Research Article

Roost Site Selection by Ring-Billed and Herring Gulls

DANIEL E. CLARK,[1] *Massachusetts Department of Conservation and Recreation, Division of Water Supply Protection, 180 Beaman Street, West Boylston, MA 01583, USA*

STEPHEN DESTEFANO, *U.S. Geological Survey, Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts, Amherst, MA 01003, USA*

KENNETH G. MACKENZIE, *Massachusetts Department of Conservation and Recreation, Division of Water Supply Protection, 180 Beaman Street, West Boylston, MA 01583, USA*

KIANA K. G. KOENEN, *Massachusetts Department of Conservation and Recreation, Division of Water Supply Protection, 485 Ware Road, Belchertown, MA 01003, USA*

JILLIAN J. WHITNEY, *Massachusetts Department of Conservation and Recreation, Division of Water Supply Protection, 180 Beaman Street, West Boylston, MA 01583, USA*

ABSTRACT Gulls (*Larus* spp.) commonly roost in large numbers on inland and coastal waters, yet there is little information on how or where gulls choose sites for roosting. Roost site selection can lead to water quality degradation or aviation hazards when roosts are formed on water supply reservoirs or are close to airports. Harassment programs are frequently initiated to move or relocate roosting gulls but often have mixed results because gulls are reluctant to leave or keep returning. As such, knowledge of gull roost site selection and roosting ecology has applied and ecological importance. We used satellite telemetry and an information-theoretic approach to model seasonal roost selection of ring-billed (*L. delawarensis*) and herring gulls (*L. argentatus*) in Massachusetts, USA. Our results indicated that ring-billed gulls preferred freshwater roosts and will use a variety of rivers, lakes, and reservoirs. Herring gulls regularly roosted on fresh water but used salt water roosts more often than ring-billed gulls and also roosted on a variety of land habitats. Roost modeling showed that herring and ring-billed gulls selected inland fresh water roosts based on size of the water body and proximity to their last daytime location; they selected the largest roost closest to where they ended the day. Management strategies to reduce or eliminate roosting gulls could identify and try to eliminate other habitat variables (e.g., close-by foraging sites) that are attracting gulls before attempting to relocate or redistribute (e.g., through hazing programs) roosting birds.

KEY WORDS herring gull, *Larus argentatus*, *Larus delawarensis*, Massachusetts, ring-billed gull, roosting, selection.

Communal roosting is common in birds and can be defined as a group of >2 individuals that come together to rest and sleep (Beauchamp 1999). Within the family Laridae, large communal roosts on inland and coastal waters are widespread and may number in the thousands or tens of thousands (Schreiber 1967, Gosler et al. 1995, Nugent and Dillingham 2009). Gosler et al. (1995) speculated that the creation of human-made inland roosting sites (e.g., reservoirs and flooded gravel pits) coupled with reliable inland sources of food (e.g., landfills) has increased the abundance of gull (*Larus* spp.) populations and their prevalence on inland water bodies.

There are a number of potential benefits to roosting communally, including reduced thermoregulation costs, increased predator detection, and safety in numbers from predators (Weatherhead 1983, Bijleveld et al. 2010). Additionally, communal roosts may function as communication centers where individuals share information about the location of patchily distributed food (Ward and Zahavi 1973). Although there has been some research on the behavioral mechanisms influencing the evolution of communal roosting, very few studies have identified the characteristics of sites gulls choose for roosting. Further, most of these studies have relied on visual surveys of known or suspected roosting sites, and did not assess roost site occupancy through satellite transmitters (Schreiber 1967, Hickling 1973). Although visual surveys can be helpful in characterizing roosting sites that are already known, satellite tracking individual gulls can provide information on known and unknown roost sites on a large spatial and temporal scale.

Roost site selection can have a variety of ecological and societal impacts. Gulls roosting on water supply reservoirs can lead to increased contamination and the potential for disease transmission (Benton et al. 1983, Hatch 1996, Nugent and Dillingham 2009). Further, gulls roosting on recreational water bodies (e.g., swimming beaches) can substantially increase fecal pollution and the prevalence of

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[1]*E-mail: dan.clark@state.ma.us*

other pathogens, leading to degraded recreational water quality (Fogarty et al. 2003, Jeter et al. 2009, Converse et al. 2012). Roosting gulls have also been linked to increased levels of phosphorus and nitrogen in freshwater ponds (Portnoy 1990). In addition, gulls moving between roosting and feeding sites may pose a major hazard to aviation (Gosler et al. 1995, Dewey and Lowney 1997). Gulls are the most commonly struck bird in the United States, and communal roosts near airports may increase risks to airplanes as approaching aircraft cross paths with gulls flying to and from roosting areas (Dewey and Lowney 1997, Cleary et al. 2006).

In Massachusetts, USA, 65% of the state's population depends on surface water reservoirs for their drinking water (Lent et al. 1997). Quabbin and Wachusett reservoirs are the first and second largest bodies of fresh water in the state, respectively (MassGIS 2010). These reservoirs serve as the treated but unfiltered water supply for >2 million consumers in metropolitan Boston. Gulls roosting on these reservoirs were first noted anecdotally in the 1960s and have been formally monitored since the 2000s. The number of roosting gulls increases from late summer through fall and typically peaks during mid-winter; 4,000 gulls may roost on these reservoirs. Seasonal fluctuations in the number of roosting ring-billed (*L. delawarensis*) and herring (*L. argentatus*) gulls on Wachusett and Quabbin reservoirs are strongly correlated with increased fecal coliform levels in water quality samples and subsequent water quality degradation (Metropolitan District Commission 1991, 1992). The presence of gulls on these reservoirs necessitates a costly and potentially hazardous (e.g., use of firearms, boating during winter) bird harassment program to maintain source water quality standards. Although harassment has been used successfully to reduce the impact of roosting gulls (Benton et al. 1983, Nugent and Dillingham 2009), identifying important roost site characteristics may provide insight into why particular water bodies are selected. This information could lead to preventative measures to exclude gulls completely or increase the efficiency or effectiveness of current programs. Our objectives were to characterize the seasonal roost selection of ring-billed and herring gulls and to identify the key environmental factors influencing selection of inland water roost sites in Massachusetts.

