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Evaluation of Disturbance Factors and Their Effect on Breeding Common Loons at Lake Umbagog National Wildlife Refuge, New Hampshire and Maine

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EVALUATION OF DISTURBANCE FACTORS AND THEIR EFFECT ON BREEDING COMMON LOONS AT LAKE UMBAGOG NATIONAL WILDLIFE REFUGE, NEW HAMPSHIRE AND MAINE

A Dissertation Presented

by

KYLE PATRICK MCCARTHY

Submitted to the Graduate School of the
University of Massachusetts, Amherst in partial fulfillment
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DEDICATION

To my forthcoming little one

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I would like to thank my advisor, Stephen DeStefano, for his guidance and support throughout this process. I have never received such thoughtful edits in such a short time frame. I would also like to thank my wife, a fellow Ph.D. student who still found time to join me in my field work and provide helpful comments throughout the writing process. I thank my family for always helping Jen and I pursue our dreams.

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ABSTRACT

EVALUATION OF DISTURBANCE FACTORS AND THEIR EFFECT ON BREEDING COMMON LOONS AT LAKE UMBAGOG NATIONAL WILDLIFE REFUGE, NEW HAMPSHIRE AND MAINE

FEBRUARY 2010

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Virtually any person exposed to American movies or television has likely heard the call of a common loon (*Gavia immer*). Its use as a sound prop has become ubiquitous in any scene related to the outdoors or the wilderness, even if the area filmed is in no way related to true loon habitat. The reason behind this is that the common loon and its haunting cries have come to symbolize the great outdoors. The sound of their call is meant to make the audience feel like the scene they are watching is in a remote area, far from the trappings of civilization, and, in our experience, it works. Hollywood has picked up on a sentiment held by many outdoor enthusiasts and is using it successfully.

Unfortunately the southern range of the common loon is contracting and concern has been expressed over disturbance to breeding pairs by human activities, such as shoreline development, boating, and water-skiing, as well as possible contamination with lead, mercury, and other pollutants. If this alarming trend continues it may be that

Hollywood movies will be the last place where a loon call can be heard in the United States.

In the following chapters I will explore various threats to common loon populations. I will start in Chapter 1 with an evaluation of the potential effects of global warming on common loons within the North American breeding range. In Chapter 2 I review the available literature on wildlife disturbance and discuss some of the shortcomings and future research needs. I then go to a finer scale of study in Chapter 3 with a spatial analysis of disturbance factors and the effects on breeding common loons at Lake Umbagog National Wildlife Refuge. From there, in Chapter 4, I proceed to an analysis of specific behavioral responses exhibited by common loons in response to observed and experimentally imposed disturbance events. Finally, in Chapters 5 and 6, I briefly describe two natural disturbance events observed during our research, an immature bald eagle (*Haliaeetus leucocephalus*) predating a loon nest, and a loon nest defense of an aggressive American mink (*Nevison vison*).

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS v

ABSTRACT vi

LIST OF TABLES x

LIST OF FIGURES xii

CHAPTER

I. MOVING NORTH: GLOBAL WARMING AND THREATS TO COMMON LOONS 1

- Abstract 1
- Introduction 2
- Study Area 4
- Methods 5
- Results 8
- Discussion 9
- Management Implications 13

II. THE STATE OF WILDLIFE DISTURBANCE LITERATURE AND FUTURE NEEDS IN A CHANGING WORLD 21

- Abstract 21
- Introduction 22
- Overview 23
- Methods 26
- Results 31
- Discussion 33

III. SPATIAL DISTURBANCE FACTORS AND THEIR EFFECT ON COMMON LOON NEST SITE SELECTION AND TERRITORY SUCCESS 54

- Abstract 54
- Introduction 55
- Study Area 56
- Methods 57
- Results 61
- Discussion 62
- Management Implications 66

IV. COMMON LOON BEHAVIORAL RESPONSES TO DISTURBANCE DURING BREEDING 74

Abstract 74
Introduction 75
Study Areas 80
Methods 81
Results 87
Discussion 93
Management Implications 100

V. BALD EAGLE PREDATION ON COMMON LOON EGG 140

Abstract 140
Introduction 140
Methods 141
Results 141
Discussion 142

VI. COMMON LOON NEST DEFENSE AGAINST AN AMERICAN MINK 145

Abstract 145
Observation 145

APPENDICES

APPENDIX A. GROUPING USED TO CATEGORIZE INDIVIDUAL COMMON LOON PRE-NESTING BEHAVIORS. 150
APPENDIX B. GROUPING USED TO CATEGORIZE INDIVIDUAL COMMON LOON NESTING BEHAVIORS. 151
APPENDIX C. GROUPING USED TO CATEGORIZE INDIVIDUAL COMMON LOON BROOD-REARING BEHAVIORS. 152
APPENDIX D. INITIAL LIST OF POTENTIAL DISTURBANCE EVENTS TO RECORD DURING OBSERVATIONS 153

BIBLIOGRAPHY 155

LIST OF TABLES

Table Page

2.1. Key words and resultant articles found on ISI Web of Knowledge^{SM}, Web of Science® engine. 38

2.3. Resultant classification of disturbance literature showing area/region where research occurred and type of disturbance discussed. 40

2.4. Resultant classification of disturbance literature showing species class (classes of invertebrates have been grouped together and amphibians and reptiles have been grouped into herps) and species group (specificity was dependent upon what could be interpreted from each publication). 42

2.5. Resultant classification of disturbance literature showing ecosystem. 45

2.6. Resultant classification of disturbance literature showing focus level. 46

2.7. Resultant classification of disturbance literature showing ultimate cause of disturbance discussed. 47

2.8. Resultant classification of disturbance literature showing primary effect of disturbance. 48

4.1. Behavioral categories, codes, and descriptions used to explain observed common loon behavior on LUNW R and Azicohos lake, ME. 102

4.2. Disturbance codes, and descriptions used to explain observed disturbance on LUNW R and Azicohos lake, ME. 105

4.3. Common loon pre-nesting territorial pair behavior in the absence of disturbance factors on Lake Umbagog NWR. 106

4.4. Behavior profile of pre-nesting territorial loon pairs in the presence and absence of motorboat traffic on Lake Umbagog NWR. 107

4.5. Behavior profile of pre-nesting territorial loon pairs in the presence and absence of non-pair loons in surveys on Lake Umbagog NWR. 108

4.6. Behavior profile of primary nesting common loon from in absence of disturbance factors onLake Umbagog NWR. 109

4.7. Behavior profile of off- nest common loon from nesting pair (visible 12% of total survey time) on Lake Umbagog NWR. 110

4.8. Nesting loon behavior profile (proportion of time spent) when non-pair loon(s) are present and absent in surveys on Lake Umbagog NWR. 111

4.9. Nesting loon behavior profile with eagle presence and absence in surveys on Lake Umbagog NWR. 112

4.10. Nesting loon behavior profile in the presence of high, medium, low, and no motorized boat traffic on Lake Umbagog NWR.. 113

4.12. Common loon primary Brood-rearing adult behavior in the absence of disturbance factors on Lake Umbagog NWR and nearby Round Pond....... 115

4.13. Primary brood-rearing loon behavior profile (proportion of time spent) when non-pair loon(s) are absent and present in surveys on Lake Umbagog NWR. 116

4.14. Primary brood-rearing loon behavior profile with eagle presence and absence in surveys on Lake Umbagog NWR. 117

4.15. Primary brood-rearing loon behavior profile in the presence of high, medium, and no motorboat traffic on Lake Umbagog NWR. 118

4.16. Primary brood-rearing loon behavior profile with canoe/kayak presence and absence in surveys on Lake Umbagog NWR. 119

4.17. Total minutes in specific behaviors of primary nesting loons in the presence of disturbance factors on Aziscohos Lake, ME. 120

4.18. Total minutes in specific behaviors of primary brood-rearing loons in the presence of disturbance factors on Aziscohos Lake, ME. 121

4.19. Initial behavioral response distance in meters of nesting common loons to experimental approaches on Lake Umbagog, NWR, each approach consisted of slowly moving to within 100 m, stopping for 5 min, then slowly departing.. 123

4.20. total behavioral response time in 20 second increments of nesting common loons to experimental approaches on Lake Umbagog, NWR, Each approach consisted of slowly moving to within 100 m, stopping for 5 min, then slowly departing.. 124

4.21. End behavioral response distance in meters of nesting common loons to experimental approaches on Lake Umbagog, NWR, Each approach consisted of slowly moving to within 100 m, stopping for 5 min, then slowly departing.. 125

LIST OF FIGURES

Figure Page

1.1. Common loon breeding and wintering range in Canada and the United States based on data from “Digital Distribution Maps of the Birds of the Western Hemisphere” project available for download at naturserve.org (Ridgely et al. 2003). 15

1.2. Average estimated temperature change, with error bars and min/max envelope, between present (1979-1999) and future (2040-2060) in North American common loon range. 16

1.3. Projected average temperature change within current common loon range 50 years from now based on the Community Climate System Model for the 4th assessment report of the IPCC. 17

1.4. Projected maximum temperature change within current common loon range 50 years from now based on the Community Climate System Model for the 4th assessment report of the IPCC. 18

1.5. Classification tree of historic loon range within North America each branch shows n = non-territory and t = territory followed by correct classification rate and number of samples classified. 19

1.6. Predicted change in available common loon breeding habitat based on criteria from classification and regression of current loon range and historic average monthly air temperatures. 20

2.1. Trend in percent of evaluated species listed as threatened on the IUCN Red List in the last decade. Data used for graph is from the 2008 IUCN Red List summary table. 49

2.2. Percentage of disturbance literature search results by year, with 78% being from the last decade. 50

2.3. Time trend in search results for wildlife and wildlife disturbance publications on web of science search engine. 51

2.4. Trend in wildlife disturbance publications from developed and developing countries over time. 52

2.5. Trend in disturbance publications focusing on bird, mammal, and multiple species groups over time. 53

3.1. Lake Umbagog National Wildlife Refuge, study area for spatial analyses of disturbance variables and their effect on loon nest site selection and nest success 67

3.2. Flowchart depicting GIS processes in Arc GIS to develop spatial disturbance variables for analysis of common loon nest site selection and territory success on Lake Umbagog National Wildlife Refuge................................ 68

3.3. Classification tree separating groups of nest and random point data on Lake Umbagog National Wildlife Refuge pruned to 3 leaves based on 1 SE rule.. 69

3.4. Classification tree separating groups of nest and random point data on Lake Umbagog National Wildlife Refuge pruned to 5 leaves based on 1SE rule.. 70

3.5. Simple linear regression of dependant territory success variable given independent Euclidean distance to nearest house variable......................... 71

3.6. Potential nest site locations, highlighted in yellow, based on classification and regression tree analysis including human related and eagle related disturbance variables, Lake Umbagog National Wildlife Refuge.............. 72

3.7. Potential nest site locations, highlighted in yellow, based on classification and regression tree analysis including only human related disturbance variables, Lake Umbagog National Wildlife Refuge. 73

4.1. Lake Umbagog and Aziscohos Lake, study areas for analysis of common loon behavior in response to disturbance. 126

4.2. Observed nesting pairs and chicks hatched on Lake Umbagog, from 1995 – 2006. Data from the Loon Preservation Committee's annual "Lake Umbagog Loon Population and Management Report." 127

4.3. Historical breeding status of the common loon on Lake Umbagog from 2000 to 2008... 128

4.4. Redundancy analysis tri-plot with significant overall model ($p = 0.02$). Survey sites are separated by territory via color. Behavior variables SW = swimming, DR = drifting, AF = foraging, PR = preening, AP = alert posture, SL = sleeping, BD = Bill dip, and DS = dive swim. Other behaviors are insufficiently separated to assess effects. Disturbance variable MB = motor boat, CL = common loon. Postscripts A, B, C, and D indicate distance bins of 0-75m, 75-150m, 150-300m, and 300-600m respectively.. 129

4.5. Redundancy analysis tri-plot with significant ($p < 0.05$) axes 1 and 2. Survey sites are separated by territory via color. Behavior variables SW = swimming, DR = drifting, NH = nest head hung, NA = nest alert, VW = vocalizing wail, AP = alert posture, WF = wing flap, BD = Bill dip, and DS = dive swim. Other behaviors are insufficiently separated to assess effects. Disturbance variable BE = bald eagle, CL = common loon, SM = fishing motor boat, NM = non-fishing motor boat, NK = Kayak, and NC = Canoe. Postscripts A, B, and C indicate distance bins of 0-75m, 75-150m, and 150-300m respectively............................. 130

4.6. Percent disturbance type observed within 0-75 meters of nesting loon, 512 total observations, Lake Umbagog NWR.. 131

4.7. Percent disturbance type observed within 75-150 meters of nesting loon, 476 total observations, Lake Umbagog NWR.. 132

4.8. Percent disturbance type observed within 150-300 meters of nesting loon, 958 total observations, Lake Umbagog NWR.. 133

4.9. Percent observed non-fishing motorboat, fishing motorboat, and canoe/kayak use during common loon nesting surveys on Lake Umbagog NWR. Lines smoothed using 7-day moving window analysis for average and adjusted for daily survey effort. 134

4.10. Percent relaxed nesting and percent motorboats observed based on survey start-time, adjusted for survey effort. 135

4.11. Percent relaxed nesting and percent paddlers observed based on survey start-time, adjusted for survey effort. 136

4.12. Percent relaxed nesting and percent eagle and non-pair loons observed based on survey start-time, adjusted for survey effort. 137

4.13. Redundancy analysis tri-plot with significant ($p < 0.05$) axes 1. Survey sites are separated by territory via color. Behavior variables AF = foraging, FC = feeding chick, BU = chick under wing, BB = chick on back, AP = alert posture, BD = bill dip, and DS = dive swim PE = peering, VT = tremolo. Other behaviors are insufficiently separated to assess effects. Disturbance variable BE = bald eagle, CL = common loon, MB = motorboat, PD = canoe/kayak. Postscripts A, B, and C indicate distance bins of 0-75m, 75-150m, and 150-300m respectively. 138

4.14. Map of Lake Umbagog and river confluences with common loon nest sites from the 2007 breeding season. Each nest is buffered by 218m and 358m, the average and maximum distance a response was evoked under experimental treatment with canoe, kayak, gas motor on skiff, and electric motor on skiff. No statistical difference was detected between boat type. 139

5.1. Common Loon egg shell remains after predation by immature Bald Eagle, Lake Umbagog National Wildlife Refuge, 2008...................................... 144

6.1. Illustration of common loon nest defense against predating American mink. Composite of public domain photographs rendered using Jasc Paintshop Pro™. 149

CHAPTER 1

MOVING NORTH: GLOBAL WARMING AND THREATS TO COMMON LOONS

Abstract

The earth's climate is warming, acting as a significant driver of ecosystem change, and as such terrestrial biological systems are being affected. As one example of potential changes to ecosystems and the distribution of species we examine what climate change cam mean to common loons. We assessed the spatial nature of projected climate change in common loon (*Gavia immer*) North American breeding territory over the next 50 years and discuss how that change may pose a threat to loon populations. Classification tree analysis suggests that common loon breeding range is partially explained by historical air temperature data. Application of the resultant classification criteria to a future climate scenario shows a northward shift in predicted breeding range of the common loon. Projected average air temperature change during breeding season between present day and the year 2050 ranges from 1.94°c in May to 4.13°c in November, with maximums ranging from 3.37°c in May to 8.47°c in November. These changes could lead to mismatched phenologies with prey resources, decreased water quality and habitat degradation, a shift in predator demographics, introduction and exacerbation of disease and pest species, and an increase in flooding and extreme weather events. We recommend both direct management of climate related threats as well as

indirect limiting of other stressors to enhance future conservation efforts for the common loon.

