Effects of Lake Characteristics and Human Disturbance on the Presence of Piscivorous Birds in Northern Wisconsin, USA

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Abstract.—Despite current anthropogenic alterations to riparian areas and littoral zones of lakes, little information is available on how human-induced alterations affect lacustrine habitat use by many piscivorous birds in northern Wisconsin, USA. The influence of lake characteristics and human disturbance on species richness and the presence of seven species of piscivorous birds was determined on 98 lakes located primarily in Vilas and Oneida counties, Wisconsin. Lakes were surveyed for species presence using shoreline perimeter surveys with total searching time standardized to two, one-hour surveys per lake. Piscivorous bird species richness was highest on large lakes with high pH levels. Using logistic regression, many species were found to be present on lakes possessing characteristics associated with high abundances of fish, including lake surface area, pH, and water clarity. At least one of these variables was included in the final models for species richness and presence of the Common Merganser (*Mergus merganser*), Bald Eagle (*Haliaeetus leucocephalus*), Great Blue Heron (*Ardea herodias*), and Ring-billed Gull (*Larus delawarensis*). Three species avoided lakes possessing characteristics associated with high levels of human disturbance; the Osprey (*Pandion haliaetus*) was not found on lakes with low percentages of macrophytes, the Common Merganser was absent on lakes with low water clarity, and the Common Loon (*Gavia immer*) was not present on lakes with many cottages. Many species of piscivorous birds were widespread regardless of the degree of human development, indicating that habituation to humans may have occurred. In addition, density-dependent factors may have precluded identification of optimal lake characteristics for some species due to habitat saturation. *Received 19 December 2004, accepted 6 July 2005.*

Key words.—habitat, human disturbance, lacustrine, lake characteristics, northern Wisconsin, piscivorous birds, species richness.

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As the interface between terrestrial and aquatic environments, natural riparian areas contain some of the most diverse and complex habitats on earth (Naiman *et al.* 1993). Riparian habitats generally support more species of birds and mammals than upland habitats because they act as travel and foraging corridors for many species (Darveau *et al.* 2001). Adjacent lake littoral zones also provide important habitat for many organisms, including some or all life history stages of many fishes (Becker 1983; Beauchamp *et al.* 1994). Many species of piscivorous birds are dependant on littoral zone fishes as forage and riparian areas for nesting, and are negatively influenced by loss of habitat caused by human alterations and disturbance.

Human alteration of riparian areas and littoral zones can adversely alter water quality, habitat structure, and animal assemblages (Poe *et al.* 1986). Fish species richness and total fish abundance are greater in naturally complex littoral zone sites (Bryan and Scarnecchia 1992), thus providing more foraging opportunities for piscivorous bird species than sites altered by human development. Undeveloped shorelines along Lake Huron, which had more emergent macrophytes, large emergent rocks, and fallen trees than developed shorelines, had higher water-bird diversity and species abundances compared to developed shores (Weseloh *et al.* 1997). These habitat features add to riparian and littoral zone habitat complexity and thus attract more piscivorous birds for foraging and loafing. Loss or fragmentation of plant cover along shorelines due to human alterations deprives birds and other organisms of food and shelter and also reduces and fragments available foraging and nesting habitat (Swanson and Duebbert 1989).

Despite extensive anthropogenic alterations to riparian areas and littoral zones of lakes, little information is available on how shoreline development and human disturbance affect the presence of many piscivorous birds in northern Wisconsin. Also, the lake characteristics associated with the presence or absence of several piscivorous bird species remain poorly understood. The objectives of this study were to identify the lake characteristics associated with the presence of seven species of piscivorous birds and also to determine the influence of shoreline development and human disturbance on the presence of piscivorous birds on lakes in northern Wisconsin.

METHODS

Study Area and Study Species

Ninety-eight randomly selected small lakes ≤200 ha in north central Wisconsin and the Upper Peninsula of Michigan, USA, were sampled in the summers of 2000 and 2001 to determine the presence or absence of the Common Loon (*Gavia immer*), Great Blue Heron (*Ardea herodias*), Common Merganser (*Mergus merganser*), Hooded Merganser (*Lophodytes cucullatus*), Osprey (*Pandion haliaetus*), Bald Eagle (*Haliaeetus leucocephalus*), and Ring-billed Gull (*Larus delawarensis*). These species were selected because their ranges extend into the study area, and despite their wide array of life history strategies, they are all piscivorous. Because all of the study species were migratory, data were collected from 25 May to 25 August, as all of the species in this study arrive in Wisconsin by late May and remain until the end of August (Robbins 1991).