STUDY AREA

We conducted this study in Massachusetts in Worcester, Franklin, Hampshire, and Hampden counties from October to April 2008–2013. The study area was comprised of a variety of small towns and medium cities, including Worcester, the second largest city in Massachusetts (population 181,000 in 2010). Large shopping centers, golf courses, residential areas, and freshwater lakes and reservoirs were common. Undeveloped land was primarily forested and was characterized by rolling, rocky hills. The study area had 4 distinct seasons (summer, fall, winter, and spring); summers were warm and humid, and winters were cold and snowy. We captured ring-billed and herring gulls at 18 trapping locations, which were located in urban or suburban areas around the cities of Worcester (42°15′N, 71°48′W) and Springfield (42° 6′N, 72°35′W; Clark et al. 2014; Fig 1). We chose trapping locations opportunistically to maximize capture success and included a variety of areas including parking lots, landfills, wastewater treatment plants, and inland beaches.

METHODS

Satellite Tracking

We used a net launcher (2008–2012) to capture gulls (Clark et al. 2014). We fitted ring-billed gulls (2008–2012) with solar powered 9.5-g (Microwave Telemetry, Columbia, MD) or 9.5-g (Northstar Science and Technology, King George, VA) ARGOS platform terminal transmitters (PTTs). We fitted herring gulls (2008–2010) with solar powered 22-g or 30-g global positioning system (GPS) transmitters (Microwave Telemetry) or 11.5-g PTTs (Northstar Science and Technology). Transmitters represented <3% of body mass of the birds. We attached transmitters as backpacks with loops around the neck and body. The harness consisted of 6-mm wide tubular Teflon ribbon (Bally Ribbon Mills, Bally, PA), braided nylon fishing line as thread, cyanoacrylate adhesive, and a 2.5-cm 2.5-cm leather breast piece. Attachment followed the procedure described by Snyder et al. (1989) but without the feather shield. Animal care and use procedures were approved by the Institutional Animal Care and Use Committee of the University of Massachusetts-Amherst (letter dated 17 Aug 2011).

We programmed GPS transmitters to transmit 6 times/day (mid-morning, noon, mid-afternoon, late afternoon, evening, and night); times shifted slightly seasonally to account for longer days. We programmed ARGOS PTTs to turn on and transmit for 8 hours each day, then turn off for 18 hours. This 26-hour duty cycle ensured that transmissions occurred throughout each 24-hour period.

The PTTs used the ARGOS system to transmit locations from tagged birds via satellite. Each received transmission was assigned a location class (LC) based on the quality of the reception (ARGOS 2013). The ARGOS system classified locations into 1 of 7 classes: Z, B, A, 0, 1, 2, or 3 in ascending order. Although ARGOS provided an associated accuracy assessment for LCs 0–3, we assessed transmitter accuracy (x distance between test location and true position) independently in the field before deployment. We activated all transmitters and placed them on a flat roof for 2 weeks. We collected all locations from these test transmitters and compared them to the actual location.

Classification of Seasonal Roost Sites

We filtered data from gulls equipped with ARGOS PTTs and retained only LCs 1, 2, or 3. We defined roost sites as locations (point coordinates) that were received 0.5 hours after sunset or 0.5 hours before sunrise. We retained 1 location/night/individual. If >1 location was received for an individual during a night, then we kept either the highest quality location, or if multiple locations of the same class were received, we selected randomly 1 location and discarded the rest.

Figure 1. Gull capture locations (●) and general study area in relation to Quabbin and Wachusett reservoirs and Springfield and Worcester (▲), Massachusetts, USA, 2008–2013.

For each nighttime location (point coordinate), we generated a circular buffer in ArcGIS 10.0 with the nighttime location as the center and a radius equal to the calculated accuracies of each transmitter for each location class. For example, for nighttime locations received from ring-billed gulls equipped Microwave transmitters that were classified as a 3, we plotted the received location in the center of a polygon with a radius of 354 m (the calculated error for that transmitter type with that location class). In ArcGIS 10.0, we plotted each location point and its associated error polygon over georeferenced color aerial photographs (Environmental Systems Research Institute, Inc., Redlands, CA). We identified the roosting site for each location based on the intersection of each error polygon with its underlying habitat feature. In most cases, the circular polygon intersected with only 1 biologically plausible roosting site (e.g., body of water; not a large forested area). In cases where the polygon intersected with multiple potential roosting sites (e.g., water body and island), we classified the location as unknown. In addition, when the error polygon intersected with a variety of habitats (e.g., an urban area), we classified the site broadly (e.g., urban) when possible, but we did not identify a specific site. We classified each identified roosting site as either land or water and further classified sites for specific land (e.g., bridge, dock, island, pier, roof, shoreline) and water (e.g., fresh, brackish, salt) locations. For fresh water roosts, we identified each site as a lake (i.e., natural body of water), reservoir (i.e., man-made), or river. We determined roosting sites from gulls equipped with GPS transmitters the same way but without an associated error polygon.

Each roosting location was assigned to a specific season. Boundaries for these seasonal breaks were determined by weather changes and gull activity patterns (e.g., breeding vs. non-breeding). We used 4 seasons: spring (Mar–May), summer (Jun–Aug), fall (Sep–Nov), and winter (Dec–Feb). We used descriptive statistics to describe the seasonal roost site selection of herring and ring-billed gulls.

Roost Site Selection Modeling

To compare the characteristics of inland water sites that were used and not used for roosting, we restricted our data to freshwater locations in the study area. For the modeling analysis, we further filtered all roost locations to include only those that also had an associated daytime location that was received 2 hours before sunset (i.e., during the same day when the roosting location was recorded). Because PTTs transmitted in 8-hour blocks only during periods when satellite communication was possible, not all nighttime locations had a daytime location from the same day.