Introduction

The earth's climate system is warming as evidenced by increases in global average air and ocean temperatures, melting of snow and ice, and rising sea levels (Bernstein et al. 2007). On all continents and in most oceans, natural systems are being affected by climate change and, in particular, by increased temperatures. Warming is greatly affecting terrestrial biological systems, based on evidence from a wide range of species showing earlier timing of spring events, such as leaf-unfolding and bird migration and egg-laying (Bernstein et al. 2007), and poleward and upward elevational shifts in ranges of plant and animal species (Bernstein et al. 2007). Additional effects may be disguised by species adaptations and the influence of non-climatic drivers on ecosystem change (Bernstein et al. 2007). There is growing confidence that the increase in average global temperatures is due to anthropogenic causes and that its effects are likely to continue for centuries, even if greenhouse gas emissions can be stabilized (Bernstein et al. 2007).

Most scientists now believe that climate change is a significant driver of ecosystem change and that it will become increasingly important in the future (Petschel-Held et al. 2005). Migratory bird species may be especially vulnerable because they rely on spatially different areas and habitats throughout their migration cycle, and changes in any one site could affect populations (Robinson et al. 2005). As such, climate change is already affecting migratory bird species and is likely to exacerbate such threats as land-use change, forest fragmentation, infrastructure development, over-harvesting, and persecution (Sanderson et al. 2006, Tucker and Goriup 2007, Kirby et al. 2008).

Robinson et al. (2005) synthesized current literature on climate change and migratory species. They concluded that climate change will impact most migratory birds listed in the Convention on the Conservation of Migratory Species of Wild Animals. These impacts include lowered water tables, increased drought frequency, a mismatch with prey abundance, sea level rises, habitat shifts, change in prey base, and increased storm frequency. They suggested that the impact of climate change may be eased through mitigation of anthropogenic impacts, thereby allowing populations greater capacity to adapt to climate change. However, the potential for threats to a given species must first be understood and key areas of concern identified before such measures take place.

The common loon (*Gavia immer*) is a migratory species that is likely to be affected by alterations to its environment, and as such can serve as an interesting case study for assessing potential impacts of climate change. Their breeding range extends from a thin band across the northern United States and broadens through Canada and Alaska to the high arctic and includes portions of Greenland and Iceland (McIntyre 1988) (Fig. 1.1). The majority of individuals winter in coastal marine areas, generally near shore, over shoals, and in sheltered bays, inlets, and channels (McIntyre and Barr 1997). They migrate from their wintering range in the coastal waters of North America and Europe in the spring as soon as stopover waterways thaw (McIntyre 1988). It is thought that loon populations expanded their breeding range with the retreat of glaciers to the north over thousands of years (McIntyre 1988). However, within the last 150 years, a contraction in the southern range of loons has been observed from the north-east and central United States. This decrease is thought to be related to increased habitat competition between humans and loons (McIntyre 1988).

Common loons feed mainly on a variety of fish species, and are sensitive to abiotic and biotic factors associated with their breeding lakes, such as predation, weather, and water-level fluctuations (see review be McIntyre and Barr 1997, Badzinski and Timmermans 2006). Typical breeding habitat for common loons includes oligotrophic, clear lakes that are sufficiently populated with fish and are located in forested, sub-arctic, and arctic regions (McIntyre and Barr 1997). Successful nests and chick survivorship rates are related to predation rates, weather, parasites, anthropogenic factors, and density-dependent factors (Evers 2004). As an ecosystem driver, climate change is likely to have an effect on each of these variables and therefore on loon productivity.

To assess the potential impact of climate change on the common loon in North America, we compared climate models presented by the Intergovernmental Panel on Climate Change (IPCC IV) to current loon breeding range. From these comparisons we determined key areas of concern based on the severity of potential climate change, i.e., maximum and average air temperature increase during breeding months. Additionally, we created a predictive map of potential shift in loon breeding range under the future climate scenario. We then discuss each potential threat created by climate change scenarios and make recommendations to mitigate population loss through early action and planning.

Study Area

We focused on the breeding and wintering grounds of the common loon in North America. The North American breeding range is limited to freshwater habitats mostly in Canada and Alaska south of the taiga shield, but also in northern areas of the contiguous

United States (Evers 2004, Fig. 1.1). Loon breeding habitat outside North America was not included due to the lack of readily available data.

Methods

Climate Data- We downloaded modeled historical and future climate data from the National Center for Atmospheric Research (NCAR) Geographic Information Systems Initiative (Boulder, CO, www.gis.ucar.edu). Modeled data were generated by the Community Climate System Model for the 4th assessment report of the IPCC. For historical data we chose a 20-year dataset (1979-1999) from the ensemble average run of the 20th Century Experiment (Thornton and Wilhelmi, web resource). The ensemble average is composed of many model runs, which helps limit inherent noise around the true climate signal. These modeled data closely represent the present day control run, but are more readily comparable to future climate simulations (Thornton and Wilhelmi, web resource).

For future climate predictions we chose a 20-year dataset (2040-2060) from the ensemble average run of the A1B scenario. The A1B scenario depicts moderate climate change in the future and is based on projections favoring convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. One could argue that the A2 model might more accurately represent the future, with a focus on high human population growth, medium GDP growth, high energy use, medium-high land use changes, low resource (mainly oil and gas) availability, and a slow pace and direction of technological change (Thornton and Wilhelmi, web resource). However, we selected the A1B to represent an average model, with trends between the extremes of the higher change A2 and lower change B1 models. We limited each model output to the tas (air temperature in Kelvin) variable.

The climate data are provided as a point shape file with each point representing the center of a Gaussian grid cell with 1.40625° longitudinal spacing and a 1.389°-1.400767° latitudinal spacing. Each point holds values for average monthly projected air temperatures by year. We averaged the temperature across all years by month. This provided us with a 20-year average monthly temperature for each point from both the 20th Century experiment and A1B model runs. Using this 20-year average reduced the influence of year-to-year variability that may have led to erroneous conclusions if only 1 year was used for comparison (Thornton and Wilhelmi, web resource). These points are provided as centroids of a representative polygon shape file which can be joined to provide continuous spatial coverage.

Natural History Data- Current geographical distribution of the common loon was obtained from the “Digital Distribution Maps of the Birds of the Western Hemisphere” project available for download at naturserve.org (Ridgely et al. 2003). This distribution map was digitized based on current published literature and collaborative data sharing. Data are in polygon format and coded based on use, such as breeding or wintering areas.

GIS Processes- Using ArcGIS 9.2 for all GIS procedures, we first projected all data layers into NAD 1983 Albers. This is an equal area projection that uses two standard parallels and is often used for area based comparisons (Snyder 1987). We then converted all spatial data to raster format, with a 5,000 m cell size, to permit map algebra and math functions. Next we clipped monthly historical and future climate datasets to the extent of common loon breeding range dataset and converted units from Kelvin to Celsius. We then subtracted the clipped historical monthly averages from the clipped future monthly averages. This resulted in an individual raster for each month, with each raster cell containing the specific amount of projected average air temperature change for that location. We used data tables for each month to calculate average, maximum, and minimum temperatures and associated standard errors within each monthly change dataset. We then used simple raster algebra within ArcGIS to determine the average, maximum, and minimum change across all months, April to November, of the breeding season (McIntyre and Barr 1997).

Analyses- To assess the relationship between average historical air temperatures and loon distribution, we joined the fields from our original projected polygon layers of historical temperature and loon breeding range. We selected 200 random points classified as either within current loon breeding range or outside current loon breeding range from our North American data set. Next we extracted monthly historic and predicted future air temperature values to each of these points. We used the categorical territory variable as our response variable and our historical monthly average temperatures as predictor variables for classification tree analysis. The resultant splitting criteria of our classification analyses were applied to historic and predicted air temperature datasets to depict potential change in future loon breeding range. We performed all analyses in the R software environment for statistical computing (R Development Core Team 2008). After analysis of climate data within and outside of loon territory we utilized map algebra to show current predicted loon territory based on temperature data and projected range shift in the future.

Results

We found that the modeled climate data for the years 2040-2060 showed variable levels of change within loon breeding range and across breeding months (Fig. 1.2). The lowest average change was in May with an average 1.94°C increase in temperature. There was a general increasing trend in average monthly change to the peak average change of 4.13°C in November. Some areas within the breeding range were projected to experience much greater change, with maximums ranging from 3.37°C in May to 8.47°C in November.

Looking at a composite of average change across all months, we assessed which areas will experience the highest and lowest average change (Fig. 1.3). Common loon range in central Alaska, western Alaska, and Wyoming of the United States and the eastern Northwest Territories and southern Baffin Island in Canada will be subjected to the highest average temperature change during breeding season, with an average increase of up to 3.59°C. The northeast United States, southeast Alaska, and southwestern British Columbia showed the lowest average change in air temperature, with an average increase of as little as 1.79°C. Graphical representation shows that the majority of average air temperature change will be between 2.6-2.8°C (Fig. 1.3).

Looking only at maximum monthly average change within the loon’s geographic breeding range, the northern border of loon range was projected to experience the highest maximum temperature changes (Fig. 1.4). There was a visibly discernable trend of increasing maximum temperature change along a general south to north gradient. Graphical representation shows that the majority of maximum temperature change will be between 3.8-4.2°C (Fig. 1.4).

Our classification tree analysis showed a high level of success in predicting points as either within or outside of current loon breeding range. With only four leaves our model showed a correct classification rate of 91% compared to a null correct classification rate of 52%, and had a Kappa = 0.82 using the Gini index splitting criteria. The model correctly classified 182/200 randomly selected points with 87 and 95 points correctly classified as non-range and range respectively. Only 9 points were misclassified in each of the two categories (Fig. 1.5). When applied to the historical temperature dataset our classification criteria (Fig. 1.5) very nearly predicted current loon range (Fig. 1.6). By applying these same criteria to predicted future climate data we then identified which areas of the current predicted range will no longer fit within our classification rules, and which new areas will be added (Fig. 1.6). This shows a potential 18.6% loss of breeding range along the southern extent and a 15.1% gain along the northern extent, given other resources such as food and breeding sites exist or will become available in the north.

Discussion

Based on our analyses, common loons will experience increased air temperatures due to climate change across their breeding range in North America in the next 50 years. The highest levels of change will be within the later months of the breeding season, but even early months show what could be a biologically significant projected air temperature change; e.g., a 2°C increase in April may cause a shift in prey life-cycles causing the loon breeding phenology to fall out of sync with available prey base. Based on projected maximum monthly changes the northern range will experience the greatest shift. However, the areas that experience the highest average monthly change are more spatially separated, with some southern areas included. It is also apparent that loon distribution is related to average historical temperatures and thus, changes to temperatures will likely influence future common loon distribution. If the classification tree criteria hold true we may see a shift in loon breeding range towards the north. These changes may be via direct physiological effects on loon phenology, and fecundity, or through indirect effects such as changes in habitat availability, predator demographics, and disease vectors.

A striking shift in breeding phenology has been associated with climate change for many other migratory bird species, with optimal timing of reproduction advancing in the northern hemisphere (Moller et al. 2008). It is imperative for a species to shift its phenology to match the timing of available food resources. Often prey or primary producers will shift their phenology more quickly than a migratory species, leading to a mismatch in phenologies. A mismatch in predator-prey phenology will then lead to a less than optimal reproduction cycle and potential population declines (Moller et al. 2008). This was evidenced by European migratory bird species. Those species that have adjusted their migration phenology the least in response to climate change are suffering population declines, while those that advanced their migratory timing accordingly have increasing or stable population trends (Moeller et al. 2008).

An increase in temperature may be most critical for common loons during the brood rearing phase, when smaller fish and minnows are needed to feed chicks. Edwards and Richardson (2004) have shown that marine fish phenologies are shifting with climate change leading to a mismatch between trophic levels and functional groups. There have also been shifts observed in freshwater systems with advancing phonologies in zooplankton to match earlier diatom blooms (Winder and Schindler 2004). When fish are not available loons are known to feed chicks macroinvertebrates, but chicks are then less likely to fledge (Gingras and Paszkowski 2006). Moeller et al. (2008) found that change in migration date of European birds is positively associated with shorter migration distance and greater number of broods. The common loon has varied migration distances depending on whether they breed in coastal or inland areas, and in general are remarkably synchronous in their migratory timing (McIntyre and Barr 1997). Common loons also have only one brood per season (McIntyre and Barr 1997). If we apply this knowledge, i.e., small number of broods and varied migratory distance, to Moeller's finding above, we may infer that the common loon is not likely to change its migration timing. Therefore they may fall out of synchrony with the available resources needed during the breeding season. There are several loon monitoring organizations with historical data on loon arrival and nest initiation dates; these data sets could be used to assess if phenologies have or are shifting in relation to recent climate change.

Climate change in the last century also appears to be driving an increase in forest fire frequency and extent, especially in the northern boreal forest, and the trend is predicted to continue under most climate change scenarios (Naiman and Turner 2000). Typical loon breeding habitat is within clear, oligotrophic lakes surrounded by forest (McIntyre and Barr 1997). With an increase in forest fires surrounding loon breeding lakes there may be effects on lake chemistry. Some studies suggest that a change in pH, increased oxygen content, and, perhaps most importantly, increased mercury deposition are all related to forest fires (Carignan and Steedman 2000). This could be critical as loons experience significant adverse reproduction, behavioral, survival, and physiological impacts from mercury (Evers et al. 2008). Lake acidity has also been negatively associated with chick fledgling rates due to lack of food resources (McNicol 2002). With climate as a driver of ecosystem change we can also expect a shift in land cover and land use surrounding current loon breeding lakes (Petschel-held et al. 2005). This could lead to habitat degradation and in turn affect loon recruitment.

Another potential threat to breeding loon populations is a shift in predator demographics. Adult loons have few natural predators but often lose nests to predation. Raccoons (*Procyon lotor*) are documented to have the greatest impact on loon nests (Sutcliffe 1978, 1980, but see Evers 2004). The raccoon expanded its range into the Canadian prairies during the 1900s, likely due to climate change leading to an increase in food availability (Lariviere 2004). With continued climate change perhaps we will see a continued increase in raccoon populations in the north as well as range expansion into new areas such as Alaska. This would increase predation pressures on common loons, perhaps leading to local declines in areas of raccoon expansion. Other novel predators may also be able to extend their range into loon breeding territory with detrimental effects.

If warming trends continue we can also expect an increase in emerging infectious diseases (Wilby 2006, Brooks and Hoberg 2007). Recently, Type E botulism has caused large scale mortalities of common loons in the great lakes, specifically on Lake Erie (Yule et al. 2006). Increasing water temperatures are believed to favor the spread of Type E botulism (Locke and Friend 1989), thus increasing levels of botulism in loon breeding habitat will likely be facilitated by global warming. Other disease and parasite species affecting common loons such as nematodes and black flies (*Simulium* spp.) (Evers 2004), may also be influenced by climate change.

Climate models suggest that there will be an increase in both annual precipitation and in the frequency of extreme precipitation events over most of North America (Bates et al. 2008). The common loon typically nests within 1.5 m of the water due to their poor terrestrial locomotive skills (Vermeer 1973). This makes their nests sensitive to water level fluctuations, and egg loss is often attributed to flooding events (McIntyre 1994). It stands to reason that with an increase in extreme precipitation events loons may experience a decrease in productivity due to nest flooding. In one study, Fair (1992, but see Piper 2002) found that 62% of loon nests on Lake Aziscohos failed due to water level fluctuation. Additionally, changes in water levels can disrupt fish and amphibian reproduction, alter nutrient flows, and facilitate biological invasions (Bates et al. 2008).

