Research Article

Reproductive Advantages for Common Loons Using Rafts

CHRISTOPHER R. DESORBO,[1] *BioDiversity Research Institute, 19 Flaggy Meadow Road, Gorham, ME 04038, USA*
KATE M. TAYLOR, *Loon Preservation Committee, 183 Lee's Mills Road, P.O. Box 604, Moultonborough, NH 03254, USA*
DAVID E. KRAMAR, *Senator George J. Mitchell Center for Environmental and Watershed Research, 104 Norman Smith Hall, University of Maine, Orono, ME 04469, USA*
JEFF FAIR, *Fairwinds Wildlife Services, P.O. Box 2947, Palmer, AK 99645, USA*
JOHN H. COOLEY, JR., *Loon Preservation Committee, 183 Lee's Mills Road, P.O. Box 604, Moultonborough, NH 03254, USA*
DAVID C. EVERS, *BioDiversity Research Institute, 19 Flaggy Meadow Road, Gorham, ME 04038, USA*
WILLIAM HANSON, *FPL Energy Maine Hydro, 150 Main Street, Lewiston, ME 04240, USA*
HARRY S. VOGEL, *Loon Preservation Committee, 183 Lee's Mills Road, P.O. Box 604, Moultonborough, NH 03254, USA*
JONATHAN L. ATWOOD, *Antioch New England Graduate School, Department of Environmental Studies, 40 Avon Street, Keene, NH 03431-3516, USA*

ABSTRACT Artificial nesting islands, or rafts, are often deployed in common loon (*Gavia immer*) breeding territories to decrease negative impacts of mammalian predation and water-level fluctuations on nesting success. The management value of rafts has been demonstrated in other studies; however, no published studies have quantified the use or associated reproductive benefits of rafts on lakes exhibiting water-level fluctuations. These lakes constitute a major portion of loon nesting habitat in New England and the Midwest. We used long-term data sets from loon survey and raft management efforts on lakes with stable (SWL) and fluctuating water levels (FWL) in New Hampshire and Maine, USA, to compare raft-use patterns on both types of lakes. We then modeled the influence of percentage of nesting attempts on rafts, lake fluctuation type, and human development index on nesting success as a function of the number of nesting attempts. Loons used 76% of all rafts for nesting, and initial use patterns were similar between SWL and FWL lakes. Half (51%) of rafts used for nesting were first used during the initial year of deployment and 90% of those used were used by the third year. Based on our model, we would expect to see an 8.6% increase in nesting success associated with each successive categorical increase in raft use (0–33%, 33–60%, 60–100%). Nesting success varied with lake fluctuation type, increasing by 21.4% from FWL to SWL types. Our model estimated a 12.8% decrease in nesting success associated with an increasing human development index. Naturally nesting loons on FWL lakes are likely to display mean nesting success levels lower than those needed to sustain populations. We suggest that natural nesting habitat on lakes with fluctuating water levels during the loon nesting season may constitute an ecological trap warranting consideration of raft management. Findings in this study are germane for managing breeding loon populations, particularly those on reservoirs requiring permits from the Federal Energy Regulatory Commission. (JOURNAL OF WILDLIFE MANAGEMENT 71(4):1206–1213; 2007)

DOI: 10.2193/2006-422

KEY WORDS artificial nesting island, common loon, *Gavia immer*, nesting success, raft, reservoirs, water-level fluctuations.

The common loon (*Gavia immer*) is a charismatic migratory species that breeds in the northern tier of the United States and much of Canada. Populations suffered regional and local declines and breeding range reductions throughout much of the 20th century due to impacts on both breeding and wintering populations (see reviews and citations in McIntyre and Barr 1997; Evers, in press). Primary factors influencing breeding populations include historical bounties and shooting, anthropogenically enhanced predator populations, habitat loss, human disturbance, contaminant exposure, and water-level fluctuations (McIntyre and Barr 1997; Evers, in press). Evidence of continuing declines and increasing anthropogenic pressures prompted a series of conferences (Sutcliffe 1979*a*, Strong 1988, Morse et al. 1993, McIntyre and Evers 2000) and the creation of numerous loon conservation programs to improve loon nesting success through habitat protection, education, and management. Management efforts implemented by these programs, especially those deploying artificial nesting islands, or rafts, have contributed to recoveries of loon populations in the northeastern United States (Evers, in press).

Islands are preferred nesting sites for common loons (Olson and Marshal 1952, Vermeer 1973, McIntyre 1975, Titus and VanDruff 1981), likely due to pressures from mammalian predators (Piper et al. 2002). A preference for nesting near the water's edge makes loon nests particularly vulnerable to water-level fluctuations, regardless of island use. Mathisen (1969) observed common loons nesting on floating sedge mat islands provided for waterfowl in Minnesota, USA. McIntyre and Mathisen (1977) anchored sedge mats and cedar log rafts within loon territories and found they enhanced nesting success. Rafts were quickly adopted into common loon management efforts in the northeastern United States (Sutcliffe 1978, 1979*b*), whereas similar efforts targeted red-throated loons (*G. stellata*) and arctic loons (*G. arctica*) in Europe (Merrie 1979, 1996).

The apparent success of these efforts led to raft programs to mitigate water-level–related nest failures on hydroelectric reservoirs in New Hampshire and Maine, USA, beginning in 1985 (Fair and Poirier 1993) and to the incorporation of rafts into loon management plans and hydroelectric project licenses overseen by state and federal wildlife agencies and the Federal Energy Regulatory Commission (FERC). Other applications for rafts have been considered, including use to replace habitat lost to shoreline development or as an

---

[1] *E-mail: chris.desorbo@briloon.org*

option to replace loon-years lost in marine oil spills (Sperduto et al. 2003). Raft deployment continues to gain popularity with conservation groups, the power industry, and citizen volunteers throughout substantial portions of the loon's breeding range. Widespread use of rafts on natural and artificial lakes in New Hampshire and Maine has resulted in extensive data sets on raft use and effectiveness. Although the value of rafts has been demonstrated in other studies (Piper et al. 2002), no published studies have quantified the use of rafts by loons and associated reproductive benefits on lakes with substantial water-level fluctuations, where management is arguably most warranted.