Because the objective of this study was to determine factors influencing piscivorous bird presence on small north temperate lakes, all lakes included in this study were limited to 200 ha or smaller. Ninety-four lakes were located in Vilas and Oneida counties, Wisconsin, where many lakes have recently undergone shoreline alterations by landowners (Christensen *et al.* 1996). This region of the state also contained many small lakes with variable morphological characteristics (i.e., maximum depth, water clarity) and variable levels of cottage development (i.e., no houses to completely altered shorelines). A stratified-random sampling design was used to select the study lakes from 777 small lakes described in a Wisconsin Department of Natural Resources lake characteristic database (Wisconsin Department of Natural Resources, unpubl. data). Lakes were sorted into five, 40-ha size classes (i.e., 0-40 ha, 40-80 ha) and 19 lakes were randomly selected from each category to ensure even representation of small lakes located within Vilas and Oneida counties. Four additional lakes located in the adjacent Sylvania Wilderness Area in Gogebic County in the Upper Peninsula of Michigan were included to better represent lakes with low levels of human disturbance (i.e., no gasoline-powered motors) and no cottage development.

Lake Sampling

Presence or absence of each bird species was assessed using lake-perimeter surveys along a shoreline contour (i.e., transect) from a boat or canoe. Presence-absence data were used and not abundance data because piscivorous birds ranged widely and their presence on lakes can be temporally variable, making abundance estimates prone to error. Individual counts and presence-absence estimates of avian density have also been found to be highly correlated (Bart and Kloseiwski 1989).

Random compass bearings were used to select shoreline-starting points for sampling. Birds were observed along a shoreline contour at a distance of 15 m from the shore. Total searching time was standardized to two hours per lake, with all piscivorous bird species seen recorded. Each lake was surveyed for one hour between 08.00 and 17.00 h on two separate days. Because species presence was temporally variable and daily activity patterns varied among the species, each lake was sampled once before midday (08.00-11.59 h) and once after midday (12.00-16.59 h). The day of the week that each lake was sampled was also rotated to incorporate potential differences in human activity; more humans visited lakes on weekends and Friday and Monday, which may have reduced detection of less human-habituated species. Bird surveys of each lake were conducted at least seven days apart and were conducted along the same transect route. Each lake was sampled with equal effort regardless of its size; a constant speed was maintained with an electric trolling motor to ensure equal transect length. Effort proportional to lake size was considered inappropriate because it can result in finding more species on larger lakes simply due to greater sampling effort (Connor and McCoy 1979).

Habitat Variables

Literature reviews were conducted on each bird species to select lake habitat variables likely to influence species presence or absence on small temperate lakes in northern Wisconsin (Table 1, Newbrey 2002). Lake maximum depth, surface area, pH, and secchi disk depth were obtained from a Wisconsin Department of Natural Resources lake characteristics database (Wisconsin Department of Natural Resources unpubl. data). Fetch, shoreline development factor (an index of shoreline sinuosity, Welch 1948), presence of islands, and riparian forest were obtained using the Wisconsin Department of Natural Resources' WISCLAND Geographical Information Systems data coverage with 30 m resolution (http://dnr.wi.gov/maps/gis/datalandcover.html).

The remaining habitat variables, macrophytes, trees, average number of boats, houses, type of boat access, and type of boat use, were collected during bird surveys. The linear density of macrophytes (i.e., any emergent non-woody plant growing in the littoral zone) was measured on each bird survey transect by dividing the amount of time spent passing macrophytes by the total sampling time. Perch trees were counted during bird surveys and were defined as any tree possessing at least one horizontal branch that was free of secondary branching for at least 0.6 m and was located above the water's surface. The number of boats was defined as the mean of the total number of boats seen in use during the two bird surveys. The number of visible houses was counted along each bird survey transect. A lake was considered to have public boat access if it had a public boat landing and all lakes without public boat landings were considered non-public access lakes. Human use was cat-

Table 1. Range of variation among independent variables included in analyses of piscivorous bird species richness and lake selection on 98 northern Wisconsin and Michigan lakes.