Management Implications

Global warming is projected to continue unmitigated for the next several decades regardless of efforts to reduce carbon emissions (Bernstein et al. 2007). As such, we must plan to limit its impacts rather than hope that the source cause will be eliminated. Direct management to address specific climate-related threats may be advised in localized areas. Food resources may need to be stocked to match loon phenology until they adjust to the new climate regime. Forest management practices might be used to try to limit the effects on water quality through watershed and fire management. Predator control can be used near prime nesting territories to limit nest loss. Water level management where possible can be tailored to fit the loon breeding cycle. Additionally, the use of nesting rafts may provide a reproductive advantage for loons by mitigating the effects of changing water levels and increased predator populations (DeSorbo et al. 2006). These methods may be unrealistic over the entire range of the loon because they take substantial effort and investment; however, local applications could preserve areas sensitive to stress. Perhaps a more feasible range wide approach may be to reduce other stressors such as human activities, which lead to direct habitat degradation through shoreline development and through increases in acidity and heavy-metal toxins.

Global climate change is considered an ecological threat and recent studies have shown that its effects are detectable, as reviewed by McCarty (2001). The specific threats to common loons that we have discussed above are hypothetical, but results from other studies suggest that there is an urgent need to consider climate change when planning for conservation (McCarty 2001). As with all species, to enhance loon conservation in the face of ongoing climate change it is important to develop new research into explicit climate effects, including physiological responses (McCarty 2001). It is also important to monitor the migration of invasives such as predators, pests, and disease, into northern latitudes and to alleviate pressures when possible (McCarty 2001). Our assessment of potential threats provides a staging ground for further research and a warning signal for potential conservation needs. It is our hope that 50 years from now rather than looking back and in hindsight realizing what could have been done, we will instead be able to spend our time looking even further forward and continue to implement new and innovative conservation techniques.

Figure 1.1. Common loon breeding and wintering range in Canada and the United States based on data from "Digital Distribution Maps of the Birds of the Western Hemisphere" project available for download at naturserve.org (Ridgely et al. 2003).

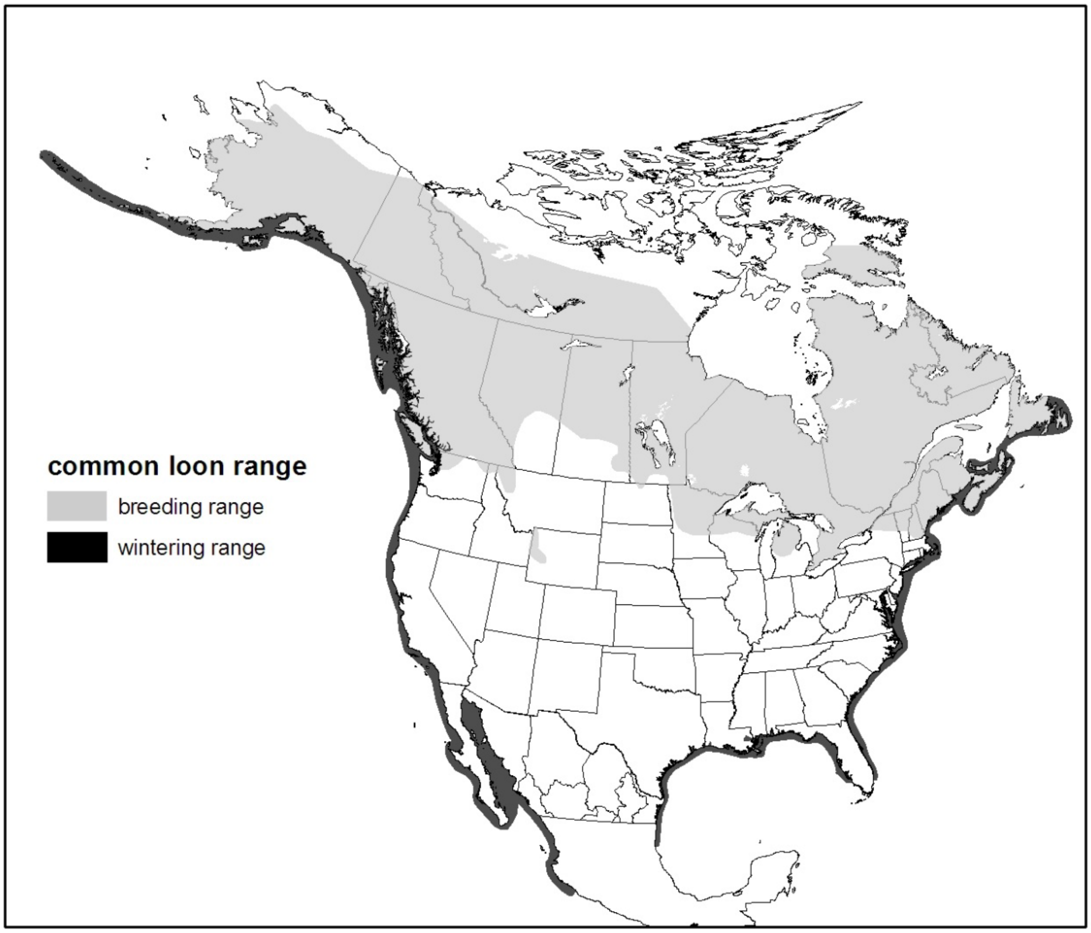


Figure 1.2. Average estimated temperature change, with SE bars and min/max envelope, between the present (1979-1999) and future (2040-2060) in North American common loon range.

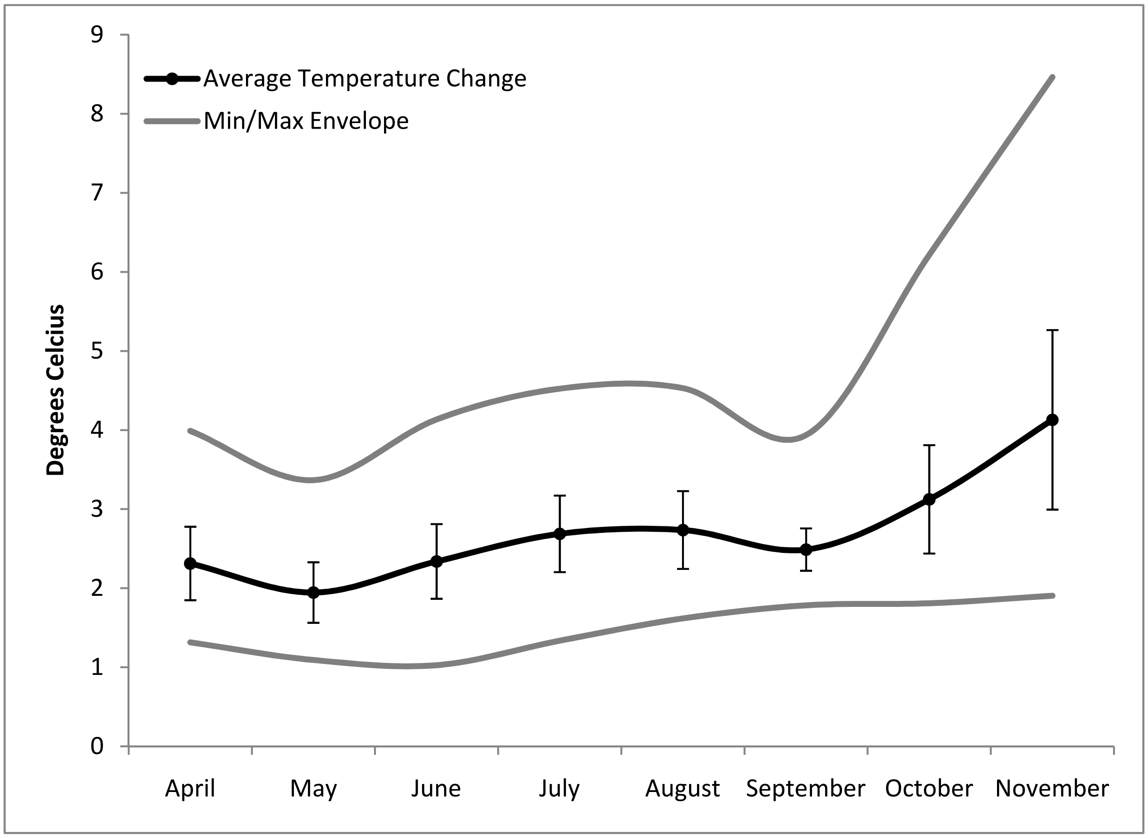


Figure 1.3. Projected average temperature change within current common loon range 50 years from now based on the Community Climate System Model for the 4th assessment report of the IPCC.

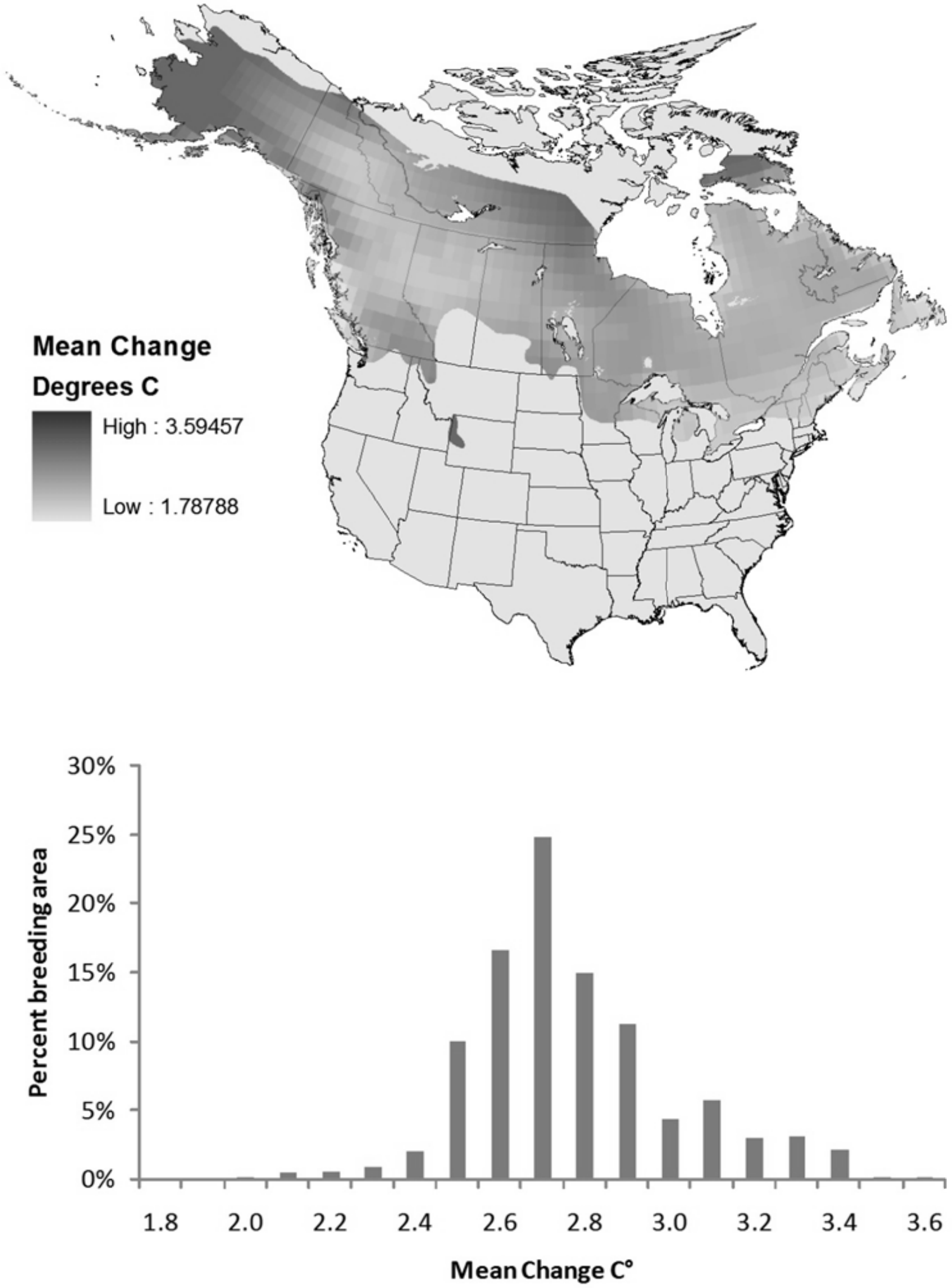


Figure 1.4. Projected maximum temperature change within current common loon range 50 years from now based on the Community Climate System Model for the 4th assessment report of the IPCC.

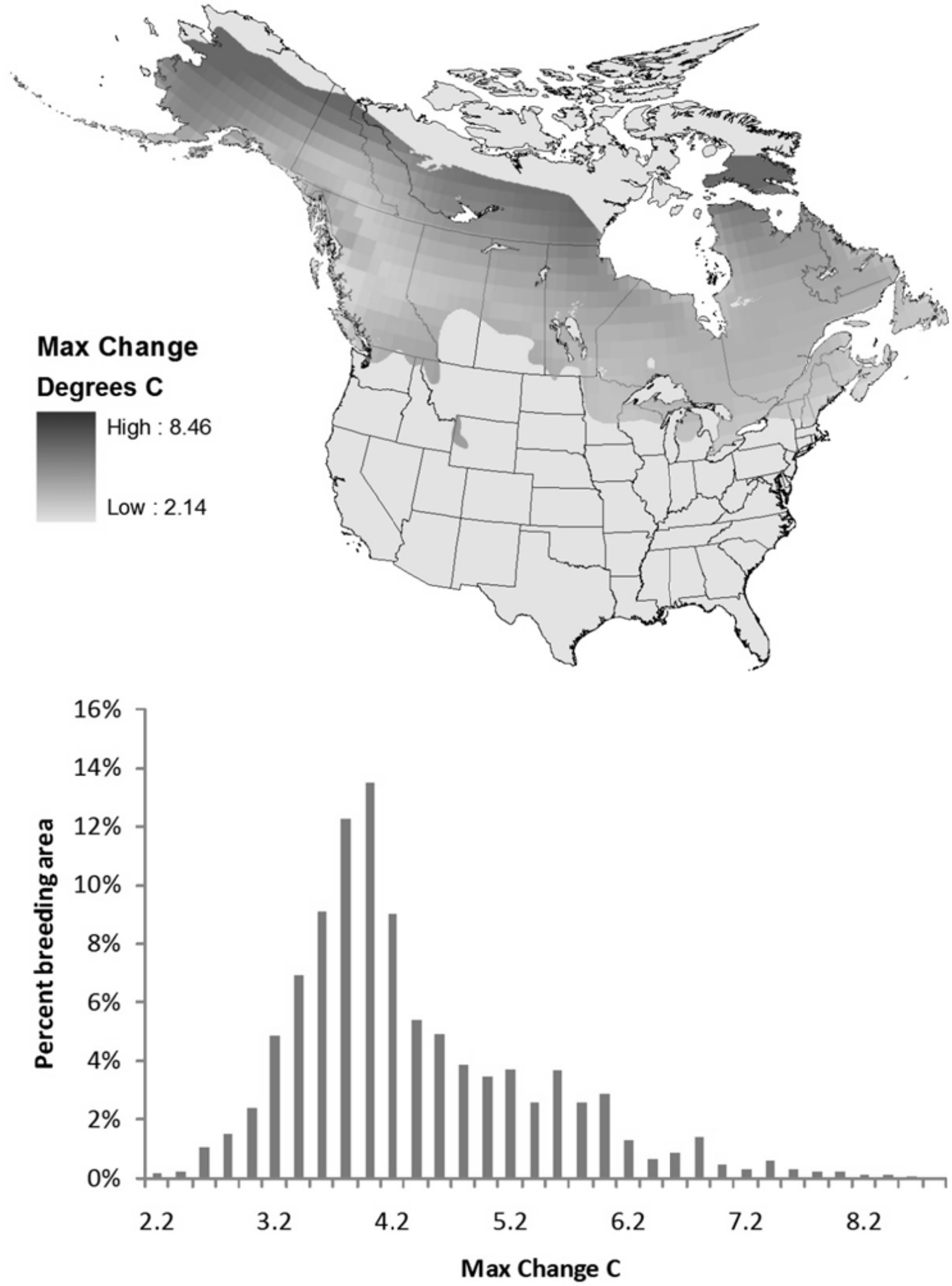


Figure 1.5. Classification tree of current loon range within North America; each branch shows n = non-territory and t = territory followed by correct classification rate and number of samples classified.