Our first objective was to analyze long-term data sets from the loon monitoring and raft management programs described above to determine if raft-use patterns differed on lakes with and without water-level fluctuations. Our second objective was to identify and quantify the effects of multiple factors (i.e., lake fluctuation type, raft use, territory type, human disturbance, lake size) on loon nesting success, as a tool to help managers develop and assess management plans.

STUDY AREA

We studied loon territories located within the same physiographic region encompassing portions of New Hampshire and Maine. Lakes displaying fluctuating water levels (FWL; definitions below) contained 8–24 loon territories and were located on 5 lakes (1,520–8,221 ha) in northwestern Maine and 4 lakes (117–3,177 ha) in northern New Hampshire. Water levels on FWL lakes fluctuated >1 m over the loon nesting period in response to rainfall, operations of hydroelectric power generators, and water demands by downstream users during dry summer months. Lakes displaying stable water levels (SWL) were located on 132 lakes (5.7–18,043 ha) throughout New Hampshire and in northwestern Maine. All lakes abutted mixed hardwood or coniferous forest types; shoreline development varied widely among lakes.

METHODS

Raft Construction and Deployment

We constructed and deployed cedar log rafts between ice-out and 20 May in established loon territories (as defined in Olson and Marshall 1952, Evers 2001) that contained suitable sites for placement (i.e., areas sheltered from impacts of wind, waves) and that had experienced nest failures due to shoreline predation or water-level fluctuation for ≥3 consecutive years. Raft construction design and deployment methodology were comparable to those outlined by Sutcliffe (1979*b*) and Piper et al. (2002).

We conducted surveys of loon territories on lakes throughout New Hampshire (1977–2004) and Maine (1986–2004) every 5–10 days from the second or third week of May to 10 August to confirm the occupancy by territorial loon pairs (Olson and Marshall 1952), nest type used (e.g., natural or raft), and nest success. In the absence of inviable eggs or observations of young, we determined site use and nest success based on evidence of egg remains in or near the nest bowl (Alvo 1985, Alvo and Prior 1986, Piper et al. 2002). We located territorial pairs from a kayak or a 4–6-m motorboat with 15–40 horsepower motor using 7–10× binoculars. Locating and surveying loon territories is facilitated by notably high within- and between-year territory fidelity of this species during the breeding season (Piper et al. 1997, Evers 2001). We located nests within marsh, mainland, and island shoreline habitats by boating 4–8 km/hour 3–10 m from shore and we searched shorelines with dense vegetation on foot (Titus and VanDruff 1981). Nest searches in FWL territories included habitat flooded or stranded by water-level increases or decreases (Fair 1979). Once we found natural or raft nests, we could verify incubating adults and raft condition from a distance (25 m) with minimal disturbance to resident loon pairs. Nest searches resumed after nest failures since loons may renest. We conducted mid– and post–nesting season nest searches to avoid overlooking initial nest attempts. Undetected nesting attempts were likely rare because failed loon nests are often easily detected given the above survey techniques.

Characterizing Raft Use by Loons

To evaluate if raft use was similar between lake fluctuation types, we compared the percentage of rafts that were used for nesting between FWL and SWL lake types for territories containing rafts for ≥3 years. We calculated the number of rafts that were used immediately during the first year of raft deployment and the proportion that were first used in subsequent years, to better understand time needed after deployment for raft use by loon pairs.

Territory Selection Criteria

Specific criteria guided inclusion of territories in our analyses. We included only established territorial pairs (pairs occupying a territory for ≤4 consecutive weeks for ≤3 consecutive yr; Evers 2001) that nested for ≥3 nesting attempts. We used only first nesting attempts (hereafter nesting attempts) because multiple nesting attempts are likely dependent (D. C. Evers, BioDiversity Research Institute, unpublished data). The influence of time periods between state data sets were negligible; model conclusions regarding significant variables were identical when limiting data sets to the 1987–2004 period and we therefore included all data in analyses. We excluded territories where loon methylmercury exposure levels were observed to be >3.0 ppm (in ad blood) or >1.3 ppm (in eggs) when data were available because elevated methylmercury exposure is associated with behavioral (Nocera and Taylor 1998, Bouton et al. 1999, Counard 2000) and reproductive impacts in loons (Barr 1986, Burgess et al. 1998) and other wildlife (Chan et al. 2003, Schwarzbach et al. 2006). Mercury exposure levels for loon territories are well documented (Evers et al. 1998, 2003, 2005), and un-sampled partial-lake-territory exposure was inferred from neighboring territories. Nest failure causes were not equally available across territories, and we did not include them in our study. We consider all loon territories sufficiently independent to conduct analyses due to the highly territorial nature of this species (Olson and Marshall 1952, Evers 2001).

Variable Selection

We selected 5 independent variables for model analysis, including 1) percent of nesting attempts on rafts, 2) lake fluctuation type, 3) human development index, 4) lake size, and 5) loon territory type. The dependent variable was the number of successful nesting attempts. We calculated the percent of territory nesting attempts on a raft by dividing the number of nest attempts on deployed rafts by the total number of nest attempts within each territory. We then used 3 raft-use categories to represent the data: 0 (0–33.0%), 1 (33.1–60.0%), and 2 (60.1–100%). Rafts do not likely influence chick survival beyond hatch; therefore, we did not include survival or fledging measures.