Independent variable	Variable description	Mean	Range
Depth	Maximum depth of lake (meters)	9.8	1.2-25.9
Lake surface area	Surface area of lake (hectares)	117	4.5-297.9
pH	Acidity or alkalinity of water in lake	7	5-9
Secchi	Secchi disk reading of water clarity in lake (meters)	3	0.9-8.8
Fetch	Longest straight-line distance across lake (meters)	1632	252-3309
Shoreline development factor	Sinuosity of the lake shoreline	214	122-457
Islands	Presence or absence of islands on lake (0 = no islands, 1 = islands)	—	0 or 1
Macrophytes	Percent of littoral zone with emergent vegetation	33.3	0-99.6
Perch trees	Number of perch trees counted during bird surveys	48.7	0-164
Riparian forest	Forest lands adjacent to lake (0 = non-forested, 1 = forested)	—	0 or 1
Average boats	Number of watercraft counted during birds surveys	2.5	0-9
Houses	Number of houses counted during bird surveys	15.6	0-61
Non-gasoline use	Type of motorized use allowed on lake (0 = gasoline, 1 = non-gasoline)	—	0 or 1
Non-public access	Type of boat access on lake (0 = public, 1 = non-public)	—	0 or 1

egorized based on the legally restricted or unrestricted use of gasoline-powered boats on each lake.

Statistical Analysis

Linear and multiple linear regressions were used to determine relationships between lake characteristics, human disturbance, and species richness of piscivorous birds (i.e., the total number of the seven species present). The logistic regression function, $E\{Y\} = e\ (\beta_0 + \beta_1 X_1)/1 + e\ (\beta_0 + \beta_1 X_1)$, where Y is the relative probability of a species occurring, β_0 is the y-intercept, β_1 is the regression coefficient, and X is the predictor variable, was used to determine how each of the independent variables influenced the presence of the study species. Logistic regression is the preferred analysis for distinguishing between two classes of response variables (i.e., presence or absence) when some or all of the independent variables are binary or categorical (Press and Wilson 1978). Logistic regression predicts the relative probability of a species' presence based on the range of variation in the independent variables used to create a model. To ensure parsimony in the final models, a correlation matrix was created to determine if any lake characteristic variables were highly correlated ($r > 0.7$). Only lake surface area and fetch were so correlated ($r = 0.898$) and because lake surface area better described the amount of open water habitat available for piscivorous bird use, fetch was excluded from all analyses. All regression and correlation analyses were performed with SYSTAT® version 9.0 (1999).

Akaike's Information Criterion (AICc) corrected for small sample size was used to select all final models (Burnham and Anderson 1998). AICc is a second-order variant of AIC, which is used when there are many parameters in relation to the size of the sample (Burnham and Anderson 1998). Akaike's general approach allows the best model in the set to be identified, but also allows the rest of the models to be easily ranked (Burnham and Anderson 2001). Model comparisons were made for each species using ΔAICc, which is the difference between the lowest AICc value and AICc from all other models (Burnham and Anderson 1998). All models with ΔAICc < 10 were included as alternative models; models with $\Delta_i \leq 2$ were considered to have substantial support, models with $4 \leq \Delta_i \leq 7$ were considered to have less support, and models having $\Delta_i \geq 10$ have little support from the data (Burnham and Anderson 1998). AICc weights (w_i), which signify the relative likelihood that a specific model is the best of a suite of models (Burnham and Anderson 1998), were also calculated for each candidate model.

Bird surveys were conducted on 53 lakes during 2000 and 45 different lakes in 2001. Because data were collected during two separate years, annual variation in weather and piscivorous bird population densities could have affected the results of this study. To determine if year did have an effect on the models, the first year's data were kept separate and were used to create logistic regression models. Next, the first year's models were used to predict the presence of piscivorous bird species on lakes sampled in the second year. Correct classification rates were calculated and compared between the two sets of models.

RESULTS

Lake characteristics and human disturbance variables influenced piscivorous bird species richness and species presence on the 98 study lakes. The results of the linear regression models indicated that species richness was positively related to lake surface area, pH, and shoreline development factor (Table 2). The multiple variable model that best described species richness contained lake surface area and pH (Table 2, Fig. 1A).

