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The Effects of Lakeshore Development on Common Loon (*Gavia immer*) Productivity in the Adirondack Park, New York, USA

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Abstract.—The effects of lakeshore development on reproductive success of Common Loons (*Gavia immer*) were examined in New York State's Adirondack Park. It was hypothesized that loon reproductive success would be negatively affected by the increased amount of shoreline development that has been occurring in the Park in recent years. Additionally, it was further hypothesized that the average distance from the nest site to the nearest point of development would be greater for successful nests than for failed nests. Historical nest productivity data collected from banded Common Loons on 53 lakes over a period of 7 years were evaluated along with residential development data collected during two field seasons in 2004 and 2005. Mean distance from successful nests ($n = 28$) to the nearest shoreline development unit (442.7 m, Range: 41.4-1,540.0 m) was greater than the mean distance from failed nests ($n = 32$) to the nearest shoreline development unit (343.1 m, Range: 2.2-1,222.9 m). Presence of nesting pairs was significantly related ($R^2 = 0.25$, $P = 0.001$) to increased shoreline length and decreased amount of development. Common Loon chick hatching success was significantly related to the density of development on small lakes ($P = 0.033$), but not on large lakes ($P > 0.05$). Our results indicate that the amount of development on lakes is not as important to nesting Common Loons as the placement of development in clusters along lakeshores. The clustering of development on one part of the lake will allow Common Loons to nest a distance away from developed areas. Thus, this study provides additional support for the buffering of loon nesting areas from development as a conservation/management tool to enhance their reproductive success.

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Key words.—Adirondack Park, Common Loon, *Gavia immer*, lakeshore, nest success, shoreline development.

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Historical records indicate that the southern border of the breeding range for the Common Loon (*Gavia immer*) in North America is slowly moving northward (McIntyre 1988). One possible explanation for this trend is the loss of available nest sites due to increased shoreline development in traditional Common Loon (loon) territories. Many anthropogenic factors likely affect loon populations, including such threats as environmental contaminants (e.g., acid deposition, mercury pollution) and human disturbance, as well as shoreline development (Evers 2007; Evers *et al.* 2010). In this study, we evaluated the potential for shoreline development to impact the breeding population of Common Loons in New York's Adirondack Park.

The Adirondack Park (Park), a stronghold for the breeding population of Common Loons in New York State, is on the southern edge of the breeding range for the species in northeastern USA (Evers *et al.* 2010). Surveys conducted in the Park during 1977 and 1978 found 105 territorial loon pairs on 83 of 301 lakes surveyed (Trivelpiece *et al.* 1979). A second survey conducted in 1984 and 1985 reported a total of 157 breeding Common Loon pairs, 196 chicks, and 247 non-breeding adults on 518 lakes (Parker and Miller 1987). Based on these results, it was estimated that 200-250 breeding pairs and 800-1,000 adult Common Loons occupied lakes in the Park by the mid-1980s (Parker 1986; Parker *et al.* 1986).

Although the Park is still largely an intact wilderness of 2.4 million ha, it is also home to more than 130,000 people who live in 105 small communities. Demand for summer homes has driven development to a rate of 820 to 850 new houses per year over the past 2 decades, and current zoning regulations allow for heavy development along roadsides and lakeshores (Bauer 2001). This is of concern for the Adirondack breeding Common Loon population, as increased development and activity have the potential to create areas of marginal breeding habitat dispersed throughout unsuitable habitat (Kelly 1992).

Additionally, increased development and the associated increase in human activity in loon breeding territories can lead to nest abandonment and decreased hatching success (McIntyre 1988). In particular, lakeshore development negatively impacts loon breeding habitat through vegetation modification and removal; increased human activity; increased density of opportunistic predators such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), and gulls (*Laridae* spp.); and decreased water clarity due to erosion and surface run-off (Taylor *et al.* 2005). These factors can result in the loss of traditional and potential nest sites, increased disturbance to nesting pairs, increased risk of nest predation, and decreased feeding efficiency.

Hence, evaluating the long-term effects of shoreline development in the Adirondack Park on the reproductive success of loons is critical to address conservation needs and make recommendations for future habitat management. In this study, we evaluated the relationship between development and loon productivity to provide a baseline for use in Adirondack land management planning. We sought to test the hypotheses that: 1) nesting success for loons in the Adirondack Park was negatively related to shoreline development; and 2) successful nests occurred at greater distances from lakeshore development than unsuccessful nests. In addition, lake characteristics were used to develop a model to best predict loon productivity on a lake.