We classified all loon territories into 1 of 2 lake fluctuation types: FWL or SWL. We classified FWL territories as those within lakes containing a FERC hydroelectric license or state-issued Lake Level Order allowing for water-level increases >0.15 m or decreases ≥ 0.30 m over any 28-day period from 1 May to 30 July. These water-level benchmarks are currently recognized by wildlife resource agencies and used in unpublished FERC license agreements in New Hampshire and Maine such as Errol FERC 3133, Upper and Middle Dam Storage Projects FERC 11834, and Indian Pond FERC 2142. In our study, FWL territories regularly fluctuated >1 m during the loon nesting season. Water-level readings were available for all FWL lakes. We classified SWL territories as those within natural lakes that were not dammed or regulated and all dammed lakes in which a FERC hydroelectric license or state-issued Lake Level Order required that water levels do not increase >0.15 m or decrease ≥ 0.30 over the same period as described above for FWL territories. Natural water-level fluctuations do occur in the FWL range on some natural SWL territories in our study area; however, water-level–induced nest failures on these lakes are rare and we considered them insignificant. We included territories from one lake in both lake fluctuation categories due to water-level stabilization beginning in 1998. We considered territories before 1998 sufficiently independent from those in years after and including 1998, given the significant changes in habitat characteristics resulting from water-level stabilization (Johnsgard 1956, Harris and Marshall 1963, Moreno-Matiella and Anderson 2005).

We derived a human development index (HDI) to account for the potential impact of shoreline development and recreation on nesting success (e.g., Titus and VanDruff 1981, Heimberger et al. 1983). We used readily available data sources, including fishing guidebooks and digitized United States Geological Survey 1:24,000 topographical maps, to evaluate the following information and assign points to all study area lakes in 3 categories: boat access (1 = private or walk-in, 2 = unimproved boat launch, 3 = paved boat launch, 4 = multiple public boat launches, paved or unpaved); level of commercial development (0 = none, 1 = campgrounds and public parks, 2 = marinas or hotel and resorts); and extent of shoreline development (0 = no structures, 1 = 1–10 structures, 2 = 10–50 structures, 3 = $\geq$51 structures). For each lake, we converted the raw sum of these category points (1–9) into 3 development classes (1 = low, 2 = medium, 3 = high), and assigned that score to all territories on the lake. Index categories represent a modification of a more sophisticated habitat suitability model incorporating field measurements and spatial variables beyond the scope of our study (H. S. Vogel, Loon Preservation Committee, unpublished data; A. Kuhn, United States Environmental Protection Agency, unpublished data). We grouped lake size (ha) into 5 categories based on natural breaks in the data: 1) 0–525.67, 2) 525.68–1,725.71, 3) 1,725.72–3,176.76, 4) 3,176.77–8,821.00, and 5) 8,821.01–18,043.40. Lastly, we classified all territories into the following territory types: 0 = whole lake (loon pair defends the only territory within a lake), 1 = partial lake (loon pair defends one of several territories on a lake), or 2 = multiple lake (loon pair defends multiple lakes as their territory) consistent with definitions described by Piper et al. (1997) and Evers (2001).

Data Characterization

We present territory sample sizes and descriptive statistics of nesting success (% of nesting pairs hatching $\geq$1 chick) and hatching success (no. chicks hatched/no. nesting pairs) relative to lake fluctuation type and nest site type (Table 1). We include both hatching success and nesting success to allow for further comparisons to numerous studies presenting only one measure; however, our analyses focus on nesting success. These 2 measures are highly correlated in our data ($r = 0.94$, $P < 0.001$, Spearman rank correlation).

Statistical Analysis

We fit a Poisson log-linear regression model to the data for loon nesting success. After determining significant variables and attempting to address for potential bias, the basic structure of the model was as follows:

$$Y = \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4) \times T,$$

where

Y = sum of successful nesting attempts per territory in a known time period;

X_1 = percent use of total territory nesting attempts that loons spent nesting on a raft, categorized as

$$0 = 0 - 33.0\%, 1 = 33.1 - 66.0\%, 2 = 66.1 - 100\%;$$

X_2 = lake fluctuation type categorized as 0 (SWL) or 1 (FWL);

X_3 = human development index;

X_4 = territory type (whole, partial, or multiple);

T = total number of territory nesting attempts;

β_n = coefficient estimates for each of the independent variables.

Table 1. Descriptive statistics for mean hatching success and nesting success of common loons using raft and natural nests on lakes in New Hampshire and Maine, USA, with fluctuating (FWL) and stable (SWL) water levels, 1977–2004.[a]

	Raft nests					Natural nests				
	Hatching success			Nesting success		Hatching success			Nesting success	
Lake type	***n***	***x̄***	**SE**	***x̄***	**SE**	***n***	***x̄***	**SE**	***x̄***	**SE**
FWL	47	1.03	0.088	65	4.8	97	0.47	0.046	33	3.0
SWL	44	1.22	0.074	73	3.6	215	0.81	0.032	55	2.0
Total	91	1.12	0.059	69	3.1	312	0.71	0.028	48	1.7

[a] Hatching success = no. chicks hatched in a territory/no. nesting pairs; nesting success = % of nesting pairs successfully hatching ≥1 chick. Sample sizes represent the no. of loon territories.

We used a loss function to obtain maximum likelihood estimates for the model. The loss function is as follows:

$$\text{Estimate} - Y \times \log(\text{Estimate}) + \text{lgm}(Y + 1).$$

We tested the independent variables against the null hypothesis ($\beta = 0$) using the Wald statistic and Wald confidence intervals. We calculated the Wald statistic and tested the significance of the parameters to the model using the likelihood ratio test as described in Agresti (1996).