Using logistic regression, Common Loon presence was found to be positively related

Table 2. Results from model selection for the influence of lake characteristics on piscivorous bird species richness. All models with ΔAICc < 10 are reported.

Model	R^2	Log likelihood	K	AICc	ΔAICc	w_i
Surface area, pH	0.329	-8.958	4	26.26	0	0.766
pH	0.231	-11.853	3	29.90	3.634	0.124
SDF [a]	0.088	-15.493	3	31.18	4.913	0.066
Surface area	0.193	-12.893	3	31.98	5.714	0.044

[a]SDF = Shoreline development factor.

to riparian forest and shoreline development factor, and negatively related to non-public boat access (Table 3). The best multiple logistic model for predicting the presence of the Common Loon contained three variables, forested riparian area, non-public boat access, and number of houses (Table 4). Great Blue Heron presence was negatively related to non-motorized use and secchi disk reading (i.e., water clarity).

Lake characteristics associated with the presence of the two species of mergansers differed (Table 3). Common Merganser presence was positively related to secchi disk reading and water depth. Hooded Merganser presence was positively associated to the presence of islands, regardless of other features. The best multiple logistic model for predicting the presence of Common Mergansers contained two variables, secchi disk reading and surface area (Fig. 1B).

The two species of plunge divers, the Bald Eagle and Osprey, showed both similarities and differences in lake features associated with their presence (Table 3). Bald Eagle presence was positively related to both pH and lake surface area (Table 4). Osprey presence was positively related to surface area, percent macrophytes, islands, and shoreline development factor, and negatively related to non-public boat access.

The presence of the Ring-billed Gull (Table 3) was positively related to pH, average number of boats, riparian forest, lake surface area, and the number of houses, and negatively related to non-gasoline motor use. The best multiple-variable model for predicting the presence of the Ring-billed Gull contained three variables: pH, number of houses, and shoreline development factor (Table 4).

The results of our model validation indicate that there was no year effect on species presence between the two years of this study. The models created during our first year predicted the presence of our study species on lakes sampled in the second year with a high degree of consistency. For example, the average of the overall correct classification rates for all independent variables for the Common Loon in the first year was 75% and was 78% using Common Loon presence data from the second year. The overall correct classification rates for the Great Blue Heron (59% and 52%), Common Merganser (86% and 88%), Hooded Merganser (79% and 76%), Osprey (77% and 67%), Bald Eagle (73% and 60%), and Ring-billed Gull (60% and 55%) showed similar results.

DISCUSSION

Northern Wisconsin provided a complex mosaic of lake environments to study how lake characteristics and human disturbance influenced the presence of piscivorous birds. The presence of the seven species of piscivorous birds was best explained by limnological, riparian structure, human disturbance, and landscape characteristics. The presence of many species was influenced by limnological characteristics, including lake surface area, pH, and secchi disk reading; at least one of these variables was included in the final models for species richness and four species of piscivorous birds.

Many of the bird species studied were present on lakes that were large and had a high pH; these lake characteristics are often associated with high abundances of fish (Youngs and Heimbuch 1982), and therefore more prey items for piscivorous birds.