For each individual bird used in the analysis, we calculated 95% minimum convex polygons using the HomeRange plugin in Quantum GIS 1.7.3 (Mohr 1947; Quantum GIS Development Team, http://www.qgis.org/, accessed 22 Sep 2012). For each roosting location, we described the used roosting site and 1 randomly selected (with replacement) inland water body site from a pool of all available water bodies within each bird's seasonal home range. We selected random sites using ArcGIS 10.0 and statewide hydrology data from MassGIS. Based on sizes of used roosts, we set a water body size of 12 ha for ring-billed and 50 ha for herring gulls to be eligible for selection. We considered all water bodies within these size limits in each bird's Massachusetts' home range to be available. For each roosting site, we recorded several variables for the used roost and randomly selected site. We selected the following variables based on the availability of data and biological relevance: the size in ha (size) of each used or random site, the distance between each gull's last daytime location (daytime) to the center of the used or random site (m), and the distance (m) between the used or random site and the nearest known foraging location (food). We determined these foraging sites through a separate analysis (D. E. Clark, Massachusetts Department of Conservation and Recreation, unpublished data) and they included parking lots, agricultural fields, landfills, and wastewater treatment plants. Finally, we considered the fourth variable to be the disturbance potential of each water body by estimating the maximum distance a gull could roost from the shoreline (disturbance). Disturbance included shoreline activities that could potentially disturb roosting gulls, including human visitation (i.e., fishing, dog walking) and terrestrial predators (i.e., coyotes [*Canis latrans*], foxes [*Vulpes* spp.]). We calculated the maximum diameter of each used and random site using the CONVEX_HULL feature of the Minimum Bounding Geometry Tool in ArcGIS 10.0. This tool calculated the maximum distance from the center of a water body to its shoreline. Larger radii would represent lower potential disturbance from shoreline activities.

Statistical Analysis

We evaluated our data for correlations to ensure no pairs of variables were highly correlated (Spearman's r_s 0.5; Zuur et al. 2010). Highly correlated variables most likely measured the same or similar roost characteristics. If we found strong correlations between variables, we retained the variable we determined to be the most biologically meaningful for later analysis. We modeled roost site selection by ring-billed and herring gulls with generalized linear mixed models (GLMMs) of the binomial family using the lme4, AICcmodavg, and MuMin packages in R 3.1.2 (Bates et al. 2014, R Development Core Team 2014, Barton 2015, Mazerolle 2015). We included each satellite-tagged gull as a random variable to account for correlation among data points within each bird (Koper and Manseau 2010). We modeled differences among gulls by allowing the intercept of the relationship between each of our independent variables and the dependent variable to be different for each gull. We coded used inland roosts as 1, and available (random) roosts as 0. We used an information-theoretic approach and Akaike's Information Criterion (AIC or AIC_c to correct for small sample sizes) to scrutinize the relative strength of a priori selected models. We calculated Akaike model weights and considered the model with the lowest AIC to be the most parsimonious model (Burnham and Anderson 2002). If the best model had a weight 0.90, we used model averaging to obtain estimates of the regression coefficients, using models with ΔAIC_c 2 (Burnham and Anderson 2002).

Because there were no previously published studies on gull roost site selection, we conducted an informal survey of gull researchers in the eastern United States and Canada to ask what predictor variables may be important in determining roost site selection. We used their input and our own experience and judgment to select predictor variables. We considered size to be an important predictor variable and modeled size with various interactions of the variables food, daytime (distance to last daytime location), and disturbance (max. radius of each water body). We included distance to last daytime location because gulls often forage just before traveling to their nighttime roost location (D. Clark, personal observation). In addition to the global model and null model (intercept only), we included 6–8 other candidate models including simple models that contained only 1 variable.

We centralized predictors of model-averaged estimates (Gelman 2008). Centralizing predictors is necessary when model averaging is used, particularly when interactions are present in the model (Grueber et al. 2011). We calculated the model-averaged parameter estimates, the unconditional standard error of each estimate, and the mean relative importance of the predictive variables that were present (Burnham and Anderson 2002).

To assess the fit of the most parsimonious models, we applied the Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000). We also assessed the discrimination capacity of the averaged models by estimating the receiver operating characteristic (ROC) curve using the R package pROC (Robin et al. 2011). Once the curve is developed, a single index can be generated. The index represents the capacity of the model to distinguish between true positives and false positives used to create the curve (Pearce and Ferrier 2000). An index between 0.5 and 0.7 indicates poor discrimination capacity; values between 0.7 and 0.9 indicate reasonable capacity, and values >0.9 indicate very good discrimination capacity (Pearce and Ferrier 2000). We used the R package LinRegInteractive (Meermeyer 2014) to visualize and plot the effects of the most supported predictor variables on the response variable for certain models. Finally, we compared differences between used and random roosting sites using Student's *t*-tests (Fowler et al. 1998).

RESULTS

Seasonal Roost Selection

We fitted 21 ring-billed gulls with satellite transmitters. Accuracy for GPS transmitters was 18 m for the 22-g models and 30 m for the 30-g models. For PTTs, we used only LC 1, 2, and 3. Transmitter accuracy for the 9.5-g Microwave model was 1,890 m (1), 1,217 m (2), and ,354 m (3). Accuracy for the 9.5-g Northstar was 1,572 m (1), 587 m (2), and 336 m (3). For 11.5-g transmitters, accuracy was 1,959 m (1), 858 m (2), and 218 m (3). Gulls transmitted an average of 12.6 months (range = 1–35). Thirteen gulls provided 1,292 nighttime roosting locations of class 1, 2, or 3 (3 most accurate ARGOS classes). The remaining 8 gulls did not provide useable locations. We fitted 13 herring gulls with transmitters, which transmitted an average of 14.2 months (range = 1–52). Six herring gulls were equipped with GPS transmitters and provided 1,328 nighttime roosting locations. Six herring gulls were equipped with PTTs and provided 970 locations of class 1, 2, or 3, and 1 herring gull provided no usable locations.