Methods

Study Area

The Adirondack Park encompasses 2.4 million ha of mountainous forest in northeastern New York State. The Park is unique in its almost equal division of land between public and private ownership. Approximately 52% of the Park is privately owned while the remaining 48% is public land that is protected by the State constitution as the Adirondack Forest Preserve (New York State Constitution 1938). There are over 11,000 lakes and ponds, including 830 lakes larger than 10 ha that are of suitable size for loon breeding territories (Jenkins and Keal 2004).

The study area included 53 lakes located in 26 townships, representing eight counties and the six principal watersheds contained in the Park's boundaries (Fig. 1). The study lakes were chosen as part of a separate study where uniquely color-banded birds were monitored annually to assess the impacts of mercury pollution on the Adirondack loon population (Schoch *et al.* 2011). They were selected to be representative of the major watersheds in the park. Additional considerations in lake selection included the presence of loons with chicks, which increased capture success for banding and sampling loons; accessibility for scientists and research equipment to capture and monitor banded loons; and prior wildlife or aquatic systems research being conducted on the lake so that the loon research would expand upon previous knowledge of Adirondack aquatic ecosystems. Size of the lakes ranged from 10.1 ha to 2,382.0 ha with shoreline lengths of 1.61 km to 185.07 km. Twelve of the lakes were located on public lands, 21 were located on lands classified as private, and 20 were on lands of mixed ownership. Lakeshores varied from no development to highly developed.

For each study lake, five measures of productivity were considered: 1) number of nesting pairs; 2) number of chicks hatched per nesting pair; 3) hatching success (number of pairs with at least one chick hatched from any nesting attempt); 4) number of chicks fledged per nesting pair; and 5) fledging success (survival to 6 weeks). Because all lakes were not monitored each year, measures of productivity were averaged for the years they were available, and then stratified into four classes: all lakes visited ($n = 53$); lakes with 3 or more years of productivity data available ($n = 43$); lakes with 4 or more years of productivity data available ($n = 31$); or lakes with 5 or more years of productivity data available ($n = 22$). To reduce the effects of annual variation in loon reproductive success, we weighted productivity variables for each lake by the square root of the number of years of available data. All study lakes were further classified as small (< 50 ha, $n = 18$) or large (> 50 ha, $n = 35$) to compare the effects of development at different lake size classes.

The relationship between development and loon productivity was considered at two spatial scales: 1) the entire lake landscape (10-2,832 ha) to evaluate the impact of overall shoreline development on loon repro-

