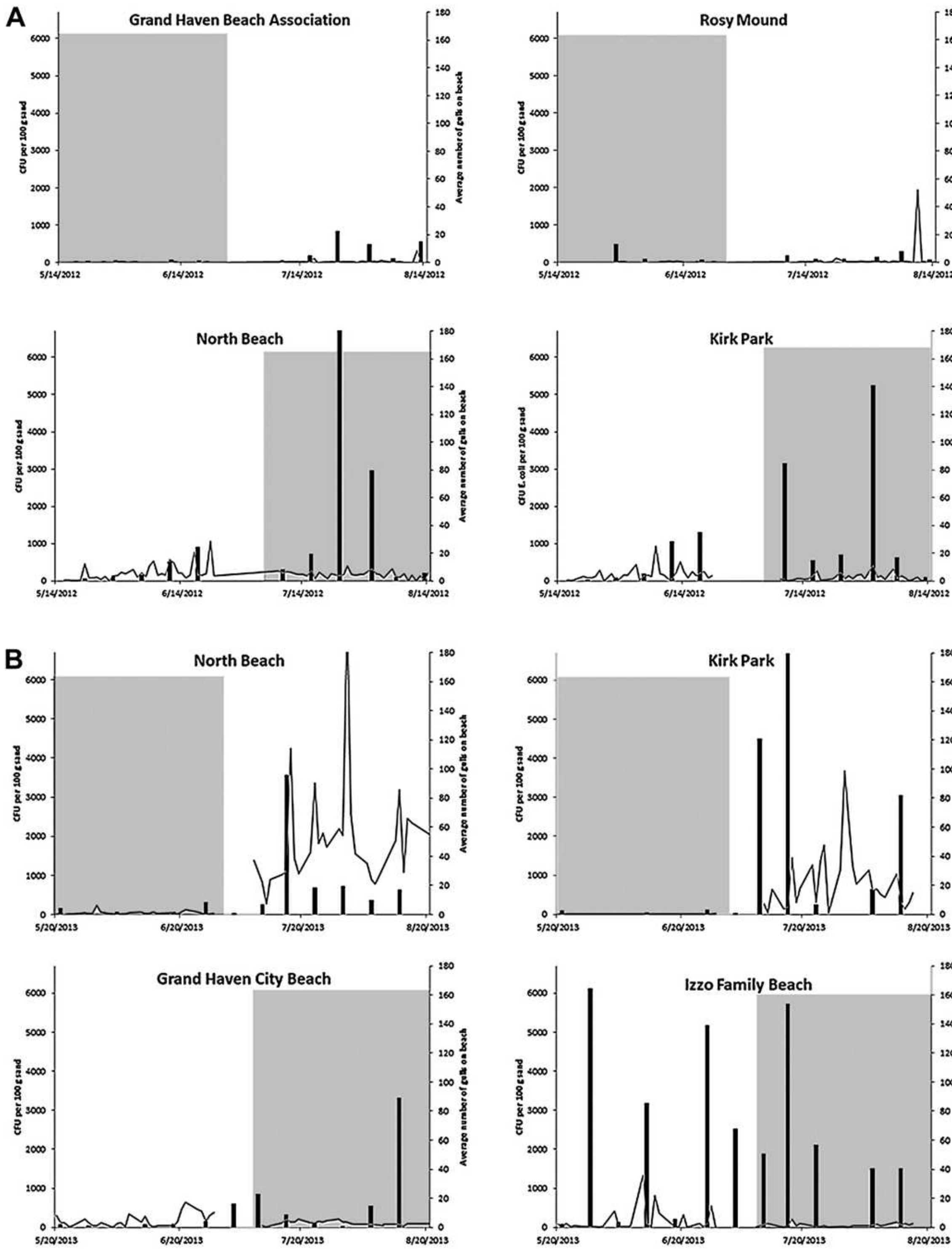

FIGURE 5. Gull and *E. coli* burdens at beaches. (**A**) Summer 2012. (**B**) Summer 2013. Black bars: CFU *E. coli* per 100 g of beach sand. Gray lines: average number of Ring-billed Gulls on beach per unit effort. Gray shaded area represents when dogs were excluding gulls.

reduction in gull numbers of up to 94% in the first year and 99% during the second. The reduction in gulls achieved at a beach may vary depending on beach-specific characteristics (width, topographic and flora features), human gull encouragement, individual dog effectiveness, and timing of exclusion. This was evidenced by our variation in effectiveness of dogs to reduce gull numbers among our treatment beaches. For example, in 2012 gull numbers at North

TABLE 1. Model selection results for variables evaluating effectiveness of border collies for decreasing the average number of Ring-billed Gulls (*Larus delawarensis*) per week present on Lake Michigan beach sites in Ottawa County during the summers of 2012 (i.e. continuous canid harassment) and 2013 (i.e. noncontinuous canid harassment). *K* is the number of parameters, w_i is AIC weight.

Year	Model	K	$-2 \ln L$	ΔAIC_c	w_i
2012	Intercept	2	84.96	0.00[a]	0.63
	Age	3	84.53	2.37	0.19
	Order	3	84.88	2.72	0.16
	Age(Site)	5	82.53	7.16	0.02
2013	Age(Site)	5	184.67	0.00[b]	0.93
	Order	3	193.29	5.39	0.06
	Age	3	198.50	10.60	<0.01
	Intercept	2	214.28	20.84	<0.01

[a] The lowest AIC_c = 89.66.
[b] The lowest AIC_c = 198.01.

TABLE 2. Model selection results for variables evaluating efficacy of border collies for decreasing the *E. coli* level in water present on Lake Michigan beach sites in Ottawa County during the summers of 2012 (i.e. continuous canid harassment) and 2013 (i.e. noncontinuous canid harassment). *K* is the number of parameters, w_i is AIC weight.