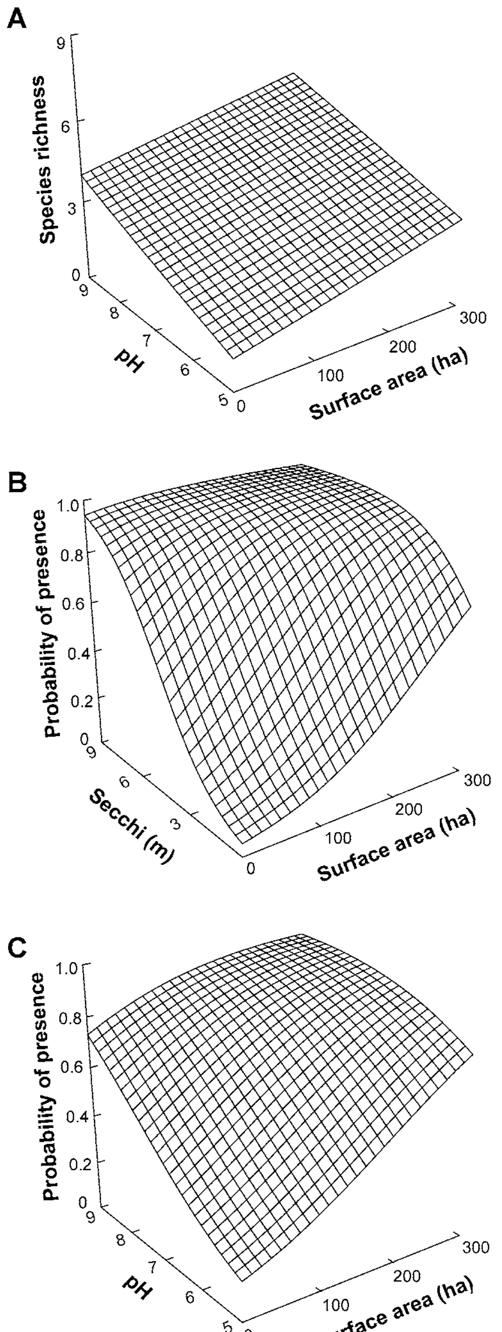

Figure 1. Response surfaces for the final multiple variable models for (A) species richness, (B) Common Merganser, and (C) Bald Eagle. All other multiple variable models could not be graphed because they contained categorical variables or more than two independent variables (Table 4).

Lake surface area was associated with increased species richness as well as the presence of the Common Merganser, Bald Eagle, Osprey, and Ring-billed Gull. Larger lakes have more shoreline habitat types for foraging, nesting, and escape cover when compared to smaller lakes. Lake pH was positively related to species richness and the presence of the Bald Eagle and Ring-billed Gull. Lakes with a high pH often support more diverse and abundant fish communities than lakes with a lower pH (Kelso *et al.* 1990), and so could be preferred by many species of piscivorous birds.

Water clarity (i.e., secchi disk readings) apparently influenced the presence of two piscivorous bird species; water clarity was negatively related to Great Blue Heron presence while positively related to Common Merganser presence. The contrast between the types of lakes used by these two species might be explained by differences in foraging tactics. Highly productive eutrophic lakes generally have low water transparency because they have greater light penetration interference by plankton and they are also more likely to have emergent vegetation along shore than lakes with high water clarity (Rawson 1960). In the summer of 2001, 59% (24 of 41) of the Great Blue Herons that were observed standing along shore were in emergent macrophytes. The Great Blue Heron may prefer the camouflage provided by emergent macrophytes, the high abundance of fish that macrophytes may attract (Bryan and Scarnecchia 1992), or the low water clarity that could make stalking fish from above more efficient. Conversely, Common Mergansers preferred lakes with high water clarity. Because Common Mergansers dive and pursue fish by sight, hunting success is likely higher in lakes with clearer water (Eriksson 1985).

Shoreline features, including shoreline development factor, islands, macrophytes, and forested riparian areas, also influenced the presence of some study species. Shoreline development factor was positively related to species richness and the presence of the Common Loon and Osprey. Lakes with high shoreline sinuosity have more bays, which may offer better, alternative, or more diverse foraging opportunities for piscivorous birds. Moreover, bays reduce lake fetch and are more likely to

Table 3. Univariate logistic regressions models for independent lake variables that influenced piscivorous bird presence on 98 lakes. Positive and negative signs indicate the positive or negative influence of independent variables on species presence. All models with ΔAICc < 10 are reported.