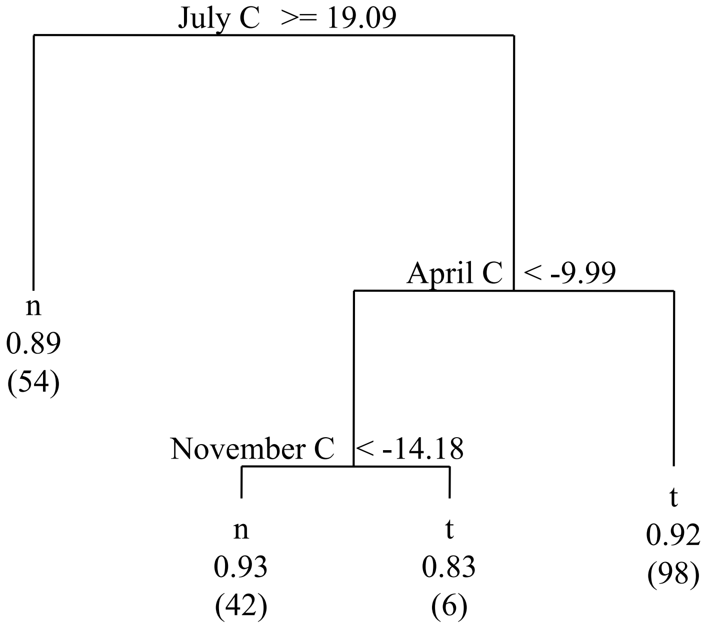
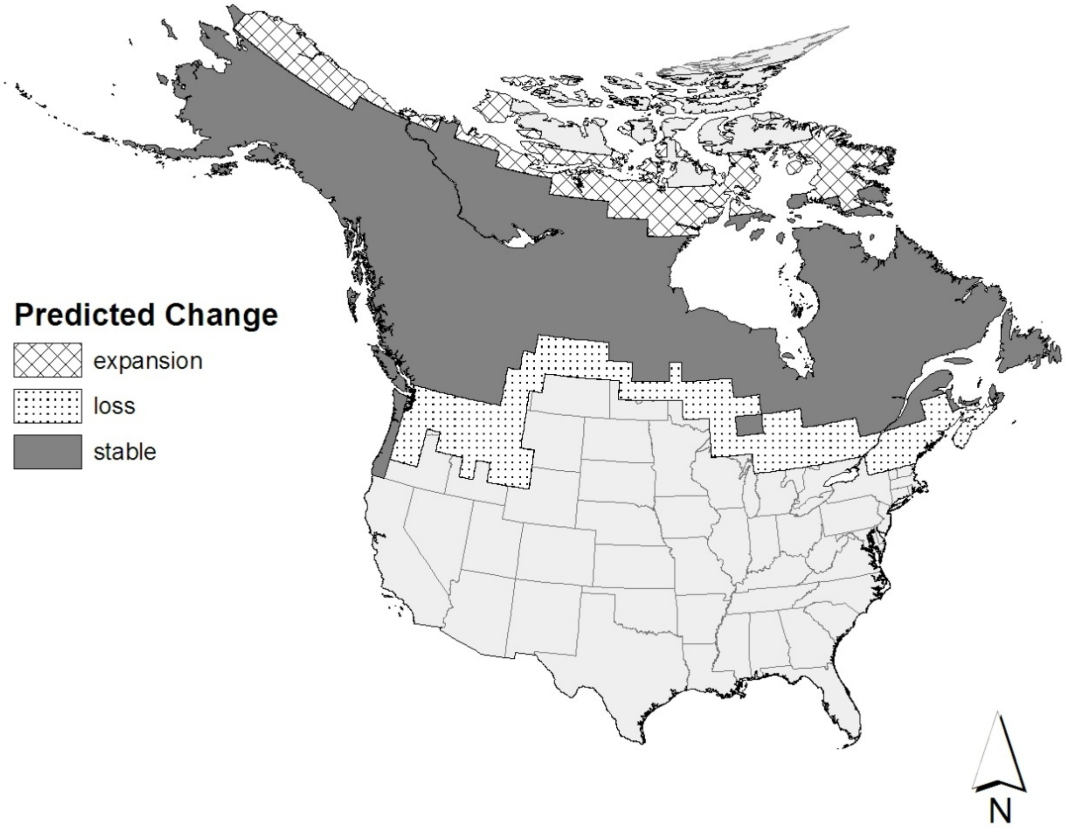


Figure 1.6. Predicted change in available common loon breeding habitat based on criteria from classification of current loon range and historic average monthly air temperatures.



CHAPTER 2

THE STATE OF WILDLIFE DISTURBANCE LITERATURE AND FUTURE NEEDS IN A CHANGING WORLD

Abstract

Human disturbance of wildlife has been a concern of wildlife biologists and managers for decades. As human populations continue to expand, a rise in human-wildlife interactions is inescapable. Habitat degradation due to resource extraction and landscape conversion is one of the most significant sources of wildlife disturbance, and worldwide trends of increasing habitat loss show no sign of slowing. Consumptive and non-consumptive recreational activities also disturb wildlife, having both direct and indirect effects, which can result in population declines. Again, increasing levels of outdoor recreation are expected throughout the foreseeable future. Given this expected increase in interactions between humans and wildlife, managers and conservationists have been striving to understand how these disturbances affect wildlife. In reviewing the published literature on wildlife disturbance we provide a holistic view of trends in research and identify needs for future focus. In total, 474 abstracts were reviewed and classified as to region, ecosystem type, disturbance type, ultimate cause, species class, species group, and effect of disturbance. We found a lack of publications from the developing world and a focus on birds and mammals with underrepresentation of other species. There is also a widening gap between the amount of published disturbance research and wildlife literature as a whole. We suggest that an overall increase in

disturbance research and publication is warranted, especially from developing countries where disturbance issues remain prevalent but underrepresented.

Introduction

Wildlife biologists and natural resource managers have been concerned with the negative effects of human disturbance on wildlife for decades (Blanc et al. 2006). As human populations continue to increase and spread across the earth, a reciprocal rise of human-wildlife interactions is inescapable. In many areas, habitat degradation has accelerated, reducing the available habitat for wildlife species, which can both reduce wildlife abundance and concentrate numbers of individuals into ever smaller patches of remaining habitat. In other areas, both commercial and recreational hunting continue to be an integral issue through direct take and indirect disturbance of wildlife populations, and participation in ecotourism and outdoor activities continues to increase drastically worldwide (Knight and Gutzwiller 1995, Laurance et al. 2006, Casas et al. 2009). These various factors are bringing humans and wildlife into closer proximity, more often than ever before. As a result, a broad and evolving array of questions have arisen as to the effect that these various interactions will have on wildlife populations. These questions often focus not only on the behavioral changes of target species, but on implications for the survival and fitness of species and health of the ecosystem as a whole. As exchanges between humans and wildlife populations continue to escalate, these issues will become increasingly relevant to long-term conservation and management efforts. The present synthesis of disturbance literature will allow an assessment of the historical focus of disturbance research and the identification of future needs in a changing world.

Overview

Habitat degradation is perhaps one of the most significant and direct human disturbance for wildlife species. Owing to both resource extraction and spreading development, wildlife habitat is being altered at an accelerating rate. Worldwide there has been an increasing trend in the amount of forest land converted to agriculture through deforestation, and this trend is projected to continue into the future (Houghton 1994). Overall levels of resource extraction are increasing steadily in all parts of the world with an aggregated growth rate of almost 36% (Behrens et al. 2007). The Millennium Ecosystem Assessment Synthesis Report (Reid et al. 2005) states "over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, fibre and fuel". This has resulted in a direct affect on wildlife populations, with a substantial and largely irreversible loss in the diversity of life on Earth. In the last decade there has been a drastic increase in the number of species listed as threatened by the International Union for the Conservation of Nature (IUCN). In particular, the number of invertebrates, fish, reptile, and amphibian species listed as threatened has increased as more efforts have been made to review these groups (Fig. 2.1, IUCN 2008).

Both commercial and recreational hunting have the obvious impact of direct loss of life to individual animals. Dependant on the quality of game management this may or may not be sustainable. However, apart from the direct loss of life, hunting disturbance can also cause disruption of normal activities of wildlife (Laurance et al. 2006, Madsen and Fox 1995). It can displace waterbirds from preferred feeding and roosting habitats and decrease the natural carrying capacity of an area (Madsen and Fox 1995). It can also affect reproductive output by disrupting pair-bonds and family structures.

Non-consumptive recreational disturbance not only decreases the amount of undisturbed habitat but also has indirect effects on wildlife behavior (Knight and Cole 1995). In a review of wildlife recreational activities Knight and Cole (1995) created a conceptual model to clarify wildlife response to disturbance. Typically, research focuses on the immediate effects of behavioral change including nest abandonment, change in food habits, or physiological changes, such as increased heart rates or stress hormone levels (Knight and Cole 1995). However, long-term behavioral changes can also occur, including alterations in productivity, abundance, distribution, demographics, species composition, and behavioral interactions (e.g., Geist 1978, Klein 1971, Guth 1978, Robertson and Flood 1980, Yarmology et al. 1988, Skagen et al. 1991 and Wood 1993). We can expect an increasing trend in outdoor recreational activities along with a decrease in undisturbed wildlife habitat (Knight and Temple 1995). Together with the continued increases in resource extraction, deforestation, agricultural expansion, and human population, this means that wildlife species across the globe will be exposed to increasing levels of both indirect and direct disturbance.

Given the increase in interactions between humans and wildlife, it has become extremely important for managers and conservationists to understand how these disturbances affect wildlife. To this end biologists have been conducting observational and experimental research into the effects of disturbance on wildlife species for decades. These studies have focused on individual species, communities, and whole ecosystems, and have addressed questions from the effect on the behavior of the individual, to implications for the survival and continuation of the species. These results have become increasingly valuable to managers and conservationists, with the data commonly used to define management goals and develop conservation strategies.

Several authors have published review papers on disturbance and research needs, but these generally focus on a small category of disturbance factors or species groups. Hill et al. (1997) reviewed the quality and utility of bird disturbance research and made recommendations for its improvement. Gutzwiller and Cole (2005) identified a lack of understanding of cause-and-effect relationships as a significant impediment to managing human disturbance impacts. Gill (2007) and Tarlow and Blumstein (2007) reviewed methodology used in disturbance research and assessed the type of results achieved. Blanc et al. (2006) reviewed literature on the effects of non-consumptive human leisure activities and made recommendations for research needs. Blumstein et al. (2005) focused on behavioral studies of multiple species and assessed how ecological traits may influence behavioral response to disturbance events. Tamisier et al. (2003) synthesized literature on the disturbance caused by waterbird hunting and discussed management options. Sallabanks et al. (2000) reviewed literature on deforestation and songbird populations while Carney et al. (1999) reviewed publications on disturbance of waterbird colonies. However, despite the above in-depth reviews, to date there has been no general review of disturbance literature in a broad sense.

We conducted a review and synthesis of disturbance research, focusing on numerous forms of disturbance, a wide variety of genera, and various levels of scale (i.e., ecosystem, landscape, or species specific). By conducting a broad review of literature that identifies itself as related to disturbance, we identified trends in the published literature and provide a holistic view of historical research efforts. Through this we hope to engender an interest in areas of study which have been previously underrepresented, and to provide a reference for biologists as to the current state of disturbance research.

Methods

Relevant disturbance literature was tabulated using the ISI Web of Knowledge^{SM}, Web of Science® search engine. Several keywords, including “wildlife disturbance”, “wildlife recreation”, “disturbance recreation”, “disturbance hunting”, and “nest flushing distance”, were used in the general search topic field with years 1900-2007 selected (Table 2.1). Citations and abstracts were then exported to a local database for review and classification. Using Microsoft® Access™ we developed a data review and classification entry form which displayed the selected citation, abstract, and several drop down menus for classification fields. Articles were classified based on review of the abstract at several levels, including relevance, disturbance type, ultimate cause, focus level, area, ecosystem, species class, species group, and effect of disturbance. Within each of these levels were specific criteria that could be selected to best represent the citation and abstract data (Table 2.2). If no abstract was available the article was excluded from further review. This occurred in only 10 instances, with 8 of the articles lacking abstracts dated from 1994 or earlier.

The term “wildlife disturbance” is ephemeral, with no specifically accepted definition in the literature. In a review of the terminology associated with habitat in ecological literature, Hall et al. (1997) concluded that the haphazard use of terms (either undefined or defined) and the use of vague terms are a deep-seated problems in the ecological sciences. This criticism can also be applied to studies of wildlife responses to human activities (Taylor and Knight 2003). For this article our working definition of "wildlife disturbance" is any event in which an activity is associated with a potential effect on wildlife species. We considered "activities" and "effects" unbounded with no exclusions. We deem a wildlife species to be any animal, both vertebrate or invertebrate, and inclusive of fish. Both positive and negative effects on the wildlife species were considered. This definition of "wildlife disturbance" is broad and allows for the inclusion of indirect effects from habitat disturbance by actions such as logging or mineral extraction, as well as indirect effects such as decreased reproductive success due to increased levels of recreational boating. In this context, disturbance can have a broad range of direct and indirect effects on wildlife.

Our working definition of wildlife disturbance could conceivably cover a very large portion of the published literature on wildlife conservation. However, our goal was not to review the entire literature on wildlife biology. Rather, we allowed the literature to define itself as disturbance related through the use of keyword search terminology. By having a broad working definition of wildlife disturbance we avoided excluding publications that the authors considered relevant to the subject, however, our search string selection did limit our final inference to certain taxa and disturbance types.

An article was considered relevant if it discussed wildlife disturbance in accordance with our predefined working definition. Articles that did not include a wildlife species were marked as non-relevant, and no further review was conducted. These articles typically discussed only plant species or geological changes, with no mention of wildlife species. Articles were also deemed irrelevant if there was no obvious assessment of disturbance and the focus of the article was solely a biological review.

Review papers were classified as such within the focus level section, and no other categorization were made for these papers.

The type of disturbance was defined based on a predefined set of criteria as follows. A habitat disturbance type involved alteration to the animal’s habitat such as loss of cover or resources, and included resource extraction. A recreational disturbance type was selected if the animal was exposed to outdoor recreational pressures, including recreational boating, hiking, or hunting (without physical take). Instances where human pursuit led to a direct loss of life for commercial or subsistence purposes, or constituted a direct physical threat for non-recreational purposes, were classified as physical disturbances. We classified a disturbance type as natural if it did not involve humans, but rather if other species of wildlife or natural meteorological or geological events caused the disturbance. Both a competition disturbance and an experimental disturbance were rarely identified. A competition disturbance was constituted by a direct competition for resources between two competing species. An experimental disturbance was identified as one in which experiments were conducted to disturb the species, but there was no acknowledged relation to a real-life disturbance factor which might affect the target species. If more than one disturbance type was identified in a single manuscript, it was defined as a multiple disturbance, and if we were unable to determine the type of disturbance it was classified as an unknown disturbance.