Year	Model	K	$-2 \ln L$	ΔAIC_c	w_i
2012	Gull	2	229.25	0.00[a]	0.49
	Intercept	2	233.08	1.03	0.29
	Order	3	232.13	2.88	0.12
	Age	3	232.47	3.22	0.10
	Age(Site)	5	230.75	8.29	0.01
2013	Intercept	2	283.70	0.00[b]	0.45
	Age(Site)	5	275.37	0.43	0.37
	Order	3	282.01	3.85	0.07
	Gull	2	282.05	3.89	0.06
	Age	3	282.64	4.48	0.05

[a] The lowest AIC_c = 236.75.
[b] The lowest AIC_c = 288.27.

Beach Park were only reduced 13% compared to a 94% reduction in gull numbers at Grand Haven Beach Association. Variation was also evident between years. In 2013, Age(Site) models were ranked higher than in 2012, showing individual differences between dogs at different beach sites was having a stronger effect on gull and *E. coli* levels. This is likely due to differences between the dogs in the 2 years. In 2013, one of the dogs was young and delivered in poor health, and this may have affected that dog's performance throughout the first part of the summer. Despite this, during 2013 there was higher overall dog effectiveness among treatment beaches, which may be linked to the using dogs on beaches during morning and evening when gulls were attempting to use beaches in greater numbers.

The effectiveness of the dogs at reducing gull numbers translated into improved beach microbial quality. When

TABLE 3. Model selection results for variables evaluating efficacy of border collies for decreasing the *E. coli* level in sand present on Lake Michigan beach sites in Ottawa County during the summers of 2012 (i.e. continuous canid harassment) and 2013 (i.e. noncontinuous canid harassment). *K* is the number of parameters, w_i is AIC weight.

Year	Model	K	$-2 \ln L$	ΔAIC_c	w_i
2012	Order	3	363.74	0.00[a]	0.84
	Intercept	2	370.44	3.91	0.12
	Age(Site)	5	363.63	6.67	0.03
	Gull	2	369.75	9.17	0.01
	Age	3	369.88	9.30	0.01
2013	Order	3	432.65	0.00[b]	0.64
	Intercept	2	437.59	2.31	0.20
	Age(Site)	5	430.00	3.48	0.11
	Gull	2	436.07	6.33	0.03
	Age	3	436.68	6.94	0.02

[a] The lowest AIC_c = 371.24.
[b] The lowest AIC_c = 439.85.

dogs were deployed during the first half of the summer, *E. coli* levels in sand were reduced compared to control beaches (Figure 5). Order was the most important predictor for *E. coli* levels in sand, likely because *E. coli* levels in sand build up throughout the summer. Continuous gull exclusion on a beach throughout an entire summer season was not tested in this study; therefore *E. coli* counts during the second half of the summer during continuous treatment could vary. It is likely that while continued *E. coli* loading by gulls would be minimal with sustained canid harassment, *E. coli* already deposited in the sand may persist and perhaps replicate in situ, resulting in increased abundance in sand despite gull exclusion. This indicates that in future management efforts, dogs should be used as early in the season as possible to prevent initial *E. coli* loading by gulls.

The noncontinuous use of dogs (i.e. morning and evening harassment for 5 days per week) still provided a reduction in gull numbers and *E. coli* levels at beaches. Thus, beach management to exclude gulls may not need to be continuous from dawn to dusk, 7 days per week, and instead might target harassment of gulls during peak gull-use times. While gull numbers were greatly reduced throughout the time period that dogs were used, it is unclear what the long-term response of gulls would be once dogs are no longer used to harass gulls. Some sources indicate that gull numbers quickly return to previous levels after harassment from border collies (Hartmann et al. 2009, Koski and Kinzelman 2010, Hartmann et al. 2012).

When considering border collies as a management tool for gulls it is important to weigh the costs and benefits of implementing such a program. While dogs are effective for excluding gulls from beaches and improving beach quality, leasing or purchasing border collies along with the costs of properly housing and caring for the dog can be expensive. The costs of hiring a handler to work with the dog at all times must also be considered. With this in mind, managers should first determine the severity of their gull problem and decide if there are cheaper removal or harassment methods available. If there is a large number of persistent gulls on the property, it may be necessary to employ dogs for harassment purposes. The use of falcons (*Falco* spp.) for reducing gulls at beaches may offer another strategy similar to use of dogs. Baxter and Allan (2006) found that falcons reduced gull numbers at landfill sites an average of 65.6%. However, use of falcons requires a professional falconer (Baxter and Allan 2006), which may result in higher costs compared to dogs. Further, use of falcons may result in lethal removal of gulls, which may be received poorly by the public (Cook et al. 2008). Falcons can be used only during dry weather conditions (Baxter and Allan 2006), whereas dogs may be used in nearly all weather conditions. An integrated approach, where dogs are part of an arsenal of prevention and control techniques, would likely be most effective for long-term gull management at beaches (Koski and Kinzelman 2010, Hartmann et al. 2013). Further, educational campaigns of public beach users and restrictions on gull access to food resources at beaches should be included in this integrated approach. State Park properties were not used in this study, as the state would not allow dogs on beach areas or off leash at any time. Thus, beach managers may be limited to where dogs can be used or required to seek special exemptions to use dogs at restricted sites. However, our noncontinuous use of dogs for harassing gulls was effective by targeting peak use of beaches by gulls and largely avoiding time periods when most public beach users were present during mid-day. We projected that costs associated with noncontinuous dog use were 42% lower compared to continuous dog use.

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