To avoid a potential violation of the large-sample chi-square theory (several observations consisted of <5 successful nesting attempts), we grouped the data into 11 categories based on the total number of nesting attempts. We calculated chi-square and G^2 statistics to determine if the model fit the data based on formulas described in Agresti (1996). Finally, we evaluated over-dispersion of the model by calculating the scaling factor as described by Agresti (1996). We used Systat 11 (Systat Software Inc., Richmond, CA) to construct the model and performed other tests using JMP 4.0.0 (SAS Institute, Cary, NC). We used a chi-square test to compare proportions of rafts used by loons, and a Wilcoxon test to compare the mean year of first use. We used a Spearman rank test to evaluate correlations between variables. We present standard errors in text and tables unless otherwise noted.

RESULTS

Loons used 76% (80/105) of deployed rafts for nesting. The patterns of first year of initial use were similar between FWL and SWL groups; 90% of all used rafts were used by the third year (Table 2). We found no difference between lake fluctuation types in the percentage of rafts used ($\chi^2_1 = 0.15$, $P = 0.69$) or mean year first used ($\chi^2_1 = 3.14$, $P = 0.077$).

Of the 5 independent variables we tested in our model, we found coefficient estimates for 3 to be significant to nesting success as evidenced by their confidence interval and the associated Wald statistics: percent of nesting attempts on rafts, the lake fluctuation type, and HDI (Table 3). Territory type did not exhibit a relationship ($z_1 = 0.915$, $P = 0.34$, 95% CI = -0.0418 to 0.121) and we therefore did not include it in the final analysis. We did not include lake size category in the model due to a strong correlation with the HDI ($r = 0.80$, $P < 0.001$, Spearman rank correlation). Likelihood ratio tests indicated that each of the identified variables was important in determining nesting success (Table 4).

The chi-square and G^2 statistics indicated a strong fit between the model and the data ($G^2_7 = 7.36$, $P = 0.39$; $\chi^2_7 = 7.38$, $P = 0.39$). A visual inspection of the Pearson residuals also indicates a good fit, with all values <2. The scaling factor of 1.021 indicates the model variance is approximately one times the mean and over-dispersion is not present in the model. We found a visually good fit between the 11 groups of years selected (Fig. 1). Categorizing the mean number of successful nesting attempts by lake fluctuation type and nest type reveals the influence of these 2 parameters on loon nesting success (Fig. 2).

Based on the above indications that the model fits the data, we would expect to see an 8.6% increase in loon nesting success associated with each increasing raft-use category over a given time period. Lake fluctuation type was highly significant to nesting success; we estimated a 21.4% increase in nesting success when moving from FWL to

Table 2. Proportion of deployed rafts used versus not used and year of first use statistics for common loons on lakes in New Hampshire and Maine, USA, with fluctuating (FWL) and stable (SWL) water levels, 1977–2004.

		Raft use			Yr first used[a]						
Lake type	***n*[b]**	**Yes (*n*)**	**No (*n*)**	**(%)**	**1 (%)**	**2 (%)**	**3 (%)**	**4 (%)**	**5+ (%)**	***x̄*[c] year**	**SE**
FWL	54	42	12	78	43	21	21	7	7	2.40	0.35
SWL	51	38	13	75	60	18	16	5	–	1.66	0.15
Total	105	80	25	76	51	20	19	6	4	2.05	0.20

[a] The proportion of territories using rafts on yr after raft deployment. Yr 1 = initial deployment yr.

[b] No. of loon territories in which we deployed rafts as potential nest sites for common loons.

[c] Means were not significantly different ($\chi^2_1 = 3.14$, $P = 0.077$, Wilcoxon test).

Table 3. Parameter estimates, confidence intervals, and Wald statistics for Poisson log-linear model of nesting success for common loons in New Hampshire and Maine, USA, 1977–2004.

				Wald CIs				
Parameter	Estimate	ASE[a]	Parameter/ASE	Lower 95% CI	Upper 95% CI	Wald statistic	df	P
β_0	−0.252	0.0670	−3.765	−0.384	−0.121	14.172	1	0
β_1	0.0828	0.0299	2.771	0.0242	0.141	7.677	1	0.005
β_2	−0.241	0.0661	−3.650	−0.371	−0.112	13.322	1	0
β_3	−0.120	0.0310	−3.878	−0.181	−0.060	15.038	1	0

[a] ASE = asymptotic SE.

SWL lakes. Our data also show a decrease of 12.8% in nesting success as the HDI classification increases.

DISCUSSION

Our data indicate that a substantial portion of rafts deployed in loon territories are used for nesting by loons and little influence of water-level fluctuations on raft use. The proportion of rafts used was similar to the proportion of nests occurring on island sites (78%) reported in Titus and VanDruff (1981). Patterns of initial raft use were similar to those reported for raft-nesting loon populations in Wisconsin (50%; Piper et al. 2002) and Vermont, USA (64%; E. Hanson, Vermont Institute of Natural Science, unpublished data); Merrie (1996) also reported high initial acceptance of rafts by other loon species in Scotland. Loons used 90% of rafts by the third year, and few (10%) rafts were first used in years >3, suggesting that 3 seasons is a sufficient trial period to predict if loons will use a raft.