We were able to identify 1,205 of the 1,292 (93%) ring-billed gull roosting locations. Ring-billed gulls provided roosting locations from all 4 seasons. Most locations were received in winter ($n = 402$), followed by fall ($n = 307$), spring ($n = 287$), and summer ($n = 209$). For herring gulls, we were able to identify 2,242 of the 2,298 (98%) locations. Most locations were received in spring ($n = 842$), followed by winter ($n = 561$), summer ($n = 554$), and fall ($n = 285$).

The majority of ring-billed gull roosting locations were identified as water (93%), and gulls used water roosts consistently across seasons (Fig. 2). Herring gulls also roosted on water (64%), but frequently roosted on land

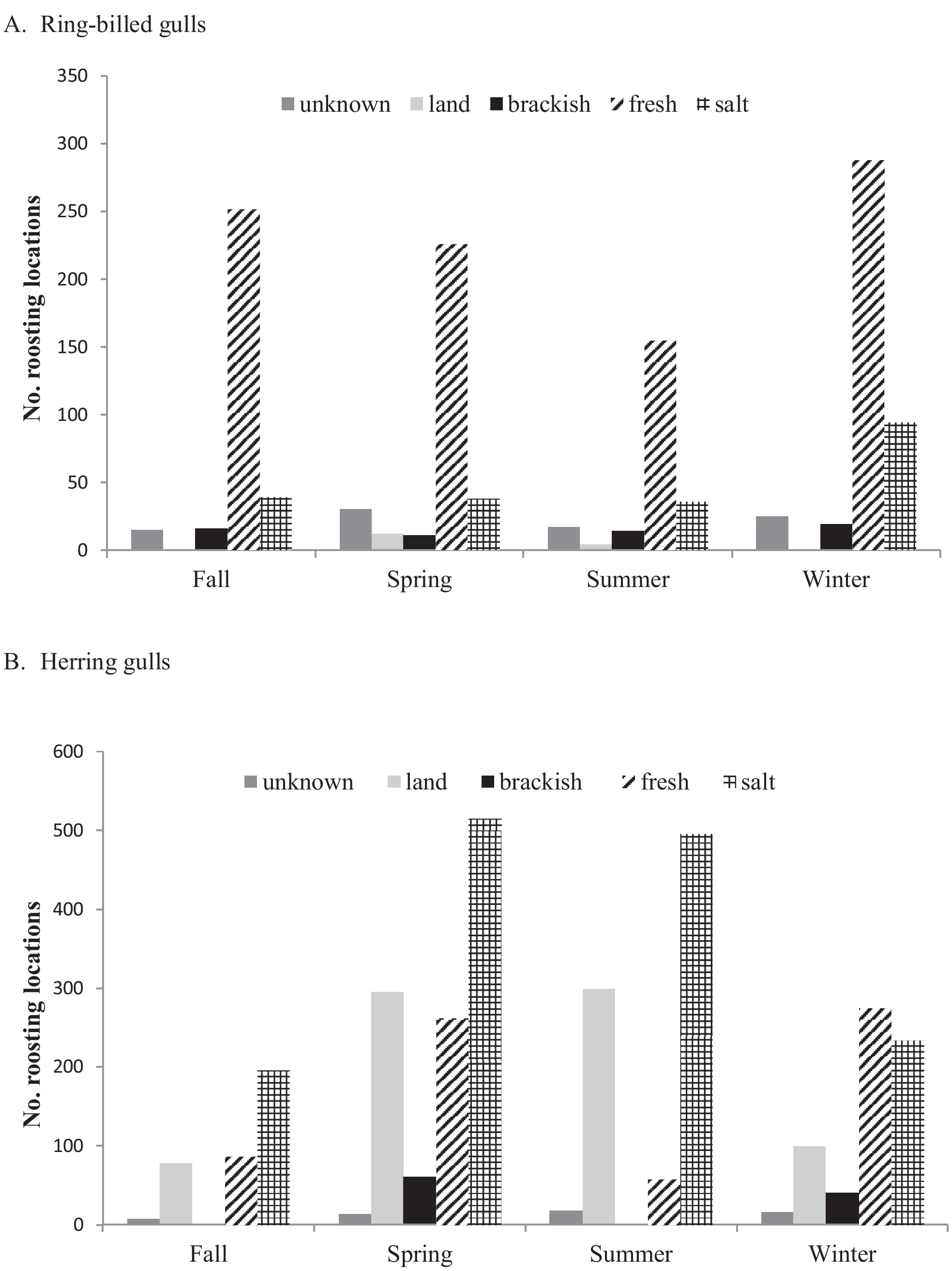

Figure 2. Number of times satellite tagged ring-billed ($n = 13$; A) and herring gulls ($n = 12$; B) roosted on unknown, land, brackish, fresh, or salt water during spring (Mar–May), summer (Jun–Aug), fall (Sep–Nov), and winter (Dec–Feb), in the United States and Canada, 2008–2012.

(34%), particularly during spring and summer (Fig. 2). Most land roosts were identified as islands ($n = 502$, 65%), followed by piers ($n = 143$, 19%) and roofs ($n = 101$, 13%). Other land roosts used less frequently were bridges, docks, and coastal shorelines.

Ring-billed gulls were most often identified roosting on fresh water, whereas herring gulls were more likely to be found roosting on salt water in all seasons except winter, when they used fresh water slightly more often (Fig. 2). When roosting on fresh water, both herring and ring-billed gulls used lakes, rivers, and reservoirs. Ring-billed gulls used lakes (37%), reservoirs (32%), and rivers (31%) in about the same proportion, whereas herring gulls used lakes (47%) more often than rivers (29%) or reservoirs (25%).

Roost Site Selection in Massachusetts

Twelve of the 13 tagged herring gulls and 12 of the 21 tagged ring-billed gulls provided 364 and 333 inland Massachusetts water roosting locations, respectively. Ring-billed gulls roosted on 22 different water bodies, and herring gulls roosted on 34 different water bodies; however, only 14 roosts were used >5 times during the study, and 4 roosts accounted for 66% of the locations (Table 1).