After the initial classification of disturbance type, we further classified the disturbance type by identifying the ultimate cause behind the disturbance (Table 2.2). Agricultural causes included not only crop farming, but also livestock-related disturbances. Commercial take was defined as any consumptive collection for nonpersonal use, and included gathering for the bush meat trade; consumptive recreation included personal collection for recreational purposes only. Non-consumptive recreation involved boating, hiking, and other activities in which there was no physical take of target species. Experimental causes were once again identified as those in which there was no acknowledged relation to real-life disturbance factors that might be disturbing the target species. Natural processes were causes in which humans were not involved, such as a meteorological or geological event. Predation involved a direct animal interaction between predator and prey. Resource extraction referred to any mineral, oil, or similar removal of the earth's resources, excluding timber harvest causes. The latter were related to any management, removal, or modification of timber resources. Urban or rural development was defined as the expansion of towns or villages, or other development of previously undeveloped habitat, while road and transit related causes referred directly to transportation related issues. This was inclusive not only of all terrestrial transportation methods, but also all types of air travel. Once again, if there was more than one cause identified, it was defined as a multiple cause, and if the cause could not be adequately defined, it was classified as an unknown cause.

To assess the focus level of each manuscript, we determined the level of classification at which it addressed the disturbance issue. The lowest level was defined as the species level, when the focus was solely on a single, particular species. If the focus was on several species of the same family, we defined it as a family focus level. If the research concentrated instead on several families and species that coexisted in the same area, we classified the article as a community focus level. If the focus was broad and reaching, covering not only different species and genera, but different classes and phyla, we classified the article as an ecosystem focus level.

We determined the area and ecosystem for each manuscript from the abstract or title, and recorded it as specifically as possible. We defined area as the region in which the research was conducted and reported broadly as Europe, United States, Canada, etc. We described the ecosystem as the general ecoregion in which the research was conducted (i.e., alpine, tundra, savannah). If it was not possible to determine these categories from the abstract or title, we defined them as unknown. We also determined the class of the species from examination of the abstract and then we defined the particular group of the species as narrowly as possible.

Finally, we recorded one or more of the end effects of disturbance on the species. We defined this effect as the change caused to the animal as a result of the described disturbance. If the overall abundance or population number of the target animals were affected, we selected the abundance effect. If the disturbance resulted in a change of any behavioral aspect for the animals, we selected the behavior effect. The breeding effect corresponded to any change in reproductive success or juvenile survival, while the distribution effect was defined as any alteration of the species' temporal or spatial distribution. Habitat use was closely related to the distribution effect, but was more specifically defined as a particular change in the use of available habitat due to some disturbance effect. The species richness effect was selected when the disturbance event led to a reduction or addition in the number of species represented within the study area. The stress effect was defined as any altered level of stress experienced by the animal in direct response to the disturbance, while the survival effect related directly to either an increase or decrease in the survival of the target animal.

Our final dataset contained all relevant classifications for each article returned by our original search terms. These classification data were then exported to Microsoft® Excel™ for tabulation and analysis.

Results

The ISI Web of Knowledge℠, Web of Science® search engine returned a total of 824 unique articles based on the entered keywords. Of these, 78% were published between the years 1997 and 2007. A positive trend can be seen in the number of publications by year (Fig. 2.2). Comparing this trend to that of the number of publications returned when using "wildlife" as the key word, we see that there has been a relatively slow increase in the number of disturbance publications compared to the increase in the total number of wildlife publications (Fig. 2.3).

In total, 474 articles were deemed relevant to our review based on our definition of wildlife disturbance. Articles that were not relevant either did not conform to our definition of wildlife disturbance (n = 340, 41.3%), or more rarely (n = 10, 1.2%), lacked an abstract. In most cases lack of conformity was due to a focus on disturbance of plant species with no review of the effects on wildlife. The majority of relevant research occurred in the more developed regions of the world, led by the United States (32.28%), Europe (12.24%), and Canada (9.49%) (Table 2.3). Although there continued to be fewer publications on research from developing regions than developed regions, publications from both types of countries had a positive trend over time, with higher representation in recent years (Fig. 2.4). Despite these increases, there did not appear to be any sign that the number of publications from developing countries will meet or exceed the number focused on developed countries in the near future.

Habitat disturbance and recreational disturbance were the most prominent types of disturbance discussed. More than one third of the articles discussed habitat disturbance, while another third was devoted to recreational disturbance (Table 2.3). Only 12.66% of the studies focused on multiple types of disturbance. Bird and mammal studies accounted for the vast majority of relevant published disturbance papers with 214 and 157 of the 474 relevant articles respectively (Table 2.4). Of the bird studies, waterfowl, wading birds, and sea birds accounted for 105 of the 214 articles. There are also several studies (40) focusing on multiple species groups within the avian class. Of the mammal studies, ungulates had the highest representation with 61 of the 157 publications. Large carnivores, primates, and marine mammals made up the bulk of the remaining mammal publications with 20, 19, and 18 articles, respectively. A positive trend in publication of bird, mammal, and multiple species disturbance publications can be seen over time with an apparent increase in interest in research on bird species since 2000 (Fig. 2.5). There was a paucity of papers on other classes of wildlife species including reptiles, amphibians, fish, marsupials, and invertebrates (Table 2.4).

Wetland (15.2%), forest (14.8%), coastal (11.6%), tropical (11.4%), and mountain (9.9%) ecosystems were the focus for the majority of articles reviewed (Table 2.5). The scale at which each article focused on disturbance was predominately either at the species level or the community level, with 47.9% and 31.5% of total relevant articles reviewed, respectively (Table 2.6). Relatively few papers assessed effects at the ecosystem level (11.1%).

The ultimate cause behind wildlife disturbance was varied in our review; however, non-consumptive recreation was the dominant factor, with 25.4% of articles (Table 2.7). The next highest ultimate cause was from multiple sources, with 16.2% of relevant articles. Urban and rural development was the ultimate cause of disturbance in 10.9% of the reviewed articles, but all other causes fell below 10%, including likely key players such as consumptive recreation (8.2%) and agriculture (6.9%).

Our final assessment was of the primary effect on wildlife as discussed in reviewed articles. By far the most prevalent effect was on species abundance with 26.8% of reviewed articles focusing on this subject (Table 2.8). Behavior was second with 15.8% of articles discussing its effect on wildlife in relation to disturbance. Other effects such as distribution, breeding, habitat use, and survival were well represented with an average of 10.8% in reviewed articles.

Discussion

Disturbance literature as a whole has proliferated in the last decade with a positive trend in publication numbers. If we only look at this trend, we may feel comfortable that wildlife disturbance literature is advancing well to meet current needs. However, upon further examination, we see that it has not increased at the rate of general wildlife publications, meaning it has actually decreased as a percentage of the wildlife literature base. This may be cause for concern given the trend for increasing levels of disturbance from resource extraction, habitat modification, and recreational pursuits (Houghton 1994, Knight and Temple 1995, Behrens et al. 2007). These factors have recently brought humans and wildlife into increasing contact worldwide and the likelihood that these disturbances will have a significant effect on wildlife populations continues to grow. It has become important to characterize these disturbances and effects in order to mitigate human-wildlife interactions. As these factors increase in frequency, the lack of corresponding disturbance literature may indicate a fundamental deficiency in wildlife research. However, it should be recognized that our results are reliant upon keywords matching our search terms. It is possible that over time, as the field of wildlife biology has become increasingly specialized, broad terms such as disturbance may be absent from articles, having been replaced by more specific terminology, i.e., habitat fragmentation, or stress hormone response. In this case, these articles may be underrepresented in our sample. Nonetheless, a more detailed consideration of the role of disturbance literature in an increasingly human-dominated world is called for.

Deforestation and natural resource extraction is increasing worldwide (Behrens et al. 2007, Houghton 1994), particularly in tropical forests in developing countries. Indonesia, home to the highest level of mammal biodiversity in the world (IUCN 2008), is unable to adequately protect its forest resources and available habitat is shrinking rapidly (Kinnaird et al. 2003). Brazil, which currently harbors the largest contiguous blocks of tropical rainforest on earth, has continued to experience extensive deforestation, which currently threatens the extinction of 644 plants and animals (United Nations Environmental Program 2009). However, despite extensive habitat loss in many developing nations, and increased development which appears to be increasing human-wildlife interactions, there is a paucity of disturbance research focused in developing countries when compared to that conducted in developed nations. Again, despite potential biases in search terminology, this discrepancy may be cause for concern, and efforts to increase the quantity of published disturbance research in the developing world are warranted.

In the present review, bird and mammal studies accounted for the majority of research conducted. According to the World Conservation Union (IUCN 2008) there are approximately 5,488 mammal species and 9,990 bird species on the planet, so these numbers correspond relatively to the studies conducted on both bird disturbance (214) and mammal disturbance (157). It is interesting to note that there are 30,700 described fish species, 15,081 described reptile and amphibian species, and more than a million described invertebrate species (IUCN 2008). However, our search only returned 6, 11, and 19 publications for these species groups, respectively. Our initial keyword search was biased towards the bird and mammal classes, as they fit the strictest definitions of wildlife. It is likely that other species such as fish and invertebrates may be excluded from the term wildlife. A search using "insect disturbance" in the subject line returns 677 hits and "fish disturbance" returns 1,647 hits, suggesting that we limit our inference to subjects best captured by our original search terminology. Search strings using "reptile disturbance" or "amphibian disturbance" return much fewer results (n = 36 and n = 101, respectively). This low number of returns indicates that it is likely there are very few disturbance studies published on these species groups. This may be due in part to the fact that disturbance has less obvious and visible effects on these species because they are often smaller than many charismatic megafauna and there may also be a reduced focus on their fate. Despite the fact that wildlife classes such as amphibians and reptile may be difficult to study, it is likely that they too experience significant effects from human disturbance. The present review suggests a paucity of disturbance data on these species and identifies an important need for future research.

Managers have a continuum of options for managing wildlife resources, which can range from management for a single species to management of landscapes, ecosystems, or entire regions (Finch and Martin 1995). Each strategy has advantages and disadvantages and selection of one option over another involves a series of tradeoffs (Finch and Martin 1995). In our review, almost one third of the articles focused on the community level. This suggests that some researchers are taking a broader approach to the problem of wildlife disturbance. In contrast, nearly half of the publications focused on a single species. It is apparent that disturbance research occurs at many different levels and the choice of focus level is reliant upon the needs of management.

In our review, we found that species abundance was the dominant effect discussed in disturbance research. Species abundance is obviously a critical factor in conservation of wildlife species and of key concern to many managers and researchers. By causing a decrease in species abundance, disturbance factors may influence the rapid decline of many species throughout the world. This is an important topic for disturbance research and it is promising that many articles directly address this point. The second most prevalent effect reported was behavioral change in wildlife due to disturbance. This is also an important facet of disturbance research as it can, in turn, lead to a plethora of indirect effects. Behavioral changes can cause alterations in productivity, abundance, distribution, demographics, species composition, and behavioral interactions. Again, research focus is dictated by the driving question behind each project and we cannot fairly evaluate it for shortcomings. However, we caution that focusing only on behavioral change without further elucidating the resultant effect may limit the value of disturbance research.

The literature base on wildlife disturbance has experienced expansive growth within the last decade. However, there are several key concerns and knowledge gaps as noted above. Wildlife disturbance is not an issue limited to the developed world and wildlife science would benefit from an increase in published research from developing countries. Additionally, amphibians and reptiles are underrepresented despite growing concern and increasing levels of endangerment. As such, an increase in publication of research on these taxa is warranted. Further, each management issue requires a different level of focus and research should strive to meet individual conservation needs. Finally, a continued pursuit of the effect of disturbance on wildlife abundance and behavior fulfills two of the most important needs in species conservation, but care must be taken to elucidate the final effect that behavioral change might have on a species.

Table 2.1. Key words and resultant articles found on ISI Web of Knowledge^{SM}, Web of Science® engine.

Key Words	Number of Returns
Wildlife Disturbance	516
Wildlife Recreation	291
Disturbance Recreation	162
Disturbance Hunting	207
Nest Flushing Distance	9
Total Unique Articles	824

Table 2.2. Criterion for each level of classification used to classify wildlife disturbance literature and examples.

Criteria		**Examples**	
Disturbance Type	*Competition*	*Experimental*	*Habitat*
Ultimate Cause	*Agricultural*	*Climate Change*	*Commercial Take*
Focus Level	*Community*	*Ecosystem*	*Family*
Species Class	*Amphibians*	*Birds*	*Fish*
Species Group	*Arthropods*	*Bats*	*Bees*
Effect On Species	*Abundance*	*Behavior*	*Breeding*
Area/Region	*Africa*	*Antarctica*	*Australia*
Ecosystem	*Alpine*	*Coastal*	*Desert*

Table 2.3. Resultant classification of disturbance literature showing area/region where research occurred and type of disturbance discussed.

Area/Region	Competition	Experimental	Habitat	Multiple	Natural	Physical	Recreation	Unknown	Total	Percent
Africa	1	0	13	11	1	3	3	0	32	6.75%
Antarctica	0	0	1	0	0	1	4	0	6	1.27%
Australia	0	1	10	4	4	1	6	0	26	5.49%
Canada	1	1	21	1	2	3	15	1	45	9.49%
Caribbean	0	0	0	0	1	0	2	0	3	0.63%
Central America	0	0	3	1	0	0	0	0	4	0.84%
East Asia	1	0	7	1	0	0	1	2	12	2.53%
Europe	0	2	13	8	0	2	31	2	58	12.24%
Greenland	0	0	0	0	0	1	2	0	3	0.63%
Mexico	0	0	0	1	0	1	0	0	2	0.42%
Middle East	0	0	0	0	0	0	1	0	1	0.21%

Multiple	0	0	0	1	0	1	0	0	2	0.42%
New Zealand	0	0	0	0	0	0	3	0	3	0.63%
Oceana	0	0	0	0	1	1	0	0	2	0.42%
Russia	0	0	1	0	0	0	1	0	2	0.42%
South America	0	1	13	1	3	3	9	0	30	6.33%
Southeast Asia	0	0	7	5	3	1	1	0	17	3.59%
United Kingdom	1	0	6	1	0	0	8	0	16	3.38%
United States	1	6	43	20	14	5	59	5	153	32.28%
Unknown	1	5	21	5	2	7	16	0	57	12.03%
Total	6	16	159	60	31	30	162	10	474	
Percent	1.27%	3.38%	33.54%	12.66%	6.54%	6.33%	34.18%	2.11%		

Table 2.4. Resultant classification of disturbance literature showing species class (classes of invertebrates have been grouped together and amphibians and reptiles have been grouped into herps) and species group (specificity was dependent upon what could be interpreted from each publication).

Class	Species Group	Count	Class	Species Group	Count
Birds	Bucerotidae	1	Invertebrates	Arthropods	4
	Cavity Nesters	3		Bees	1
	Chlamydotis	1		Beetles	1
	Corvus	2		Butterflies	4
	Galliformes	10		Crustaceans	1
	Multiple	40		Dragon Flies	1
	Opisthocomus	1		Flies	1
	Otidae	1		Moths	1

	Passerines	15
	Raptors	20
	Ratites	1
	Sea Birds	32
	Shrikes	1
	Tropical Birds	3
	Wading Birds	19
	Waterfowl	64
	Total	**214**
Fish	Cat Fish	1
	Multiple	3
	Salmon	2
	Total	**6**
Herps	Crocodilian	2
	Lizard	4
	Multiple	4
	Shellfish	1
	Total	**19**
Mammals	Bats	3
	Bovid	2
	Furbearers	3
	Herbivores	4
	Large Carnivores	20
	Marine Mammals	18
	Meso-Carnivores	4
	Multiple	15
	Primates	19
	Rodents	7
	Seals	1
	Ungulates	61

	Sea Turtles	1		**Total**	**157**
	Snakes	1	Marsupials	Marsupials	6
	Turtles	1		Wallabies	1
	Frogs	1		**Total**	**7**
	Salamanders	1			
	Total	**11**			

Table 2.5. Resultant classification of disturbance literature showing ecosystem.