Our data indicate that increased raft use resulted in increased loon nesting success in both lake fluctuation type categories. Other studies have demonstrated that water-level fluctuations lower loon nesting success (Fair 1979, Barr 1986, Reiser 1988). Rafts have also been noted to provide significant reproductive benefits to nesting loons in the absence of water-level fluctuations, primarily by lessening shoreline-based mammalian predation (Piper et al. 2002). Raft-nesting loons on FWL territories in our study exhibited levels of mean nesting success or hatching success similar to those reported for other populations considered stable (Reiser 1988, Belant and Anderson 1991, Croskery 1991), whereas naturally nesting loons on FWL territories displayed lower mean nesting success (33 ± 3%) than all published population comparisons. Mean nesting success for raft-nesting SWL territories in our study are similar to those reported for the statewide population in Vermont (25-yr $\bar{x} = 77 \pm 10\%$ [SD]; E. Hanson, unpublished report), which is experiencing rapid population recovery. In comparison, exclusively raft-nesting loons in Wisconsin displayed similar or higher nesting success than populations in Vermont or in our study (83%; Piper et al. 2002).

Table 4. Likelihood ratio test (LRT) statistics and P-values for Poisson log-linear model of nesting success for common loons in New Hampshire and Maine, USA, 1977–2004.

Test[a]	LRT	df	P
Full model—human disturbance index	14.968	1	<0.001
Full model—lake type	13.660	1	<0.001
Full model—ranked % of nesting attempts on rafts	7.495	1	0.006

[a] We conducted each test with one parameter absent against the full model.

Loons prospecting for territories may be attracted to lakes with fluctuating water levels in our study area given generally abundant shoreline and island nesting habitat, adequate food availability, and relatively low human disturbance (Newbrey et al. 2005, Piper et al. 2006). However, naturally nesting loons on FWL territories may not hatch a sufficient number of young to sustain populations, and FWL territories where rafts are not deployed or used might therefore represent an ecological trap (Dwernychuk and Boag 1972, Gates and Gysell 1978, Schlaepfer et al. 2002). In these cases, population sustainability might rely upon effective management. Other studies have noted the potential of rafts to transform population sinks to sources (Merrie 1996, Piper et al. 2002). Raft-nesting loons often contribute a higher proportion or all of the fledged young to hydroelectric reservoir loon populations (C. R. DeSorbo, BioDiversity Research Institute, unpublished report). Beyond hatching, site-specific factors

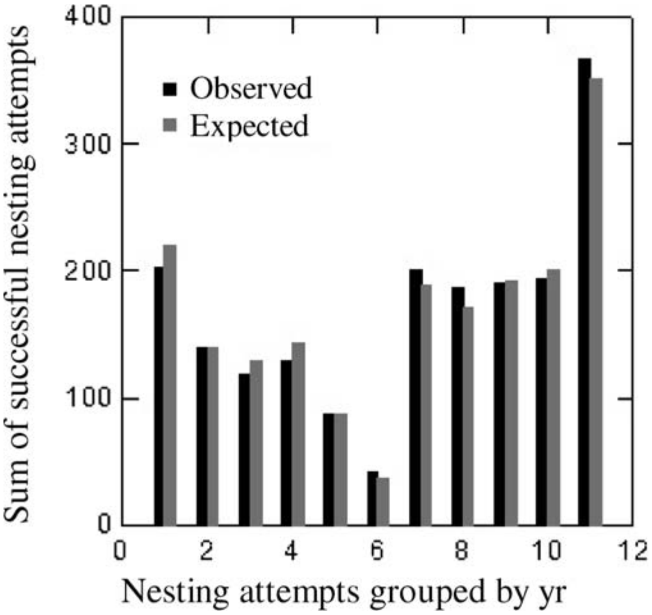

Figure 1. Observed and expected numbers of successful nest attempts for common loons in New Hampshire and Maine, USA (1977–2004), grouped by the total number of nest attempts. Goodness-of-fit tests on these data indicate a good model fit.

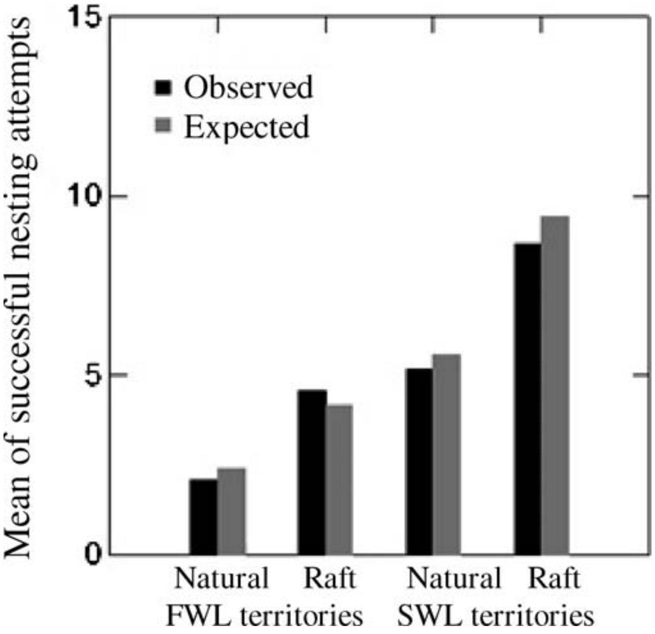

Figure 2. Observed and expected mean numbers of common loon successful nest attempts in New Hampshire and Maine, USA (1977–2004), grouped by lake type (SWL = stable water level; FWL = fluctuating water level) and nest type. Calculations account for differences in the total number of territory nesting attempts. Presented in this manner, the effect of lake type and nest type on nesting success are evident.

such as food availability (Barr 1986, Parker 1988, Gingras and Paszkowski 1999), predator pressures (Douglas and Reimchen 1988), and contaminant exposure (Burgess et al. 1998, Nocera and Taylor 1998, Counard 2000) will influence chick survival independent of the nest site used.