For the modeling analysis, 9 ring-billed and 10 herring gulls provided 42 and 166 useable roost locations, respectively. Spearman tests showed strong correlation ($r_s = 0.98$) between size and disturbance variables for roosting ring-billed gulls only. Therefore, we retained size in our ring-billed models but eliminated disturbance because we felt size was a more relevant variable. No correlations existed among the rest of the variables. Our modeling suggested that herring and ring-billed gulls selected roost sites based on the interaction of >1 variable. For ring-billed gulls, the most supported of the a priori models included the interaction between size of a water body and distance from the last daytime location to the roosting location ($w_i = 0.52$; Table 2). There was also strong support for the second ($\Delta AIC_c = 1.35$, $w_i = 0.27$) model, which included the interaction between size and last daytime location in addition to distance to foraging area (food). Because there was some model uncertainty, we averaged these top 2 models. Model-averaged coefficients for size and food were positive, whereas averaged coefficients for daytime and size daytime were negative (Table 3). However, the confidence interval for the model-averaged regression estimate of food included 0, indicating there was little evidence that distance to foraging

Table 1. Inland water roosting sites used by ring-billed ($n = 12$) and herring gulls ($n = 12$) in Massachusetts, USA, 2008–2013. Only locations used 5 times by 1 species were included.

			No. times used		
Water body	**Size (ha)**	**Radius (m)**	**Ring-billed**	**Herring**	**Total**
Quabbin Reservoir	9,895	1,600	13	1	14
Wachusett Reservoir	1,564	2,157	187	117	304
Merrimack River	642	288	0	11	11
Connecticut River	531	254	1	48	49
Webster Lake	506	1,069	9	27	36
Sudbury Reservoir	376	1,205	21	8	29
Quaboag Pond	221	925	25	2	27
Singletary Pond	143	721	2	46	48
Stiles Reservoir	128	424	0	8	8
Lake Quinsigamond	84	258	3	7	10
Flint Pond	67	486	0	11	11
Foss Reservoir	63	434	7	0	7
Indian Lake	61	409	13	45	58
Lake Cochituate	58	391	32	1	33

Table 2. Results of generalized linear models testing the effects of water body size, distance to foraging, and distance from last daytime location on roost site selection of ring-billed gulls in Massachusetts, USA, 2008–2012. We also included individual bird as a random effect in all models.

Model[a]	**Log-likelihood**	K[b]	AIC_c[c]	ΔAIC_c	w_i[d]
Size daytime	33.35	5	77.48	0.00	0.52
Size daytime + food	32.87	6	78.83	1.35	0.27
Size	37.16	3	80.61	3.14	0.11
Size + daytime + food + size daytime + size food + (global)	32.87	7	81.21	3.73	0.08
Size food	36.76	5	84.28	6.81	0.02
Daytime	54.19	3	114.68	37.20	0.00
Intercept only (null)	58.22	2	120.60	43.12	0.00
Food	57.66	3	121.62	44.15	0.00

[a] Size: area in ha; food: distance (m) of a water body to nearest foraging location; daytime: distance (m) from a bird's last daytime location to its nighttime roost.
[b] Number of parameters.
[c] Second-order Akaike's Information Criterion (for small sample sizes).
[d] Akaike weight.

Table 3. Results from model averaging the top 2 models of the effects of each parameter on a ring-billed gull roost site being used or random (available), Massachusetts, USA, 2008–2012.

Parameter	Estimate[a]	Unconditional SE	CI	Relative importance
(Intercept)	1.069	0.763	(0.182, 2.319)	
Size	6.474	2.381	(2.571, 10.377)	1.00
Daytime	2.558	1.158	(4.456, 0.660)	1.00
Size daytime	5.667	3.446	(11.314, 0.020)	1.00
Food	0.097	0.219	(0.195, 0.771)	0.34

[a] Effect sizes have been standardized.

areas affected whether a roost was used or not. Size had a positive effect on whether a roost was used; as roost size increased, they were more likely to be used (Fig. 3). Daytime and size daytime had a negative effect on whether a roost was used; roosts closer to the last daytime location were more likely to be used, but ring-billed gulls were more likely to travel farther to roost on a larger water body (Fig. 3). The Hosmer–Lemeshow goodness-of-fit statistic ($\chi^2 = 15.66$, $P = 0.05$) on the most parsimonious model suggested a reasonably poor fit; however, the ROC curve index for the averaged model was 0.907, suggesting very good discrimination ability.