			Correct classification rates						
Species	Model	Rho^2	Overall	Presence	Absence	Log likelihood	AICc	ΔAICc	w_i
Common Loon									
	Riparian forest, +	0.083	79	94	30	-47.68	99.46	0	0.858
	Non-public access, -	0.083	76	100	0	-50.00	104.09	4.63	0.085
	SDF[a], +	0.064	76	100	0	-51.06	106.20	6.75	0.029
	Lake area, +	0.052	76	100	0	-51.72	107.52	8.06	0.015
	pH, +	0.049	76	99	4	-51.88	107.84	8.38	0.013
Great Blue Heron									
	Non-gasoline use, -	0.115	65	96	33	-60.12	124.32	0	0.949
	Secchi, -	0.066	59	74	44	-63.43	130.95	6.63	0.035
	pH, +	0.055	57	38	77	-64.16	132.41	8.09	0.017
Common Merganser									
	Secchi, +	0.169	85	8	97	-31.89	67.86	0	0.801
	Maximum depth, +	0.131	87	8	99	-33.34	70.77	2.91	0.187
	Lake area, +	0.059	87	0	100	-36.11	76.29	8.43	0.012
Hooded Merganser									
	Islands, +	0.075	79	0	100	-47.10	98.29	0	1
Bald Eagle									
	Lake area, +	0.073	66	88	22	-57.41	118.91	0	0.806
	pH, +	0.050	64	85	22	-58.84	121.76	2.85	0.194
Osprey									
	Lake area, +	0.075	78	19	99	-52.46	109.00	0	0.628
	Macrophytes, +	0.034	72	0	99	-54.47	112.14	3.14	0.131
	Islands, +	0.047	74	0	100	-54.03	112.93	3.94	0.088
	Non-Public access, -	0.046	74	0	100	-54.07	113.03	4.03	0.084
	SDF, +	0.040	74	4	99	-54.43	113.40	4.40	0.070
Ring-billed Gull									
	pH, +	0.119	65	46	83	-59.70	123.48	0	0.302
	Average boats, +	0.078	63	40	82	-59.74	123.56	0.09	0.290
	Riparian forest, +	0.066	57	98	20	-60.09	124.27	0.79	0.204
	Lake area, +	0.104	60	54	65	-60.71	125.50	2.02	0.110
	Non-gasoline use, -	0.095	61	96	31	-61.33	126.74	3.26	0.059
	Houses, +	0.068	62	48	75	-67.75	130.34	6.86	0.010
	SDF, +	0.051	59	48	69	-67.75	132.68	9.20	0.003
	Macrophytes, -	0.037	55	57	53	-67.11	133.33	9.86	0.002

[a]SDF = Shoreline development factor.

have a still water surface to better allow piscivorous birds to see into the water column during foraging. The Common Loon may prefer lakes with irregular shorelines because they prefer sheltered, shallow water areas for nurseries for young chicks (McIntyre and Barr 1997). Irregular shorelines also increase the rich inshore littoral zone environment of lakes (Rawson 1960); fish congregate in shallow water areas near shore where there is protective structure such as macrophytes (Bryan and Scarnecchia 1992).

Four species of piscivorous birds showed a preference for lakes with structural complexity in the riparian area and littoral zone. The Bald Eagle and Osprey were more likely to be found on lakes with high percentages of emergent macrophytes along shore. Numerous fish species, including Lahontan Redside (*Richardsonius egregius*), Tui Chub (*Gila bicolor*) and Rainbow Trout (*Oncorhynchus mykiss*), have been found to concentrate in or around near-shore cover (Beauchamp *et al.* 1994), and juvenile fish densities are

Table 4. Model selection results for all multiple logistic models of lake characteristics that influenced the presence of piscivorous bird species on northern Wisconsin lakes. All models with ΔAICc < 10 are presented

Species	Model[a]	Rho^2	Correct classification rates: Overall	Presence	Absence	Log likelihood	K	AICc	ΔAICc	w_i
Common Loon										
	Forest, non-public access, houses	0.225	83	94	48	-37.49	4	83.36	0	0.902
	Forest, non-public access	0.180	82	100	26	-40.80	3	87.80	4.44	0.098
Great Blue Heron										
	Non-gasoline use, secchi	0.167	68	78	58	-54.28	3	114.76	0	0.429
	Non-gasoline use, macrophytes	0.145	71	84	58	-56.57	3	114.81	0.05	0.418
Common Merganser										
	Secchi, surface area	0.250	90	39	98	-28.75	3	63.70	0	0.605
	Secchi, fetch	0.239	86	23	95	-29.18	3	64.55	0.85	0.395
Bald Eagle										
	Surface area, pH	0.117	68	89	25	-54.29	3	114.77	0	0.505
	Surface area, macrophytes	0.117	73	89	40	-54.31	3	114.80	0.04	0.495
Ring-billed Gull										
	pH, houses, SDF	0.224	75	74	75	-45.39	4	99.20	0	0.515
	Surface area, houses	0.163	63	54	71	-49.84	3	105.92	6.72	0.018