Our analyses also indicate a significant negative relationship between nesting success and our HDI. Heimberger et al. (1983) found that hatching success declined as cottage density increased. Vermeer (1973) and Newbrey et al. (2005) similarly note negative relationships between shoreline development and the presence of breeding or territorial loons, respectively. Human development and recreational activities are likely correlated (Heimberger et al. 1983) and human recreation can negatively impact loon nesting success (Titus and VanDruff 1981, Heimberger et al. 1983; but see Caron and Robinson 1994). Variability in the observed relationship between the HDI and loon nesting success is likely influenced by differences in loon sensitivities or acclimation to human activity at nests (Titus and VanDruff 1981, Heimberger et al. 1983). Significance between nesting success and the HDI may be related to the wide spectrum of development among lakes (low, $n = 62$; moderate, $n = 53$; high, $n = 25$). The HDI we used in analyses represents a coarse, cost-efficient, and objective measure of 3 development extremes at lakes. More sophisticated models (i.e., see discussion in Caron and Robinson 1994, Newbrey et al. 2005) incorporating quantitative measures of development and habitat features to predict loon productivity are being developed with this data set and will further refine results presented here (A. Kuhn, unpublished data; H. S. Vogel, unpublished data).

Numerous factors we addressed are associated with lake size; thus, their influence on loon nesting success should be considered. For example, high collinearity between the HDI and lake size reflects higher developmental pressures at large lakes. These 2 variables were both correlated with nesting success and were essentially surrogates for each other in our statistical model. Titus and VanDruff (1981) noted higher hatching success on lakes <200 ha compared to larger lakes. Larger lakes are also associated with partial lake territory types, whereas smaller lakes tend to be whole or multiple lake types. Although territory type was not significant to nesting success in our analyses, other studies report higher intrusion rates on partial lake territories because large lakes can act as bases for nonbreeding individuals (Croskery 1988, Paruk 1999, Piper et al. 2000). Higher intrusion rates have been related to decreased time spent incubating and guarding eggs (Paruk 1999), as well as increased territorial disputes, and lower hatching success following mate displacements (Piper et al. 1997, Evers 2001, Mager 2005, Piper et al. 2006). There may have been potential in our analysis to find a negative correlation between the sum of successful nesting attempts and the percent nesting attempts on rafts because both variables are related to the total number of nesting attempts (e.g., the no. successful nest attempts likely increases as the no. total nest attempts increases, which is used to calculate the percent time spent nesting on a raft). Our model indicated a positive correlation between these 2 variables, however, and can thus be considered conservative.

Other variables we did not include may also influence nesting success. Predation pressures may differ between lake fluctuation types or territory types depending on habitat characteristics or lake size. Many known predators of loon eggs such as common ravens (*Corvus corax*), bald eagles (*Haliaeetus leucocephalus*), and gulls (*Larus* spp.; Olson and Marshall 1952, Belant and Anderson 1991, Alvo and Blancher 2001) may have higher densities on larger versus smaller lakes due to differences in food availability, species composition, or other factors. Prey species composition has been noted to influence loon presence, tendencies to nest, and ability to raise young in some studies (Parker 1988, Gingras and Paszkowski 1999); however, those studies do not report similar influences on nesting success. Fish species composition may vary among the 140 lakes in our study, given variations in size, depth, and other factors. No lakes in our study are comparable, however, to fishless or minnow-based lakes in the abovementioned studies, and the influence of prey variables on our findings is unknown. Numerous factors such as predator or fish populations, human recreation, human protection, or water-level fluctuations may similarly influence territories within large lakes. Therefore, although we considered territories sufficiently independent, further study may be needed to evaluate lake-specific factors influencing loon nesting success. Although we considered undetected nest failures or attempts a rarity, such cases would likely result in the conservative overestimation of nesting success for naturally nesting loons in comparison to easily detected raft nests. Lastly, many factors discussed above have likely changed over our monitoring period. Given higher variability in short-term measures of loon nesting success (K. M. Taylor, Loon Preservation Committee, unpublished data), long-term data sets provide robust measures with higher accuracy despite temporal factors.

MANAGEMENT IMPLICATIONS

Our quantitative model will help managers evaluate the efficacy of raft use on loon nesting success on both types of lakes. Raft-use patterns by loons in our study indicate that 90% of rafts displaying use are initiated by the third year of deployment. Therefore, we recommend that a 3-year trial period is sufficient to evaluate if deployed rafts will be used for nesting. Our model demonstrates that increased raft use positively influences nesting success for loons on lakes with and without significant water-level fluctuations. Our data also suggest a negative influence of human development or disturbance on loon nesting success. This topic warrants further research given steadily increasing developmental and recreational pressures on lakes throughout the southern breeding range of the common loon. Our data also suggest that territories in waterbodies with highly fluctuating water levels may represent an ecological trap, and raft-nesting loons on such waterbodies provide productivity necessary to sustain populations. We therefore recommend loon population management using rafts on lakes with artificial water-level fluctuations comparable to those we described for FWL territories. Nesting success that we found for naturally nesting SWL populations (55 ± 2%) provide a robust measure that managers can use as a measure of success.

ACKNOWLEDGMENTS

Funding for this research and manuscript preparation was provided by BioDiversity Research Institute, the Loon Preservation Committee, and FPL Energy Maine Hydro. Data for this study were collected by numerous biologists in addition to coauthors, especially K. Murphy, S. Murphy, L. Savoy, and D. Yates. Thanks to J. Barr, K. Murphy, and S. Murphy for filling numerous data queries. E. Hanson, Vermont Loon Recovery Project, Vermont Institute of Natural Science, provided unpublished comparison data and other information. Thanks to W. Halteman at the University of Maine for his guidance in the nonlinear modeling portions of this research, and especially J. Eadie, W. Piper, J. Mager, and 2 anonymous reviewers for their valuable critiques of this manuscript.

LITERATURE CITED

Agresti, A. 1996. An introduction to categorical data analysis. John Wiley & Sons, New York, New York, USA.