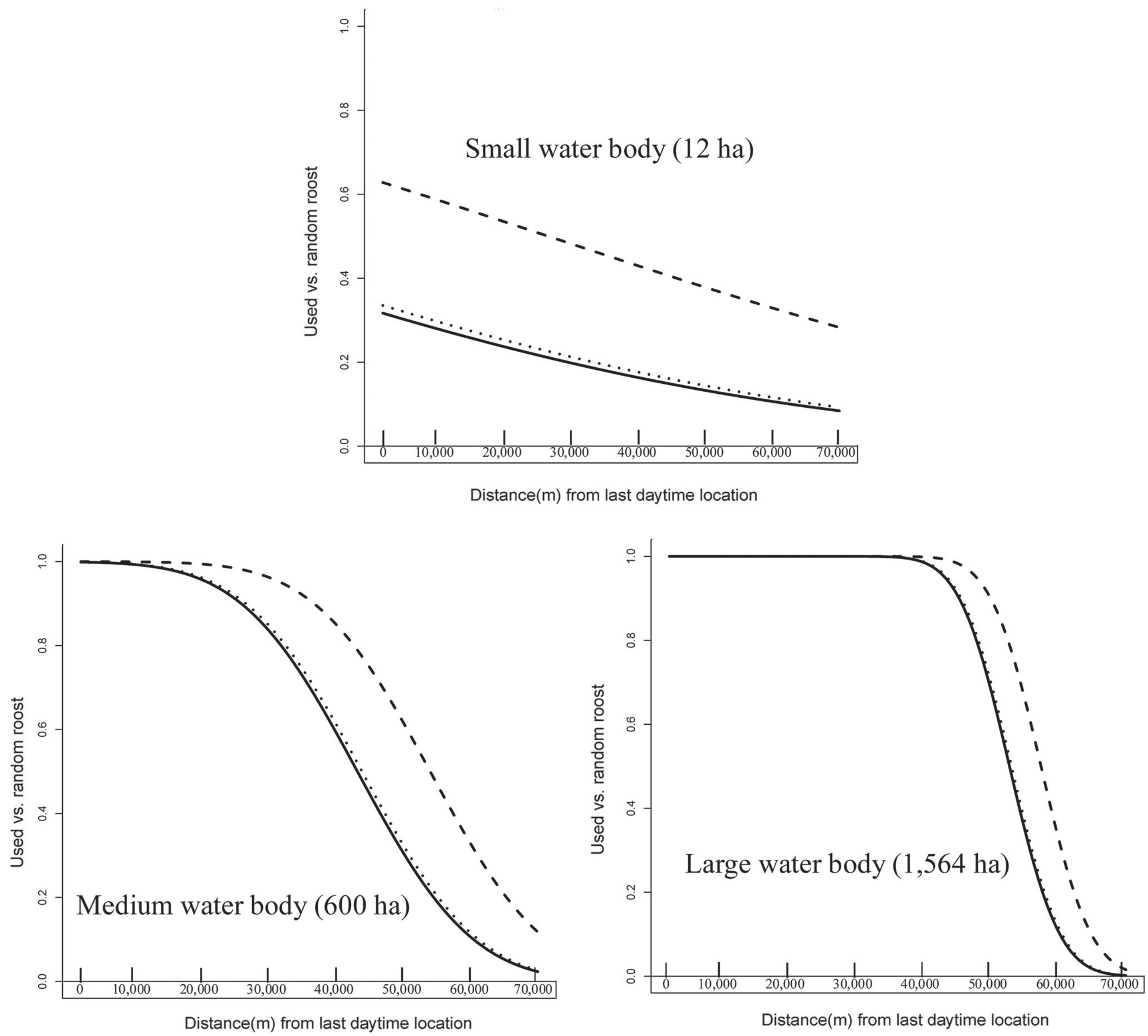

Figure 3. Effects of the covariates distance from last daytime location (m) and nearest food source (close [dashed line; <2,000 m], near [dotted; <5,000 m], or far [solid; >5,000 m]) on the response variable (used vs. random roost) in relation to water body size (small, medium, or large) for ring-billed gulls in Massachusetts, 2008–2012.

Ring-billed gulls used water bodies that were larger than random sites (P 0.001). When considering other mean values of used roosts versus random sites, distances from last daytime location was greater for random sites versus used sites ($P = 0.01$). Used roosts had a radius that was larger than random roosts (P 0.001), but there was no difference in distance to foraging areas between used and random roosts ($P = 0.306$).

For herring gulls, the most supported model included the interaction between size of a water body and distance from the last daytime location, in addition to the variable food (Table 4). There was strong evidence ($w_i = 0.56$) for the selected model. One other model was also supported (ΔAIC = 1.55) and included all the variables (global model). We calculated model average coefficients using these top 2 models. Model average coefficients for size and size disturbance were positive, whereas coefficients for daytime, food, disturbance, size daytime, and size food were negative (Table 5). However, the confidence intervals for the model average regression estimates of disturbance and size food included 0, indicating these variables had little affect whether a roost was used or not. Size had a positive effect on whether a roost was used; as roost size increased, herring gulls were more likely to use them (Fig. 4). Daytime and size daytime had a negative effect on whether a roost was used; roosts closer to the last daytime location were more likely to be used, but herring gulls were more likely to travel farther to roost on a larger water body (Fig. 4). The Hosmer–Lemeshow goodness-of-fit statistic ($\chi^2 = 28.09$, P 0.001) on the most parsimonious model suggested a poor fit. However, the ROC curve index for the averaged model was 0.89, suggesting reasonable discriminating ability.

Herring gulls used water bodies that were larger than random sites (P 0.001). Distances from used roosts to last daytime locations and foraging areas were smaller than random sites (P 0.001, $P = 0.002$, respectively).

DISCUSSION

Seasonal Roost Selection

Ring-billed and herring gulls demonstrated a different pattern of roost selection throughout the year. Ring-billed gulls used water roosts almost exclusively, and a majority of those roosts were on fresh water. Although herring gulls also used water roosts throughout the year, they were commonly found on land roosts. Other studies have identified herring gulls roosting exclusively on fresh water (Schreiber 1967, Hickling 1973, Nugent and Dillingham 2009); however, these studies only surveyed known roosting sites or potential freshwater lakes and reservoirs for the presence of gulls.

Table 4. Results of generalized linear models testing the effects of water body size, disturbance buffer, distance to foraging, and distance from last daytime location on roost site selection of herring gulls in Massachusetts, USA, 2008–2012. We also included individual bird as a random effect in all models.

Model[a]	Log-likelihood	K[b]	AIC[c]	ΔAIC	w_i[d]
Size daytime + food	157.26	6	326.51	0.00	0.56
Size + daytime + disturb + food + size food + size daytime + size disturb (global)	155.03	9	328.07	1.55	0.26
Size daytime	159.37	5	328.74	2.22	0.18
Size food	204.37	5	418.74	92.23	0.00
Size disturb + food	210.78	6	421.28	94.76	0.00
Size	211.99	3	429.98	103.47	0.00
Size disturb	210.78	5	431.57	105.05	0.00
Disturb	220.21	3	446.43	119.91	0.00
Food	226.16	3	458.31	131.80	0.00
Null (intercept only)	231.51	2	467.02	140.51	0.00

[a] Size: area in ha; disturb: maximum distance (m) from the center of a water body to its shoreline; food: distance (m) of a water body to nearest foraging location; daytime: distance (m) from a bird's last daytime location to its nighttime roost.
[b] Number of parameters.
[c] Akaike's Information Criterion.
[d] Akaike weight.

Table 5. Results from model averaging the top 2 models of the effects of each parameter on a herring gull roost site being used or random (available), Massachusetts, USA, 2008–2012.