Ecosystem	Total	Percent
Alpine	3	0.63%
Coastal	55	11.60%
Desert	6	1.27%
Forest	70	14.77%
Grassland	36	7.59%
Heath	2	0.42%
Mountain	47	9.92%
Multiple	11	2.32%
Oceanic	11	2.32%
Riverine	21	4.43%
Savannah	11	2.32%
Snowpack	9	1.90%
Tropical	54	11.39%
Tundra	13	2.74%
Unknown	33	6.96%
Urban	20	4.22%
Wetlands	72	15.19%

Table 2.6. Resultant classification of disturbance literature showing focus level.

Focus Level	Total	Percent
Community	156	31.52%
Ecosystem	55	11.11%
Family	24	4.85%
Review Paper	22	4.44%
Species	237	47.88%

Table 2.7. Resultant classification of disturbance literature showing ultimate cause of disturbance discussed.

Ultimate Cause	Total	Percent Total
Agricultural	33	6.93%
Climate Change	1	0.21%
Commercial Take	16	3.36%
Competition	2	0.42%
Consumptive Recreation	39	8.19%
Experimental	18	3.78%
Herbivory	1	0.21%
Multiple	77	16.18%
Natural Processes	30	6.30%
Non-Consumptive Recreation	121	25.42%
Predation	2	0.42%
Resource Extraction	13	2.73%
Road/Transit	24	5.04%
Timber Harvest	35	7.35%
Unknown	12	2.52%
Urban/Rural Development	52	10.92%

Table 2.8. Resultant classification of disturbance literature showing primary effect of disturbance.

Effect on species	Total	Percent
Abundance	172	26.83%
Behavior	101	15.76%
Breeding	75	11.70%
Distribution	79	12.32%
Habitat Use	63	9.83%
Species Richness	43	6.71%
Stress	49	7.64%
Survival	59	9.20%

Figure 2.1. Trend in percent of evaluated species listed as threatened on the IUCN Red List in the last decade. Data used for graph is from the 2008 IUCN Red List summary table.

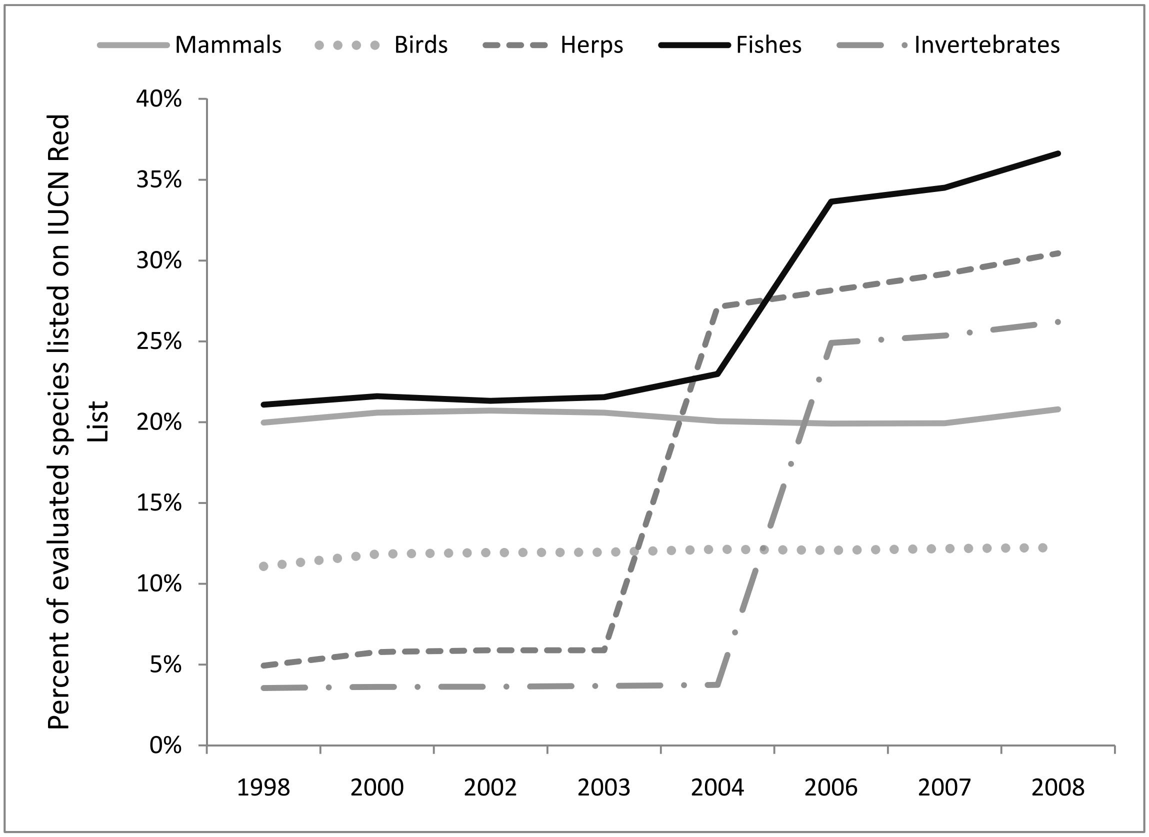


Figure 2.2. Percentage of disturbance literature search results by year, with 78% being from the last decade.

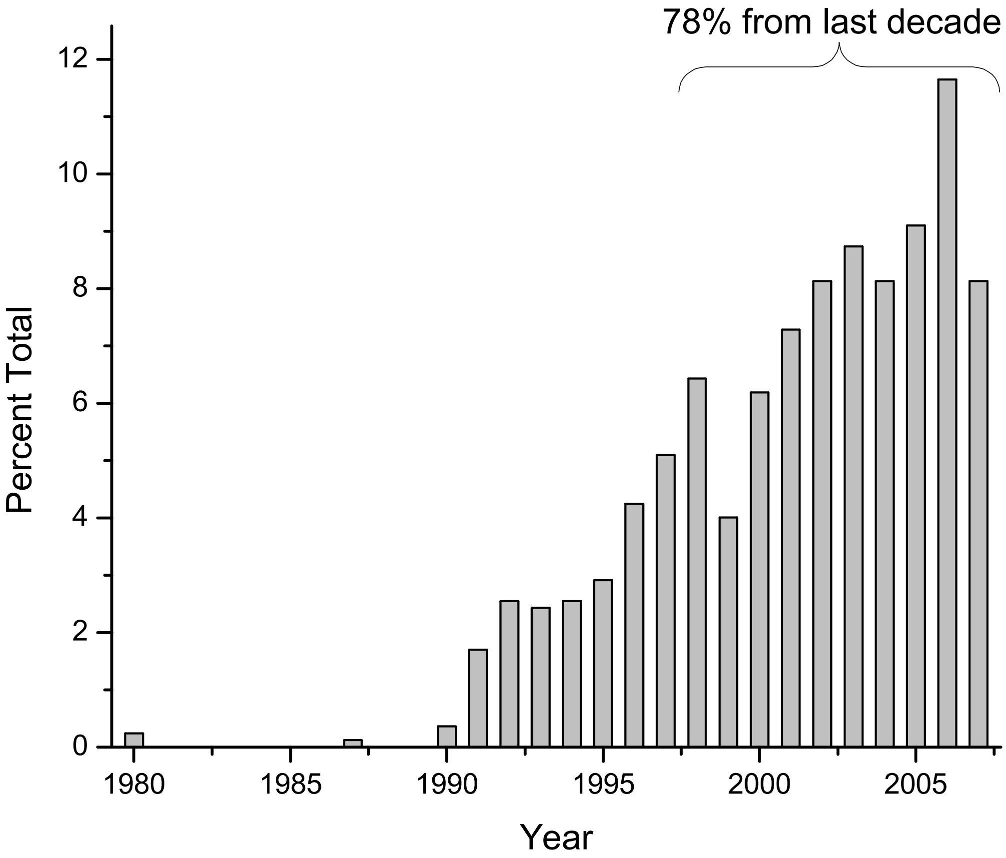


Figure 2.3. Time trend in search results for wildlife and wildlife disturbance publications on web of science search engine.

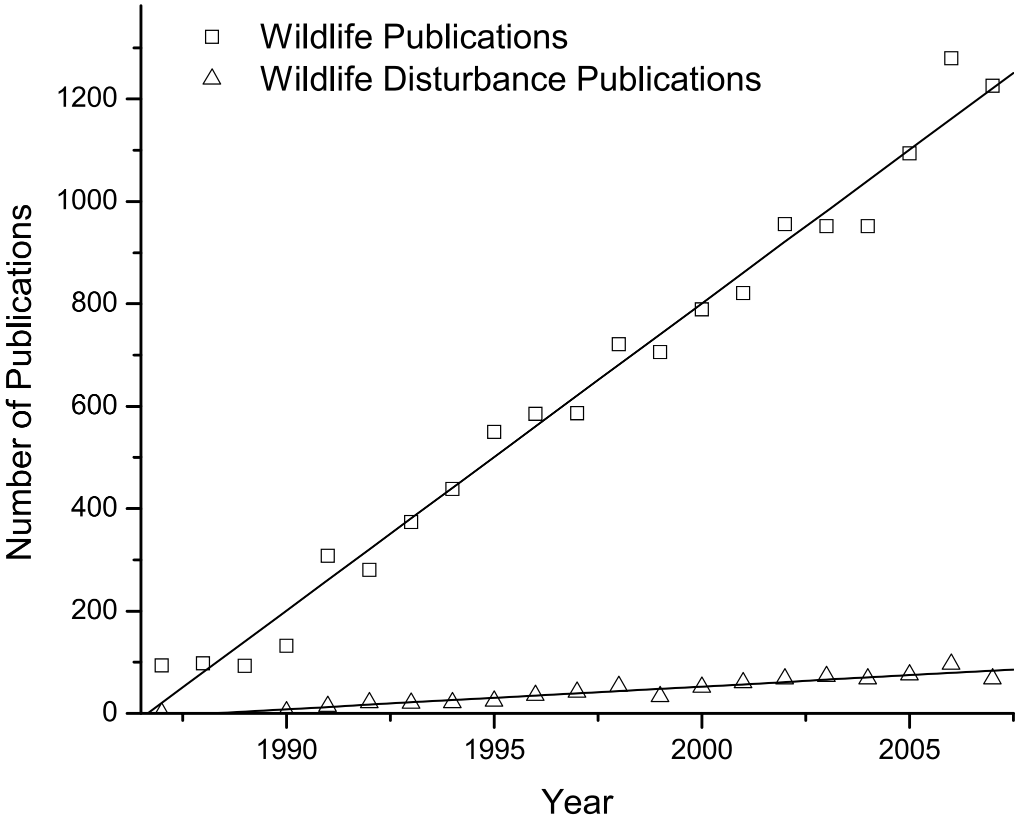


Figure 2.4. Trend in wildlife disturbance publications from developed and developing countries over time.

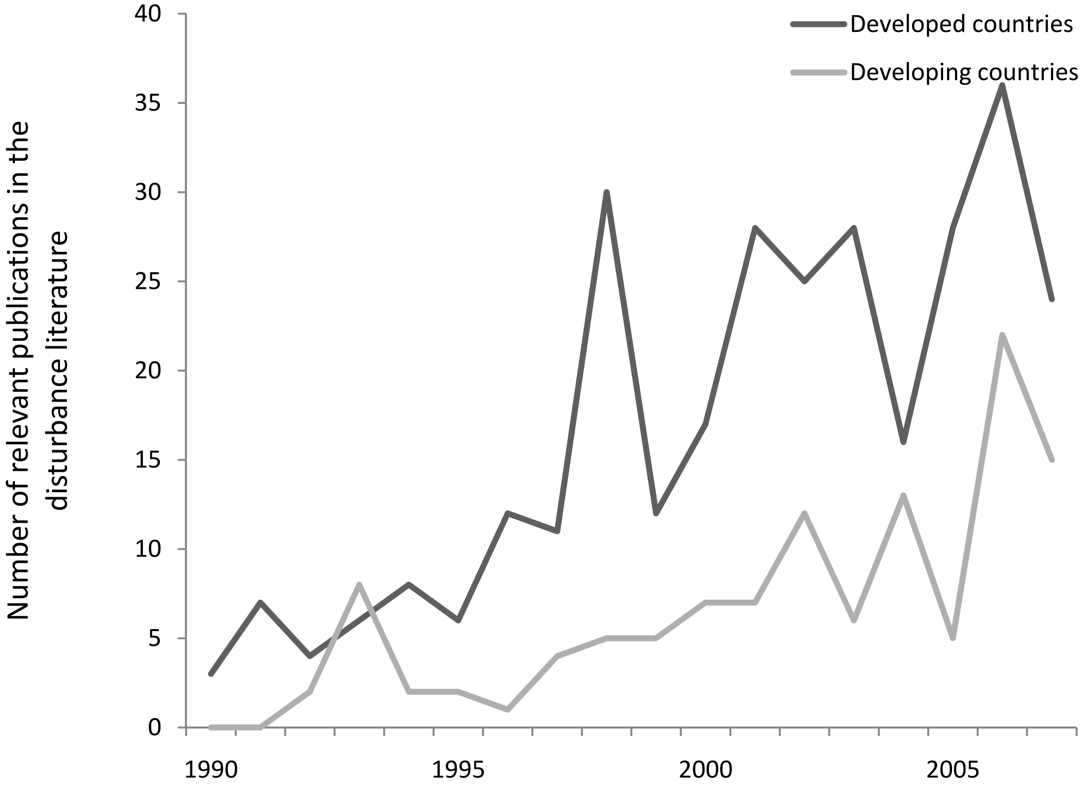
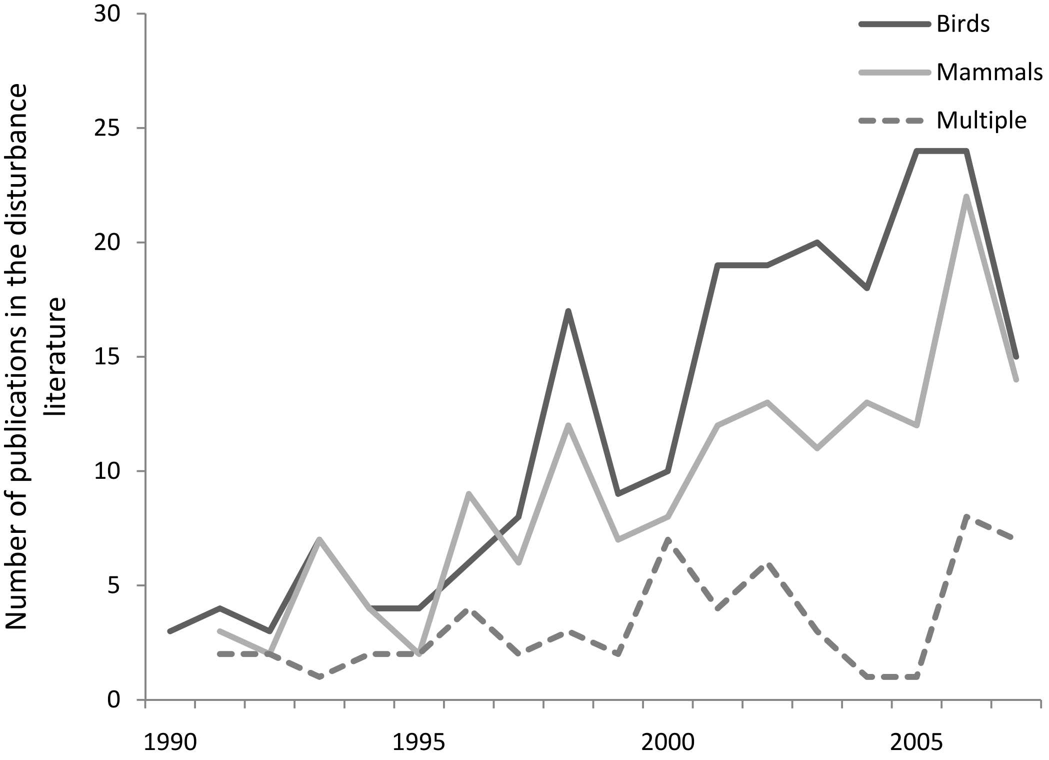


Figure 2.5. Trend in disturbance publications focusing on bird, mammal, and multiple species groups over time.