Alvo, R. 1985. Determining whether common loon eggs have hatched. Wilson Bulletin 97:242–243.

Alvo, R., and P. J. Blancher. 2001. Common raven, *Corvus corax*, observed taking an egg from a common loon, *Gavia immer*, nest. Canadian Field-Naturalist 115:168–169.

Alvo, R., and K. Prior. 1986. Using eggshells to determine the year of a common loon, *Gavia immer*, nesting attempt. Canadian Field-Naturalist 100:114–115.

Barr, J. F. 1986. Population dynamics of the common loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario. Canadian Wildlife Service Occasional Paper 56, Ottawa, Ontario, Canada.

Belant, J. L., and R. K. Anderson. 1991. Common loon, *Gavia immer*, productivity on a northern Wisconsin impoundment. Canadian Field-Naturalist 105:29–33.

Bouton, S. N., P. C. Frederick, M. G. Spalding, and H. McGill. 1999. Effects of chronic, low concentrations of dietary methylmercury on the behavior of juvenile great egrets. Environmental Toxicology and Chemistry 18:1934–1939.

Burgess, N. M., D. C. Evers, J. D. Kaplan, M. Duggan, and J. J. Kerekes. 1998. Mercury and reproductive success of common loons breeding in the Maritimes. Pages 104–109 *in* N. M. Burgess, editor. Mercury in Atlantic Canada: a progress report. Environment Canada, Sackville, New Brunswick, Canada.

Caron, J. A., Jr., and W. L. Robinson. 1994. Responses of breeding common loons to human activity in Upper Michigan. Hydrobiologia 279/280:431–438.

Chan, H. M., A. M. Scheuhammer, A. Ferran, C. Loupelle, J. Holloway, and S. Weech. 2003. Impacts of mercury on freshwater fish–eating wildlife and humans. Human and Ecological Risk Assessment 9:867–883.

Counard, C. J. 2000. Mercury exposure and effects on common loon (*Gavia immer*) behavior in the upper midwestern United States. Thesis, University of Minnesota, St. Paul, USA.

Croskery, P. R. 1988. Flocking behavior of common loons (*Gaiva immer*) in northwest Ontario: early summer sites. Pages 66–75 *in* V P. I. V. Strong, editor. Papers from the 1987 Conference on Loon Research and Management. North American Loon Fund, 18–19 September 1987, Meredith, New Hampshire, USA.

Croskery, P. R. 1991. Common loon, *Gavia immer*, nesting success and young survival in northwestern Ontario. Canadian Field-Naturalist 105: 45–58.

Douglas, S. D., and T. E. Reimchen. 1988. Reproductive phenology and early survivorship in red–throated loons, *Gavia stellata*. Canadian Field-Naturalist 102:701–704.

Dwernychuk, L. W., and D. A. Boag. 1972. Ducks nesting in association with gulls—an ecological trap? Canadian Journal of Zoology 50:559–563.

Evers, D. C. 2001. Common loon population studies: continental mercury patterns and breeding territory philopatry. Dissertation, University of Minnesota, St. Paul, USA.

Evers, D. C. In press. Status assessment and conservation plan for the common loon (*Gavia immer*) in North America. U.S. Fish and Wildlife Service Technical Report Series, Denver, Colorado, USA.

Evers, D. C., N. Burgess, L. Champoux, B. Hoskins, A. Major, W. Goodale, R. Taylor, and T. Daigle. 2005. Patterns and interpretation of mercury exposure in freshwater avian communities in northeastern North America. Ecotoxicology 14:193–221.

Evers, D. C., J. D. Kaplan, M. W. Meyer, P. S. Reaman, W. E. Braselton, A. Major, N. Burgess, and A. M. Scheuhammer. 1998. Geographic trend in mercury measured in common loon feathers and blood. Environmental Toxicology and Chemistry 17:173–183.

Evers, D. C., K. M. Taylor, A. Major, R. J. Taylor, R. H. Poppenga, and A. M. Scheuhammer. 2003. Common loon eggs as indicators of methylmercury availability in North America. Ecotoxicology 12:69–89.

Fair, J. S. 1979. Water level fluctuations and common loon nest failure. Pages 57–63 *in* S. A. Sutcliffe, editor. Proceedings of the second North American Conference on Common Loon Research and Management. National Audubon Society, 14–17 January 1979, Syracuse, New York, USA.

Fair, J., and B. M. Poirier. 1993. Managing for common loons on hydroelectric project reservoirs in northern New England. Pages 221 *in* L. Morse, S. Stockwell, and M. Pokras, editors. Proceedings of the 1992 Conference on the Loon and Its Ecosystem. U.S. Fish and Wildlife Service, 22–24 August 1992, Concord, New Hampshire, USA.

Gates, J. E., and L. W. Gysel. 1978. Avian nest dispersion and fledgling success in field–forest ecotones. Ecology 59:871–883.

Gingras, B. A., and C. A. Paszkowski. 1999. Breeding patterns of common loons on lakes with three different fish assemblages in north-central Alberta. Canadian Journal of Zoology 77:600–609.

Harris, S. W., and W. M. Marshall. 1963. Ecology of water-level manipulations on a northern marsh. Ecology 44:331–343.

Heimberger, M., D. Euler, and J. Barr. 1983. The impact of cottage development on common loon reproductive success in central Ontario. Wilson Bulletin 95:431–439.

Johnsgard, P. A. 1956. Effects of water fluctuation and vegetation change in bird populations, especially waterfowl. Ecology 37:689–701.

Mager, J. N., III. 2005 What information is communicated by the territorial yodel of male common loons (*Gavia immer*)? Dissertation, Cornell University, Ithaca, New York, USA.