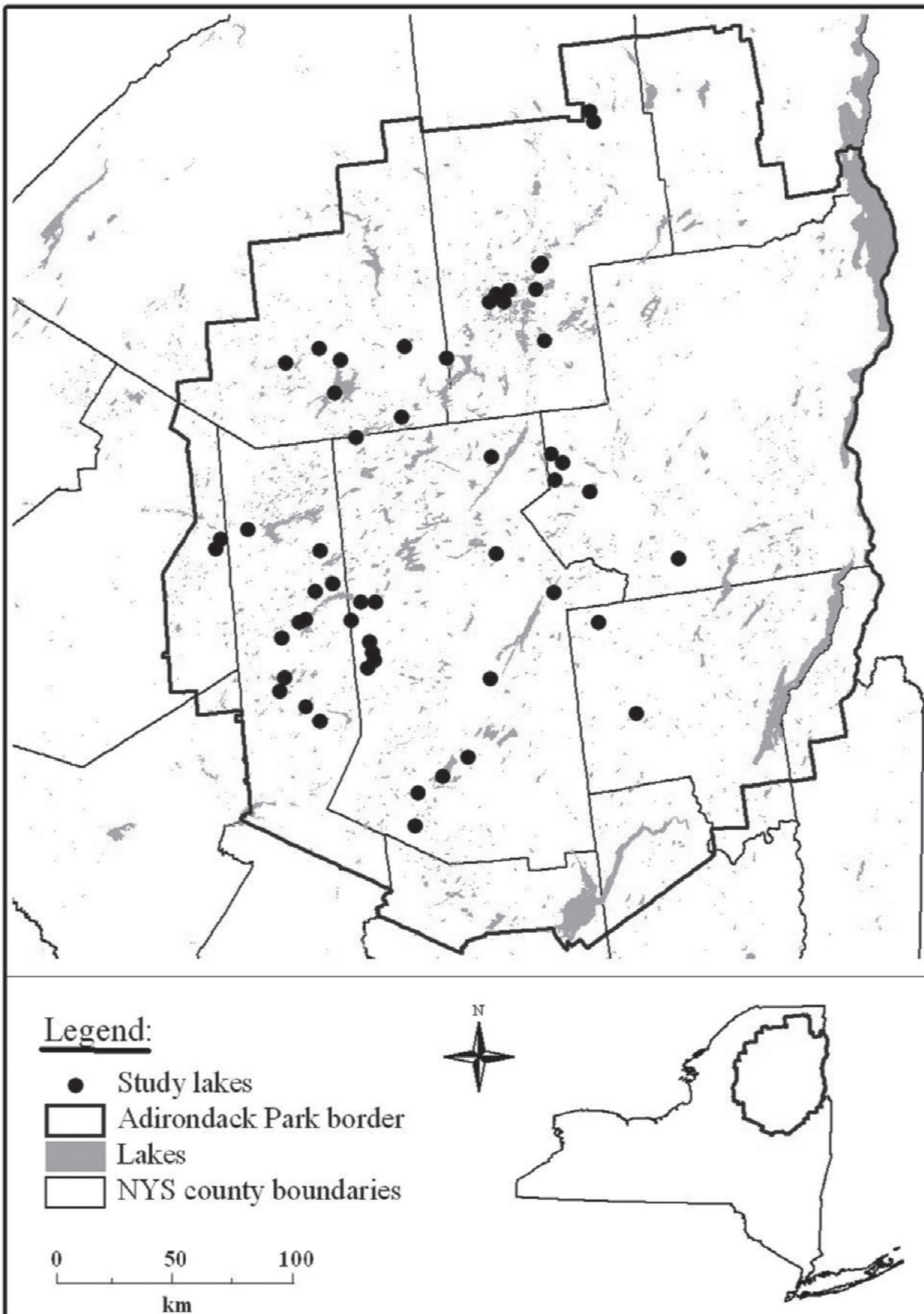

Figure 1. Locations of lakes included in an evaluation of the effects of human development on productivity of the Common Loon in Adirondack Park, New York, during 1999-2005 (n = 53). NYS = New York State.

ductive success; and 2) the loon territory within 400 m of nesting locations to assess potential development impacts in close proximity to a nest. Historical loon productivity data for banded loon pairs on the study lakes was collected by the former Adirondack Cooperative Loon Program (now Biodiversity Research Institute's Adirondack Center for Loon Conservation). Loons had been captured and color-banded for these separate studies by night-lighting with chick distress-call playback. Reproductive success data on banded loon pairs were based on weekly visits to the study lakes during a 15-week period (late May to early September) each breeding season from 1999 to 2005 (Schoch *et al.* 2011).

Shoreline development was quantified for each lake (n = 53) using data collected during the 2004 and 2005 loon breeding seasons. At each lake, the number and types of development points along the entire shoreline, including all islands, were recorded. Development points (e.g., houses, boat launches, campgrounds) were classified into one of 12 categories weighted according to their potential for structural shoreline alteration and facilitating disturbance to nesting pairs (Table 1). Shoreline alterations that enabled public lake access or had the potential to increase disturbance received a higher weight than did those that imposed only a structural alteration or were considered private property (Vermeer 1973; Valley 1987). For example, each habitable dwelling (house, cabin, or cottage) received a weight of one unit, while public boat launches and campgrounds received a weight of 10 units. A single measure of development for each study lake was generated by calculating the total of all development units. Development units were then divided by both shoreline length and lake surface area to yield a shoreline development index for each lake that accounted for variation in lake size and shoreline configuration of study lakes.

A handheld global positioning system (GPS) unit was used to mark the locations of nest sites and all development points within 400 m of the nest site. Measurements were also taken of the distance from each nest to the two closest shoreline alterations. All nests and development points were mapped using ArcGIS 9.1 (Environmental Systems Research Institute 2005). The total number of development units was calculated for buffered areas at 50-m intervals up to 400 m around each nest site (n = 60).

Pearson correlation coefficients were calculated for all combinations of variables. Each of five predictor variables (shoreline length, surface area, total development, development/shoreline, and development/area) was standardized by subtracting the mean and dividing by the standard deviation. A stepwise regression was performed using forward and backward selection (PROC REG, α = 1.50) in SAS 9.0 (SAS Institute, Inc. 2003) to test each of the five lake variables as predictors of the five measures of loon productivity identified above. The output from the stepwise regression models was used to determine simple and multiple regression models for each response variable (Table 2). Two-sample t-tests (α = 0.05) were performed to compare: 1) total development within buffered areas of nest sites; and 2) distance from nest to nearest point of development for failed and successful nests. The Mann-Whitney U test was used to compare lake surface area and total shoreline development for lakes with failed and successful nests.