CHAPTER 3

SPATIAL DISTURBANCE FACTORS AND THEIR EFFECT ON COMMON LOON NEST SITE SELECTION AND TERRITORY SUCCESS

Abstract

The common loon (*Gavia immer*) breeds during the summer on northern lakes and water bodies that are also often desirable areas for aquatic recreation and human habitation. In northern New England, we assessed how the spatial nature of disturbance affects common loon nest site selection and territory success. We found through classification and regression analysis that spatial distance to and density of disturbance factors can be used to classify real versus random nest site locations, suggesting that these factors affect loon nest site selection (model 1, 74%, null = 51%, Kappa = 0.488, $P < 0.001$ and model 2, correct classification rate = 77%, null = 51% , Kappa = 0.544, $P < 0.001$). However, we were unable to show a relation between spatial disturbance variables and breeding success ($P = 0.595$, $R^2 = 0.436$), possibly because breeding success was so low during the breeding seasons of 2007-2008. We suggest that by selecting nest site locations that avoid disturbance factors, loons thereby limit the effect that disturbance will have on the success of their breeding efforts. Still, disturbance may force loons to use sub-optimal nesting habitat, limiting the available number of territories and overall productivity. We advise that management efforts focus on limiting disturbance factors to allow natural nest site selection, relieving disturbance pressures that may force sub-optimal nest placement.

Introduction

The common loon (*Gavia immer*) is a large piscivorous bird that breeds across northern North America, as well as in Greenland, Iceland, and rarely, although not recently, in Scotland (McIntyre and Barr 1997). Normal breeding habitat for common loons includes clear, oligotrophic lakes that are adequately populated with fish and are located in forested, sub-arctic, and arctic regions (McIntyre and Barr 1997). Common loons typically migrate to the breeding grounds as early as March and into June, returning to wintering grounds between September and December. This summer breeding period coincides with peak human recreational activities on North American lakes and, as such, makes loons potentially vulnerable to a disturbance-related decrease in breeding success.

Loons have attracted much public attention, and virtually every state and region within their breeding range has a society of citizen volunteers who actively monitor loon populations, provide artificial nesting platforms, safeguard nests, and band adults and chicks. Despite these activities, breeding populations have decreased along the southern edge of the range, and concern has been expressed over disturbance to breeding pairs by human activities such as shoreline development, boating, and water-skiing (Evers 2004), and over possible contamination with lead, mercury, and other pollutants (Evers 2001; Evers et al. 1998, 2003).

In New England, the common loon is considered endangered in Vermont, threatened in New Hampshire, and a species of special concern in Massachusetts and Connecticut (Evers 2004). One of the largest lakes in New Hampshire, Lake Umbagog, has long hosted a healthy breeding population of common loons; however, recent concern has been expressed by National Wildlife Refuge Staff, biologists, visitors, and other stakeholders about biophysical and anthropogenic factors that may be affecting their status (numbers of breeding pairs) and fitness (reproductive output and fledgling success). The Loon Preservation Committee (LPC), a New Hampshire based private organization, has been documenting loon nesting and nest success on Lake Umbagog since 1976. Their research indicates that there has been a declining trend in numbers of nesting loon pairs and hatched chicks on Lake Umbagog since 1995, with severe drops in both 2002 and 2006 (LPC annual reports 1995 through 2006). In 2003 and 2004, population levels and reproductive output increased slightly, although numbers were still below the levels recorded prior to 2000.

We assessed how common loon nest site selection and breeding success may relate to the spatial details of disturbance factors. By compiling spatial human use data collected by refuge biologists, historical nest success data collected by LPC, and recent nest success and location data collected by ourselves and refuge staff, we created a multilayered spatial data set. We then analyzed these data to assess correlation between nest site selection, nest success, and spatial disturbance variables. Our spatial disturbance variables represent the distance to and density of human use such as houses and boat launches as well as bald eagle (*Haliaeetus leucocephalus*) nest sites. We used this information to address the following objectives: (1) To identify how variation in nest site selection is related to human disturbance factors, and (2) To develop management plans to help assuage the effects of disturbance according to spatial guidelines.

Study Area

Lake Umbagog National Wildlife Refuge (LUNWR) is located in Coos County, New Hampshire and spans the New Hampshire-Maine border into Oxford County, Maine

(Fig. 3.1). The refuge was established in 1992 with the primary purpose of protecting wetlands, wetland associated wildlife, and migratory birds (USFWS 2006). The refuge includes more than 8,200 ha and incorporates extensive wetland complexes that are highly productive for waterfowl and breeding common loons, which is a focal species of the refuge. LUNWR is also a popular site for wildlife-oriented recreation such as fishing, hunting, photography, and wildlife observation. Although shoreline reclamation is a priority for the refuge, there are currently a moderate number (> 100) of cottages located along the shoreline.

Methods

To assess the spatial effect of disturbance factors on loon nest site selection and nest success we first compiled base layers of independent and dependent data. These layers were then imported into ArcGIS 9.0 for analysis. All layers were projected into the NAD 1983 UTM Zone 19N coordinate system.

For dependent nest site locations we used 67 GPS points taken at common loon nest sites during the 2002 (n = 9), 2003 (15), 2006 (12), 2007 (17), and 2008(14) breeding seasons. Specific nest location data for other years was unavailable. We created 71 additional random nest points within a 1-m buffer of lake and river shoreline using the random points within polygon tool from Hawth's Analysis Tools (Beyer 2004).

Our independent layers included point data digitized by refuge staff for previous projects representing locations of houses, camp sites, boat launches, and eagle nests. To ensure accuracy we compared these locations to digital orthographs and made appropriate corrections or additions. Additionally, we incorporated a line dataset representing boat use from the summer of 2006 (Manning unpub data). These data were collected by providing GPS receivers to recreational boaters (n = 156) as they launched their watercraft during peak summer use periods. The GPS receiver then tracked the boat's location throughout their use of the lake and rivers. We considered this dataset to be an index of relative spatial use of the lake during the breeding season.

Using these base data layers we then calculated spatial variables based on distance to a disturbance factor and density of disturbance factors in a given range, i.e., 100 m or 1 km. For each nest site and random point we first calculated the Euclidean distance to the nearest point within each layer of disturbance data. This required the creation of a distance raster using the Euclidean distance function in ArcGIS and then extracting the values from the raster to each loon nest and random point based on their physical location (Fig.3.2). This process created 4 distance variables: distance to nearest house, camp site, boat launch, and eagle nest, with a representative value for each loon nest and random nest site. Eagle nest point data was year-specific to account for the increase in eagle nests over time.

Next we calculated the density of points from each disturbance layer within a 100 m and 1 km buffer of each loon nest and random location (Fig. 3.2). Buffers around each nest site and random point were created using the Buffer tool in ArcGIS, and point data within each buffer were counted using the count points in the polygon tool of Hawth's analysis toolpack. This created 8 additional variables representing the density of houses, camp sites, boat launches, and eagle nests within 100 m and 1 km of loon nests and random points. We calculated our final variables by measuring the total distance of boat travel within the 100 m and 1 km buffers around loon nests and random points using the sum line lengths in the polygon tool of Hawth's analysis toolpack (Fig. 3.2). These two variables represented the extent of boat use within close proximity to nest locations.

Our compiled spatial dataset included the dependant variable representing loon nest and random points along with 14 created spatial disturbance variables. These included distance to houses, camp sites, boat launches, and eagle nests, density of houses, camp sites, boat launches, eagle nests within 100 m and 1 km buffers, and length of boat tracks within 100 m and 1 km buffers.

Using classification tree analysis we then assessed differences between our known groups of actual loon nest sites and randomly generated nest sites. We used R statistical software with the Cartware R source code written by B. Compton (University of Massachusetts-Amherst) for these analyses. Our first model incorporated all of the disturbance variables. We used the 1 SE rule to trim the resultant tree (De'ath and Fabricius 2000). Based on our initial model we also elected to look at a model incorporating only human disturbance-related data with eagle nest variables removed. We again used the 1 SE rule to trim the resultant tree.

We then utilized the splitting criteria identified by our classification analysis to develop nest site predictive maps of Lake Umbagog and surrounding river areas. These criteria were applied by first creating a shoreline point layer with every 10 m of shoreline represented by an individual point. We then calculated each of the required disturbance distance and density variables for every shoreline point. All layers were then converted to raster format and simple raster math statements were utilized to apply our splitting criteria. This resulted in a final map layer with potential nesting shoreline identified.

Next, in conjunction with our spatial data, we incorporated nest success data collected over the last decade by Refuge staff and the LPC. We compiled these data from annual loon population status reports for each territory that we had known spatial nest data (LPC annual reports 1995 through 2006, unpub. data Lake Umbagog National Wildlife Refuge). Using these data we assigned a success value to each territory based on productivity and use between 1998 and 2008. To calculate this value, yearly productivity scores were assigned to each territory using a predetermined scoring criterion. The sum of this yearly score for each territory was then used as our territory success value. This territory success variable followed a continuum with a low success value being assigned when a territory was occupied but no nest initiated, to the highest value for chicks being fledged. Nesting rafts are known to improve nest success in common loons (DeSorbo 2008) leading us to incorporate a 50% penalty to territories with rafts. Few territories had rafts and rafts were used only during the initial years of the dataset; we used the penalty to limit their influence on the majority of the dataset. To match our territory success variable with our spatial data, we took the average value for each spatial disturbance variable across all known nest locations within a given territory.

To assess if our disturbance variables had an effect on territory success we used regression tree analysis in R statistical software. All independent spatial variables were assessed for normality and most had a tendency towards a right skew; however, attempted transformations did not improve normality. We elected to use the variables in their original state and consider our results as exploratory rather than a true statistical test. We also chose to complete simple linear regression with each individual independent variable and dependent territory success variable. We recognize that this exceeds our available degrees of freedom and completed it in a purely exploratory fashion.

Results

Based on the error plot for our first classification model using all spatial disturbance variables, we pruned the classification tree to 3 leaves. This tree resulted in a correct classification rate of 74% versus a null of 51%, and a Kappa of 0.488. Our confusion matrix shows 61 of 69 nests classified correctly and 43 of 71 random points classified correctly. Monte Carlo resampling with 1,000 repetitions showed $P < 0.001$.

The primary split of this classification tree showed that if a point was further than 3.57 km from an active eagle nest then it should be classified as random (Fig 3.3). If closer to an active eagle nest, we then looked at the secondary split. This split showed that if there were >3.21 km of boat tracks within a 100 m buffer of a point it was classified as random; <3.21 km and it is classified as a loon nest (Fig. 3.3).

Using the 1 SE rule we pruned our second classification tree to 5 leaves. This model used only human-related disturbance variables and excluded our 3 eagle nest related variables. The correct classification rate of this model was 77% versus a null of 51% with a Kappa of 0.544. The confusion matrix showed 62 of 69 loon nests classified correctly and 46 of 71 random points classified correctly. Monte Carlo resampling with 1,000 repetitions showed $P < 0.001$.

The primary split of this tree classified any point <170.9 m to a building as a random point (Fig. 3.4). The second split classified all remaining points >6.46 km from a boat launch as random. The third split classified remaining points with >3.21 km of boat tracks within 100 m as random. The fourth split classified remaining points that were closer than 586.2m to a boat launch as random.

Regression tree analysis showed no significant relationship between territory success and spatial disturbance variables ($P = 0.595$, $R^2 = 0.436$). This was also evident in our exploratory simple linear regression analyses in which only Euclidean distance to nearest house showed a small relation to territory success ($F = 3.89$, $P = 0.0614$, $R^2 = 0.15$, Adj $R^2 = 0.112$; Fig. 3.5).

Applying our splitting criteria to all available shoreline provided 2 predictive maps, one based on the classification including eagle nests, and one using only human-related disturbance variables (Fig. 3.6, 3.7). The predictive map including eagle nest data classified 53.9% of shoreline as potential for nest site locations given the spatial disturbance. The map utilizing the human only splitting criteria classified 46.1% of the shoreline as potential for nest site locations given spatial disturbance. The two maps jointly predict 35.5% of shoreline as nest site potential.

Discussion

Newbrey et al. (2005) assessed the effects of lake characteristics and human development on piscivorous birds in 98 lakes in northern Wisconsin. Presence-or-absence data were compared to habitat variables gathered from literature and during lake surveys. They found loons to be positively associated with riparian forest and an index of sinuosity, and negatively associated with nonpublic boat access. Notably, common loons were absent from lakes with a large number of cottages (Newbrey et al. 2005). Heimberger et al. (1983) studied the impact of cottage development on common loon reproductive success in Central Ontario. They found early nesters to be more successful than later nesters when human disturbance was prevalent and that 2-egg clutches were more successful (at least one egg hatched) than 1 egg clutches. Hatch success declined as the number of cottages within 150 m of the nest increased, but post-hatch survival appeared to be independent of cottage development (Heimberger et al. 1983).

Our results suggest that the physical location of nest sites and randomly selected sites can be differentiated partially based on proximity and density of disturbance factors. Our first classification tree analysis used only 2 splitting criteria to reach a 74% correct classification rate and a kappa = 0.488. The first split in this tree seems counterintuitive, suggesting that nest sites are more likely to be closer to an eagle nest. However, it is likely that in this case, the distance to eagle nest acted as an index to loon habitat suitability. Bald eagles and common loons share many similar habitat requirements, such as lack of human development and an abundance of fish (Heimberger et al. 1983, Livingston et al. 1990, McIntyre and Barr 1997), and it seems plausible that areas within 3.57 km of an eagle nest on Lake Umbagog are also those suitable for the common loon. The second and final split in this tree was more intuitive, classifying areas with excessive boat use within 100 m as non-nest site locations. The specific length of boat travel, 3.21 km, can only be considered as a relative index of recreational boat use; however, it does imply that with increased near-shore boat use there is less likelihood for potential loon nest sites.