Mathisen, J. E. 1969. Use of man-made islands as nesting sites of the common loon. Wilson Bulletin 81:331.

McIntyre, J., and D. C. Evers. 2000. Loons: old history and new findings. Proceedings of a symposium from the 1997 meeting, American Ornithologists' Union, 15 August 1997. North American Loon Fund, Minneapolis, Minnesota, USA.

McIntyre, J. W. 1975. Biology and behavior of the common loon (*Gavia immer*) with reference to its adaptability in a man-altered environment. Dissertation, University of Minnesota, Minneapolis, USA.

McIntyre, J. W., and J. F. Barr. 1997. Common loon (*Gavia immer*). Account 313 *in* A. Poole and F. Gill, editors. The birds of North America. The Birds of North America, Inc., Philadelphia, Pennsylvania, USA.

McIntyre, J. W., and J. Mathesin. 1977. Artificial islands as nest sites for common loons. Journal of Wildlife Management 41:317–319.

Merrie, T. D. H. 1979. Success of artificial island nest-sites for divers. British Birds 72:32–33.

Merrie, T. D. H. 1996. Breeding success of raft-nesting divers in Scotland. British Birds 89:306–309.

Moreno-Matiella, L. A., and D. W. Anderson. 2005. Water level variation and its effects on nesting habitat configuration and availability for the American white pelican at Clear Lake Reservoir, California. Waterbirds 28:73–82.

Morse, L., S. Stockwell, and M. Pokras. 1993. The loon and its ecosystem: status, management, and environmental concerns. Proceedings of the 1992 American Loon Conference. U.S. Fish and Wildlife Service, 22–24 August 1992, Bar Harbor, Maine, USA.

Newbrey, J. L., M. A. Bozek, and N. D. Niemuth. 2005. Effects of lake characteristics and human disturbance on the presence of piscivorous birds in northern Wisconsin, USA. Waterbirds 28:478–486.

Nocera, J. J., and P. D. Taylor. 1998. *In situ* behavioral response of common loons associated with elevated mercury (Hg) exposure. Conservation Ecology [online] 2:article 10. <http://www.ecologyandsociety.org/vol12/iss2/art10/index.html>. Accessed 9 Apr 2007.

Olson, S. T., and W. M. Marshall. 1952. The common loon in Minnesota. University of Minnesota Press Occasional Paper 5, Minneapolis, USA.

Parker, K. E. 1988. Common loon reproduction and chick feeding on acidified lakes in the Adirondack Park, New York. Canadian Journal of Zoology 66:804–810.

Paruk, J. D. 1999. Behavioral ecology in breeding common loons (*Gavia immer*): cooperation and compensation. Dissertation, Idaho State University, Pocatello, USA.

Piper, W. H., M. W. Meyer, M. Klich, K. B. Tischler, and A. Dolsen. 2002. Floating platforms increase reproductive success of common loons. Biological Conservation 104:199–203.

Piper, W. H., J. D. Paruk, D. C. Evers, M. W. Meyer, K. B. Tischler, M. Klich, and J. J. Hartigan. 1997. Local movements of color-marked common loons. Journal of Wildlife Management 61:1253–1261.

Piper, W. H., K. B. Tischler, and M. Klich. 2000. Territory acquisition in loons: the importance of take-over. Animal Behaviour 59:385–394.

Piper, W. H., C. Walcott, J. N. Mager, III, M. Perala, K. B. Tischler, E. Harrington, A. J. Turcotte, M. Schwabenlander, and N. Banfield. 2006. Prospecting in a solitary breeder: chick production elicits territorial intrusions in common loons. Behavioral Ecology 17:881–888.

Reiser, M. H. 1988. Effects of regulated lake levels on the reproductive success, distribution and abundance of the aquatic bird community in Voyageurs National Park, Minnesota. U.S. Department of the Interior, National Park Service Research/Resources Management Report MWR-13, Omaha, Nebraska, USA.

Schlaepfer, M. A., M. C. Runge, and P. W. Sherman. 2002. Ecological and evolutionary traps. Trends in Ecology and Evolution 17:474–480.

Schwarzbach, S. E., J. D. Albertson, and C. M. Thomas. 2006. Effects of predation, flooding, and contamination on reproductive success of California clapper rails (*Rallus longirostris obsoletus*) in San Francisco Bay. Auk 123:45–60.

Sperduto, M. R., S. P. Powers, and M. Donlan. 2003. Scaling restoration to achieve quantitative enhancement of loon, seaduck, and other seabird populations. Marine Ecology Progress Series 264:221–232.

Strong, P. I. 1988. Papers from the 1987 Conference on Common Loon Research and Management. North American Loon Fund, 18–19 September 1987, Ithaca, New York, USA.

Sutcliffe, S.A. 1978. Changes in status and factors affecting common loon populations in New Hampshire, USA. Transactions of the Northeast Section of The Wildlife Society 35:219–224.

Sutcliffe, S. A. 1979*a*. The common loon. Proceedings of the second North American Conference on Common Loon Research and Management. National Audubon Society, 14–16 January 1979, Syracuse, New York, USA.

Sutcliffe, S. A. 1979*b*. Artificial common loon nesting site construction, placement and utilization in New Hampshire. Pages 111–116 *in* S.A. Sutcliffe, editor. Proceedings of the second North American Conference on Common Loon Research and Management. National Audubon Society, 14–16 January 1979, Syracuse, New York, USA.

Titus, J. R., and L. W. VanDruff. 1981. Response of the common loon to recreational pressure in the Boundary Waters Canoe Area, northeastern Minnesota. Wildlife Monographs 79.

Vermeer, K. 1973. Some aspects of the nesting requirements of the common loon in Alberta. Wilson Bulletin 85:429–435.

Associate Editor: Eadie.