[a]Abbreviations: Forest = riparian forest, SDF = shoreline development factor.

higher along shores with a high percentage of macrophytes (Bryan and Scarecchia 1992). Also, large piscivorous fish are more numerous on the offshore side of emergent vegetation beds (Bryan and Scarecchia 1992). High concentrations of fish in shallow, near-shore habitats could provide the Bald Eagle and Osprey with foraging opportunities near shoreline perch sites. Common Loon and Ring-billed Gull presence was positively related to lakes with forested riparian areas. The Common Loon preferred lakes surrounded by forest stands (McIntyre and Barr 1997), perhaps because they are more likely to have submerged logs as habitat for fish in the littoral zones, where Common Loons prefer to forage. Submerged logs have been identified as important cover for both fish and the invertebrates that fish feed on (Moring *et al.* 1986; Newbrey *et al.* 2005). Lakes surrounded by forests have more recruitment of fallen trees than lakes not surrounded by forests (Christensen *et al.* 1996; Guyette and Cole 1999) and therefore have more littoral zone fish habitat than lakes with deforested riparian areas.

Three study species, the Osprey, Common Merganser, and Common Loon, were not found on lakes possessing characteristics associated with high levels of human disturbance. Ospreys were not found on lakes with low percentages of macrophytes in the littoral zones, Common Mergansers were absent on lakes with low water clarity, and Common Loons were found on lakes with low levels of cottage development. Many lakeshore property owners remove macrophytes from littoral zones to increase recreational appeal for swimming and boating, thereby removing fish habitat near Osprey perching sites. Lakes used by humans often have higher levels of nitrogen and phosphorus inputs from lakeside septic systems and fertilizers, which can accelerate eutrophication, algal blooms, and a reduction in water clarity (Carpenter *et al.* 1998), making highly disturbed lakes less preferred by Common Mergansers. Human development of shorelines can force the Common Loon into marginal nesting locations that are more susceptible to disturbance by shoreline construction and watercraft users (Titus and VanDruff 1981). While the Common Loon was able to cope with low levels of human disturbance, many cottages and excessive human activity can reduce the reproductive success of the species (Heimberger *et al.* 1983).

The final model for the Common Loon showed that they were present on lakes with public boat access, which may simply reflect the fact that larger lakes often have public boat landings. Lakes with better fishing opportunities and surrounded by some public land are usually ones selected by humans to have public access. The Great Blue Heron and Osprey selected lakes with gasoline motor use and public boat access, respectively, indicating they may also select lakes with characteristics preferred by humans. The Ring-billed Gull was more likely to be present on lakes with many gasoline-powered boats and houses. Ring-billed Gulls are opportunistic feeders that consume human refuse (Jarvis and Southern 1976), so it is not surprising they would be found on lakes intensively used by humans.

There were few significant negative relations between human disturbance variables and the presence of the study species, which may indicate that some species are habituating to human activities or that they have reached habitat saturation and are spreading into less optimal areas (Fretwell 1972). For species such as the Bald Eagle, a decrease in persecution by humans may have increased tolerance to human activities in successive generations (Buehler 2000). Common Loons nesting on lakes with high levels of human use have been found to be less likely to flush from their nests when approached by humans than loons on more remote lakes (Titus and VanDruff 1981), and have offspring that exhibit a similar habituation to human activity (Heimberger *et al.* 1983). High piscivorous bird population densities may make the detection of human avoidance impossible for several species in northern Wisconsin. When population densities become high, intra-specific pressure can force some individuals to breed in less-suitable habitats (Cody 1985). Even though more negative responses of piscivorous birds to human disturbance were not found, this study did not focus on reproductive performance of the seven species. Previous studies have shown that the Common Loon (McIntyre and Barr 1997), Bald Eagle (Buehler 2000), Osprey (Swenson 1979), and Great Blue Heron (Drapeau *et al.* 1984) suffer lower reproductive success on lakes heavily used by humans. Studies of piscivorous bird nest success or chick survival could provide a more dynamic index of the effects of human disturbance on piscivorous bird species in northern Wisconsin.

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