Parameter	Estimate[a]	Unconditional SE	CI	Relative importance
(Intercept)	0.647	0.473	(1.426, 0.131)	
Size	1.440	0.708	(0.275, 2.604)	1.00
Daytime	2.904	0.419	(3.593, 2.215)	1.00
Food	0.497	0.295	(0.982, 0.012)	1.00
Disturbance	0.078	0.271	(1.021, 0.471)	0.28
Size daytime	2.982	1.414	(5.306, 0.659)	1.00
Size food	0.295	0.808	(3.071, 0.992)	0.28
Size disturbance	0.448	0.833	(0.244, 2.911)	0.28

[a] Effect sizes have been standardized.

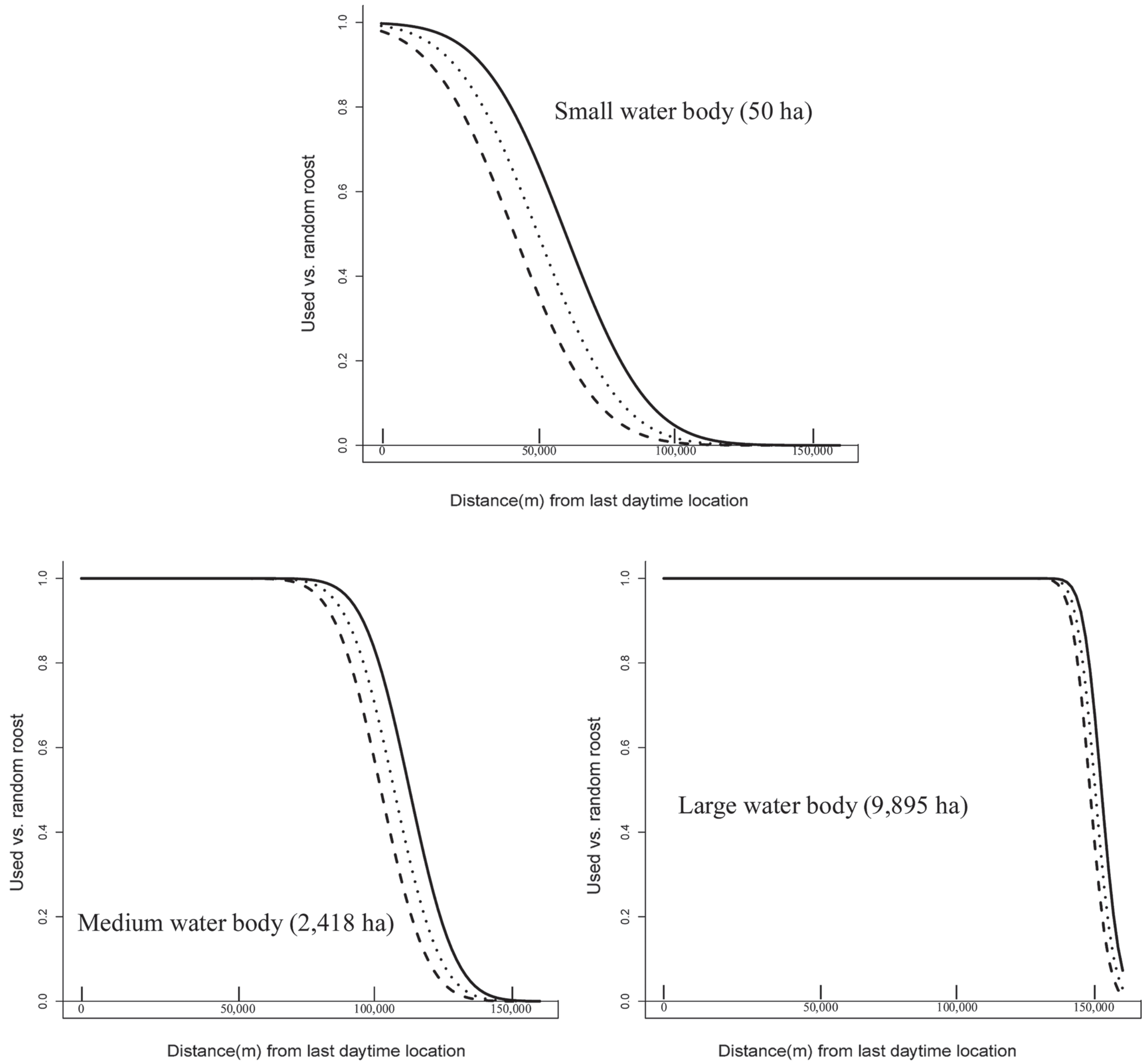

Figure 4. Effects of the covariates distance from last daytime location (m) and nearest food source (close [solid line; <5,000 m], near [dashed; <10,000 m], or far [dotted; >10,000 m]) on the response variable (used vs. random roost) in relation to water body size (small, medium, or large) for herring gulls in Massachusetts, 2008–2012.

Because individual birds were not followed in these previous studies, it is possible other roosting sites may have been used but went undocumented. We are not aware of any studies that have characterized gull roosting behavior using tagged individuals. Golightly et al. (2005) followed radio-tagged western gulls (*L. occidentalis*) in southern California and reported 47% of all locations were in marine habitats, whereas 53% were inland. However, they used very high frequency transmitters to follow birds and did not provide specific information on roost site selection. Our study indicates that ring-billed gulls were most likely to be found roosting on fresh water, whereas herring gulls more commonly used salt water, except during winter. This difference is likely related to the variability in use of marine environments by the 2 species. All of the tagged herring gulls we captured in Massachusetts during winter migrated north and concentrated their movements during the spring and summer (presumably nesting) on coastal marine islands in maritime Canadian provinces. As a result, almost all water roosting locations from late winter through late summer were marine. In contrast, our tagged ring-billed gulls traveled to the Great Lakes or St. Lawrence River during late spring and concentrated their movements (presumably to breed) around these fresh water locations.