Results

Total counts of lakeshore development had a range of 1-476 units with a mean of 71.02 units. This resulted in a range of 0.12-26.89 development units per km of shoreline ($\bar{x}$ = 5.34) and a range of 0.02-3.14 development units per ha of lake surface area ($\bar{x}$ = 0.61). Mean distance from successful nests (> 1 hatch, n = 28) to the nearest shoreline

Table 1. Number of development units assigned to each development type encountered in the lakeshore development field study. Development units were assigned according to degree of imposed habitat alteration and potential for habitat disturbance. Number and percent of lakes in dataset (n = 53) with each type of development are shown.

Development Type	Units	Number of Lakes	% Lakes
Campground	10	14	26.42
Marina	10	6	11.32
Public boat launch	10	33	62.26
Public beach/park	5	9	16.98
Resort/hotel/motel	5	12	22.64
Campsite	3	34	64.15
Canoe carry	2	8	15.09
Road	2	41	77.36
Habitable dwelling	1	33	62.26
Bridge	1	23	43.4
Man-made dam	1	21	39.62
Other[a]	1	26	49.06

[a]Included such structures as a railroad bed, silos, and memorials.

Table 2. Candidate multiple linear regression models for each dataset to predict number of Common Loon nesting pairs using standardized lake variables: shoreline length (Shore) and total development units (TotDev).

Dataset	n	Variables	β Value	SE	Prob > F	R^2
All Lakes	53	Shore	0.212	0.06	<0.001	0.24
		TotDev	-0.094	0.06	0.118	
Lakes > 3 Years of Data	43	Shore	0.209	0.06	0.001	0.26
		TotDev	-0.091	0.06	0.150	
Lakes > 4 Years of Data	31	Shore	0.200	0.06	0.004	0.29
		TotDev	-0.077	0.07	0.273	
Lakes > 5 Years of Data	22	Shore	0.248	0.11	0.039	0.37
		TotDev	-0.161	0.16	0.342	

development unit was 442.7 m (Range: 41.4-1,540.0 m), while the mean distance from failed nests (0 hatch, n = 32) to the nearest shoreline development unit was 343.1 m (Range: 2.2-1,222.9 m).

Presence of nesting pairs was significantly related (R^2 = 0.25, P = 0.001) to increased shoreline length and decreased amount of development. Development alone, however, was not a significant predictor of nesting pair presence on study lakes (P = 0.201). Variables of development density, as measured by development/lake surface area and development/shoreline length, also failed to predict the presence of nesting pairs. The best model for predicting the average number of nesting pairs included the variables of shoreline length and total development (R^2= 0.24, P = 0.001, n = 53; Table 2):

$$\text{NestPr} = 0.854 + 0.212\ \text{Shore} - 0.0939\ \text{TotalDev}$$

When lakes were classified into small (< 50 ha, n = 18) and large (> 50 ha, n = 35) lakes, it was found that hatching success was significantly related to density of development on small lakes (P = 0.033), but not on large lakes (P > 0.05). Lakes with failed nests (n = 32) were significantly smaller in area than lakes with successful nests (n = 28, P = 0.006). Distance from nest sites to the nearest development was highly correlated with lake surface area (R^2 = 0.74, P = 0.043) and total lakeshore development (R^2 = 0.71, P = 0.025).

DISCUSSION

The effects of development on loon reproductive success have been widely studied with varying results (Stockwell and Jacobs 1993; Taylor *et al.* 2005; Paugh 2006; Hammond 2008). In this study, increasing numbers of nesting pairs on study lakes were associated with increasing lake size and decreasing amount of development along shorelines. A measurable impact of lakeshore development was not demonstrated for any of the four other productivity variables tested: chicks hatched per nesting pair; hatching success (number of pairs with > 1 chick hatch); chicks fledged per nesting pair; and fledging success (number of pairs with > 1 chick fledge). These variables are dependent on the presence of nesting pairs. Therefore, at current levels of development, an important indicator of loon productivity on Adirondack lakes is the presence of nesting pairs. Additional confounding factors, such as the presence of islands, human disturbance, contaminant exposure, intraspecific interactions, and shoreline complexity, likely also affect the productivity of Adirondack loons, but investigating these factors was beyond the scope of this study.