In winter, ring-billed gulls used salt water roosts more frequently than in other seasons, although fresh water roosts were still used more often. In contrast, herring gulls increased the amount of time spent roosting on fresh water and decreased the amount of time roosting on salt water. We suspect this is related to differences in winter movements between species. During winter, our tagged herring gulls were often located at inland foraging locations and regularly used fresh water roosts in proximity to where they spent the day. Further, herring gulls tended to use the same general inland areas for much of the winter (Clark et al. 2016). Ring-billed gulls were also common inland foragers during winter; however, our study birds remained at inland areas for less time than herring gulls and often used coastal habitats during late winter. We suggest that ring-billed gulls use multiple wintering sites (onward migration), similar to what Mandernack et al. (2012) described for wintering bald eagles (*Haliaeetus leucocephalus*; Clark et al. 2015). Competition for food, availability of freshwater roosts (i.e., how much ice cover is present), or changes in food abundance all likely influence ring-billed gull movements during the winter.

Although our data indicate that ring-billed gulls roosted on reservoirs, lakes, and rivers in about equal proportions in other parts of their range, this distribution was not evident while roosting in Massachusetts. Ring-billed gulls rarely roosted on rivers in Massachusetts, even though river roosts were available and often used by herring gulls. Casual observations of one of the known Massachusetts' river roosts suggested that herring gulls were actually roosting on small rocks and boulders within the river itself, which is consistent with a herring gull roost described by Schreiber (1967) in the Penobscot River, Maine. Because herring gulls regularly roosted on land, the structure of these river roosts probably attracted herring gulls but not ring-billed gulls, which rarely roosted on land.

Although herring and ring-billed gulls used multiple freshwater roosts in Massachusetts, only a few roosts had >5 recorded locations during the length of the study. Our data show that certain water bodies were favored by either herring or ring-billed gulls, whereas other roosts were used frequently by both species (Table 1). Some comparable sized roosts seemed to be preferred by one species. Unfortunately, we did not conduct visual surveys at these roosts, and we were unable to determine if roosts were comprised of single species or were mixed. During weekly roost counts at Wachusett Reservoir, we regularly observed herring gulls and ring-billed gulls within the same roost; however, ring-billed gulls were more abundant and comprised 80–90% of the roost. Certain water bodies may be preferred by one species, and this predilection may be related to historical use or proximity of species-specific foraging areas.

Roost Site Modeling

Herring and ring-billed gulls used roosts in Massachusetts with similar environmental variables. Water body size alone was not an important determinant in whether a roost was used or not; however, the interaction between watery body size and last daytime location was important in both species' habitat models. Our data suggest that gulls used the largest available water body closest to their last daytime location. In our study area, Quabbin Reservoir is the largest potential roost site and is 6 times bigger than the next largest roost site (Wachusett Reservoir); however, gulls roosted on Wachusett Reservoir 22 times more often than Quabbin. This was related to the relative position of each reservoir in the landscape. Wachusett Reservoir is located about 12 km from the city of Worcester, which provides a variety of foraging options including parking lots (where people feed gulls), wastewater treatment plants, fields, and landfills (Clark et al. 2015). In contrast, Springfield, which provides similar foraging opportunities, is about 32 km from Quabbin Reservoir. The landscape immediately around Quabbin is dominated by forest, small towns, and residential areas, which are not attractive to gulls. Smaller roosts closer to Springfield (e.g., Connecticut River; Table 1) would attract more roosting gulls.

Distance to last daytime location was also an important variable in both species models. A gull's last daytime location is likely associated with opportunities to acquire food before traveling to a nighttime roosting location. In general, our study gulls were often located in urban and suburban areas during the day foraging on anthropogenic food sources (e.g., handouts, wastewater treatment plants, suburban farms; Clark 2014). The location of water bodies in relation to gull foraging sites would influence the chances of it being used as a roosting site. Large water bodies far away from potential or existing food sources have a smaller chance of attracting roosting gulls than those water bodies located near or adjacent to food sources. Factors not measured in this study also likely contributed to whether gulls used a particular water body. Historical use as a roosting site is an important consideration. Wachusett Reservoir has been used as a gull roost for 50 years, and other preferred roosts probably have a similar history. Gulls returning to Massachusetts each year are likely familiar with these roosting sites. Although we assessed the shoreline disturbance potential of each water body, on-water activity is probably another important factor we did not assess. Recreational boating (e.g., water skiing) may affect the formation of a roost if birds are repeatedly disturbed. Although Wachusett Reservoir has no public boating, other preferred roosts in the study area did allow various types of boating.

MANAGEMENT IMPLICATIONS

In the United States, about 258 million people rely on public water supplies for household use, and two-thirds of this supply comes from surface waters (Kenny et al. 2009). Although surface water can become contaminated from a variety of sources, birds (i.e., gulls and geese) are one of the most common and significant sources of contamination of lakes and reservoirs (Environmental Protection Agency 2001). In Massachusetts, inland gull populations fluctuate seasonally and reach their peak during late fall. Inland sources of natural food are severely limited during this time of year, and gull foraging is strongly influenced by the availability of anthropogenic food subsidies (e.g., handouts, wastewater treatment plants; Clark et al. 2015). Urban and suburban areas provide a range of foraging opportunities, and large lakes or reservoirs close to these foraging sites have the potential to attract roosting birds. Conflicts can arise when roosting gulls affect the water resources (i.e., drinking water, recreation) or the roost is located near airports causing increased aviation risks. Past efforts to relocate or remove roosting gulls have failed (Dewey and Lowney 1997), or worked conditionally (Gosler et al. 1995, Nugent and Dillingham 2009). Bird harassment efforts are often directed at the roosting birds in an attempt to discourage their presence or disrupt their roosting behavior. Most harassment programs have focused on the roost and not addressed why gulls are choosing a particular body of water. Our data suggest that where gulls roost is strongly related to 3 important factors: the size of the roost site, where gulls are during the day, and where potential food sources are located. Attempts to reduce the number of gulls or prevent a roost from forming may be challenging unless these foraging sites can be identified and eliminated. If the amount of available food close to affected water bodies can be reduced, it may be possible to reduce the presence of gulls.

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