The hypothesis that increased development in loon territories poses a threat to nesting loon pairs seems intuitive. Although some authors have demonstrated a significant negative effect of development on nesting success, the exact relationship remains undefined (Robertson and Flood 1980; Heimberger *et al.* 1983; Kelly 1992). On the other hand, some researchers such as Paugh (2006) and Hammond (2008) in northwestern Montana did not find that development affected Common Loon reproductive success, which they attributed to extensive mitigation and outreach efforts by the Montana Department of Fish, Wildlife, and Parks to protect loon nest sites and chicks.

In this study, however, outreach and mitigation in the Adirondacks are minimal, but still the data did not indicate such a relationship and, indeed, did not support the underlying hypothesis. Two possible explanations were suspected. First, this relationship may not be linear across a wide range of geographic scale. Heimberger *et al.* (1983) reported that an increase in cottage density correlated with decreased hatching success on a sample of 40 lakes in central Ontario, Canada, where lakes ranged in size from 31 to 190 ha and development levels ranged from entirely undeveloped to > 10 cottages per 500 m of shoreline. Loons did not use potential nest sites with > 5 cottages within 150 m. Development densities for our sample of 53 lakes were 0.08 to 13.45 per development units per 500 m, similar to those reported by Heimberger *et al.* (1983). The important difference, however, is that the lakes included in this study were much larger, ranging in size from 10-2,832 ha. Similar levels of development would account for a greater density on the smaller lakes sampled by Heimberger *et al.* (1983) than on the larger lakes included in this study.

If a relationship between nesting success and development exists, we would expect the impact to be related to density of development. Consequently, it would be reached more quickly on smaller lakes than on larger lakes. By reclassifying the study lakes into small and large lakes, we found that hatching success on small lakes was significantly related to the density of development, perhaps because larger lakes potentially have increased shoreline complexity that would enable nesting loons to avoid developed areas and their associated disturbance.

The finding that successful nests are more distant from development supports the conclusion that development indeed plays an important role. Alvo (1981) observed that loons nesting on heavily developed lakes chose marsh nest sites farther from developed areas over preferential island nest sites within 100 m of cottages. Similarly, Heimberger *et al.* (1983) found that loons avoided potential nest sites within 150 m of cottages. In this study, only eight nests (13%) were located within 150 m of cottages, of which only three (38%) were successful in hatching one or more chicks.

Results of this study support the hypothesis that the average distance from the nest site to the nearest point of development is greater for successful nests (one or more chicks hatched) than for failed nests (no chicks hatched). Lake size has also been observed as an important factor in territory selection by nesting loon pairs in other studies (Valley 1987; Blair 1990; Jung 1991). Some lakes may be too small to accommodate both development and successful reproduction by loons. It is suspected there may be a threshold lake size necessary to support reproduction in loons in the face of human development, but this threshold has yet to be defined (Robertson and Flood 1980; Heimberger *et al.* 1983; Kelly 1992). While loons may be able to adapt to development on lakes of 50 to 200 ha in size, there is likely to be a limit to that ability. At some point, the density of development may be too much for loons to be successful. The results of this study indicated that the density of development affected nesting success on small Adirondack lakes (< 50 ha). Thus, it is possible that the lake size threshold occurs below 50 ha. Detecting this limit may help define the threshold of development density beyond which the productivity of nesting pairs on Adirondack lakes will be negatively impacted.

The relationship between lake size and loon productivity may also be clouded by behavioral plasticity in loons and the aggressive territorial behavior of this species. Intraspecific aggression can negatively impact reproductive success when an adult loon is displaced or killed, or a chick is killed, during a territorial dispute (Mager *et al.* 2008; Piper *et al.* 2008). On lakes with high levels of recreational activity, nesting loons habituated to human activity have demonstrated a shorter flushing distance than loons on lakes less frequented by boat traffic and human activity (Smith 1981; Jung 1991; Ruggles

1994). On smaller lakes, Common Loons may not be able to get far enough away from development to be successful regardless of habituation.

Behavioral adaptation has been posed as an explanation for the lack of variation in loon productivity when comparing loon reproductive success on highly developed lakes to that of undeveloped lakes (McIntyre 1975; Titus and VanDruff 1981; Caron and Robinson 1994). Loons have exhibited an ability to adapt their behavior in response to human pressure by increasing the distance from nest sites to nearest shoreline structure or area of human activity (Alvo 1981; Heimberger *et al.* 1983; Stockwell and Jacobs 1993).

The results of this study indicate that the amount of development on lakes is not as important to nesting loons as the placement of development along lakeshores. The clustering of development may be a viable option for reducing sprawl on lakeshores, thus maintaining areas of suitable nesting habitat apart from areas of development. Consideration of development patterns on Adirondack lakes will be critical to maintaining habitat for nesting Common Loons.

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