In our second classification tree analysis we removed the eagle nest variables to focus only on disturbance associated with human use. This tree was more complex, with 4 splitting criteria and 5 leaves. It performed better than our first model with a correct classification rate of 77% and kappa = 0.544. The first split of this tree classified any location within 170.9m of a building as a random nest point. This agrees with the Heimberger et al. (1983) finding of decreased hatch success with increasing numbers of cottages within 150 m, and of Newbrey et al.'s (2005) finding that common loons were not found on lakes with high levels of cottage development. The second split classified points >6.46 km from a public boat launch as random. Similar to the eagle nest split of our first classification tree, it is possible that in this split the boat launch variable was acting as a habitat surrogate. This was similar to Newbrey et al. (2005), who associated common loon presence on a given lake with the presence of a public boat launch. Areas farther from boat launches were likely outside the main lake and river area and away from prime fishing locations and wide water bodies. The third split here is the same as our second split in the first classification tree, classifying points with >3.21 km of relative boat track within 100 m as random. The final split then classified any point closer than 586.2 m to a boat launch as random and all remaining points as nest sites. This suggests that although having a boat launch within 6.46 km may indicate suitable habitat (split 2), having one too close is detrimental.

Both classification trees were significantly different than random, and both suggested that disturbance factors do play a role in common loon nest site selection. It is important to remember that though distance to eagle nest or boat launch variables may act as surrogate habitat variables, there are several other habitat factors affecting nest site selection. However, it is evident that at a portion of the variability in nest site selection is described by our spatial disturbance variables.

Our regression tree analysis failed to show any correlation between territory success and our disturbance variable set. The power of this analysis was admittedly weak due to lack of normality, but the low level of explained variance suggests that there truly may be little correlation in our model. In exploring individual linear models, it is interesting to note that the only variable showing remotely significant correlation to territory success was the distance to nearest house (Fig. 3.5), the same variable used in the first split of our second classification tree.

It is known that a high level of metabolic cost is associated with egg development and incubation in birds (Vezina 2005). A common loon produces few eggs, each weighing about 3.5% of the females body weight (125-180g; McIntyre and Barr 1997), and then the female must incubate the eggs for about 28 days before hatching (Evers 2004). This level of investment dictates a need for a high rate of success to account for the associated costs. In allowing disturbance factors to influence nest placement, common loons may thereby limit the effect that disturbance will have on nesting success. In this manner they ensure that the high level of investment will not be capriciously wasted due to disturbance. Our results fit this scenario, showing that disturbance affects nest site selection, but a selected site is then less vulnerable to disturbance affecting breeding success. This agrees with the findings of Badzinski and Timmermans (2006), who found that shoreline development and human disturbance did not affect loon productivity during the pre-fledgling stage. In a broader scale it is likely that disturbance is affecting overall loon productivity by decreasing available nesting habitat. It has been shown that the common loon suffers lower reproductive success on lakes heavily used by humans (McIntyre and Barr 1997). However, there is a wide variety of other variables that can and do affect loon breeding success, including contamination with lead, mercury, and other pollutants (Evers 2001; Evers et al. 1998, 2003) and it is likely that some of these other factors are in place on Lake Umbagog. An ecosystem approach is warranted in loon conservation, and limiting the effect of human disturbance is only one part of that effort.

Management Implications

Our models and predictive maps provide lake level detail allowing for management actions to limit the effects of disturbance on common loons. In addition, a similar framework can be used on other loon breeding lakes to help determine the most appropriate lake level action plans.

Limiting the number of houses within close proximity to primary loon habitat and focusing boat traffic away from potential nesting shoreline may allow common loons to select nest sites based upon natural habitat suitability factors. Given that our results indicated a boat traffic effect on nest site selection, it would thus be necessary to restrict access to nesting areas before nest initiation, rather than waiting for a loon pair to establish a territory and initiate nesting before instituting area closures. This may in turn improve breeding success by allowing loons to access prime nesting habitat. Further analysis of other lakes and their spatial disturbance could serve to both validate our model as well as gain a broader understanding of region-wide disturbance effects.

Figure 3.1. Lake Umbagog National Wildlife Refuge, study area for spatial analyses of disturbance variables and their effect on loon nest site selection and nest success.

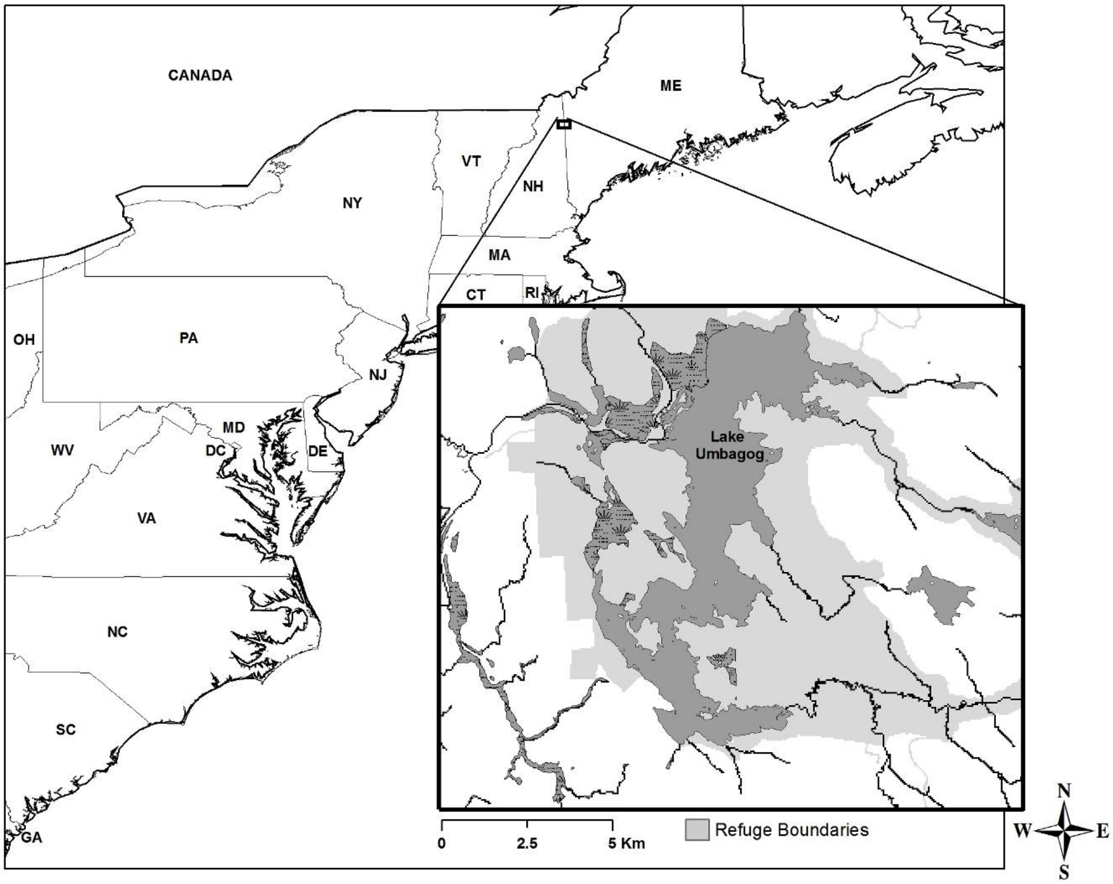


Figure 3.2. Flowchart depicting GIS processes in Arc GIS to develop spatial disturbance variables for analysis of common loon nest site selection and territory success on Lake Umbagog National Wildlife Refuge.

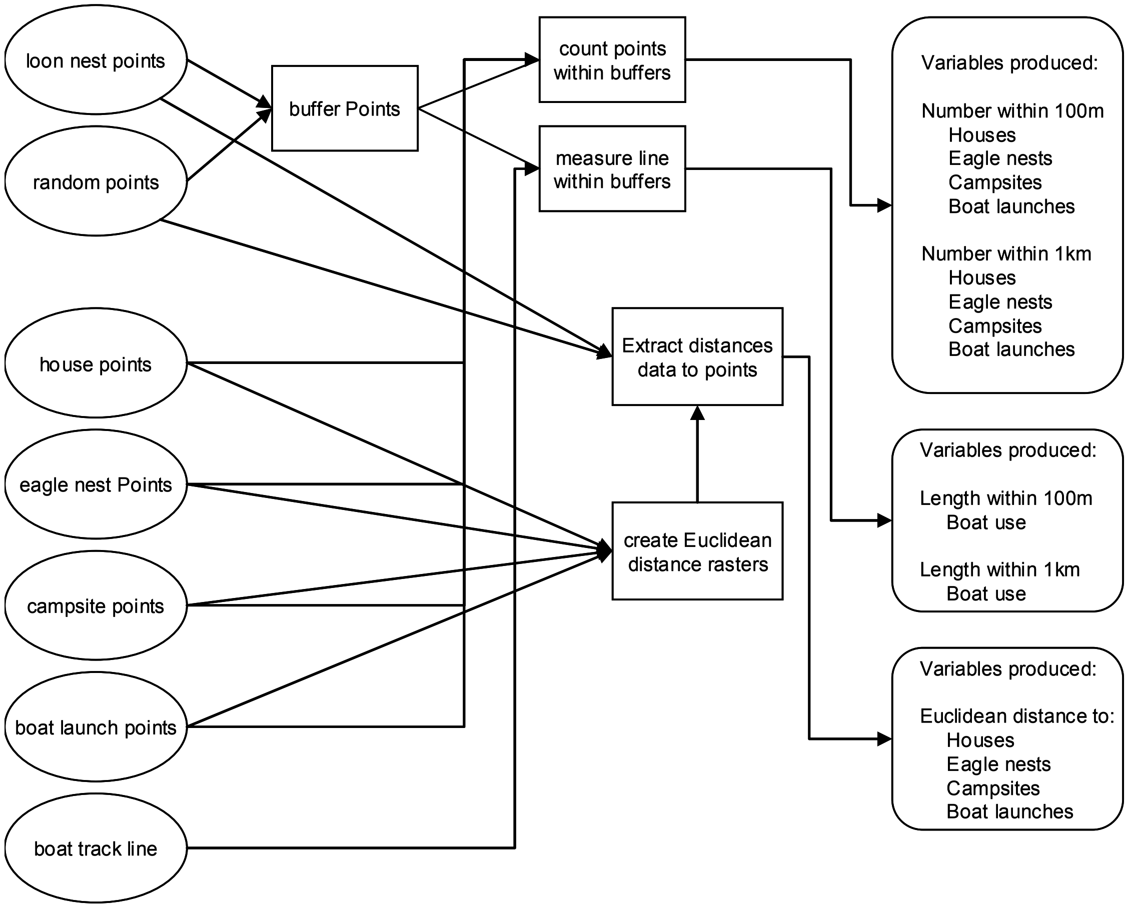


Figure 3.3. Classification tree separating groups of nest (N) and random (R) point data on Lake Umbagog National Wildlife Refuge pruned to 3 leaves based on 1 SE rule. Splitting criteria fall on the horizontals, correct classification rate and group membership follow the N or R classification.

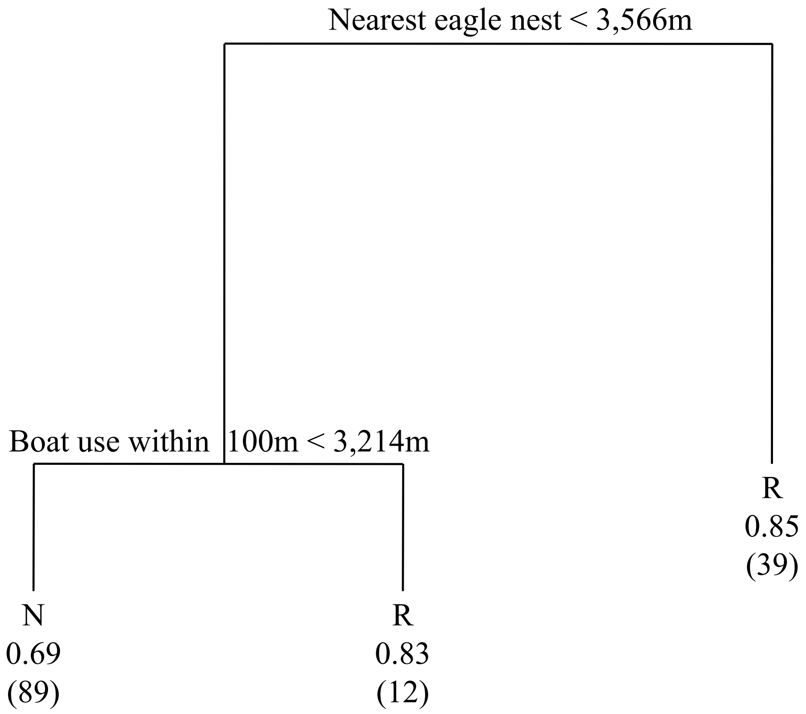


Figure 3.4. Classification tree separating groups of nest (N) and random (R) point data on Lake Umbagog National Wildlife Refuge pruned to 3 leaves based on 1 SE rule. Splitting criteria fall on the horizontals, correct classification rate and group membership follow the N or R classification.

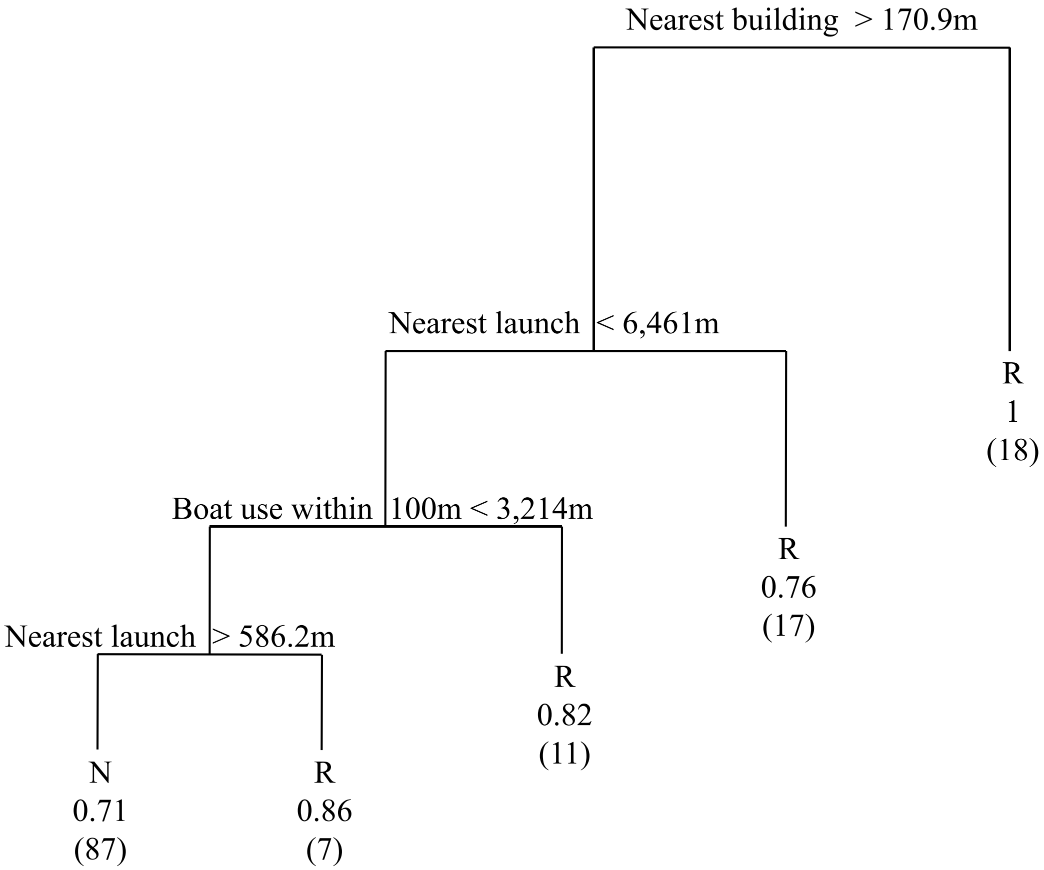


Figure 3.5. Simple linear regression of dependent territory success variable given independent Euclidean distance to nearest building variable.

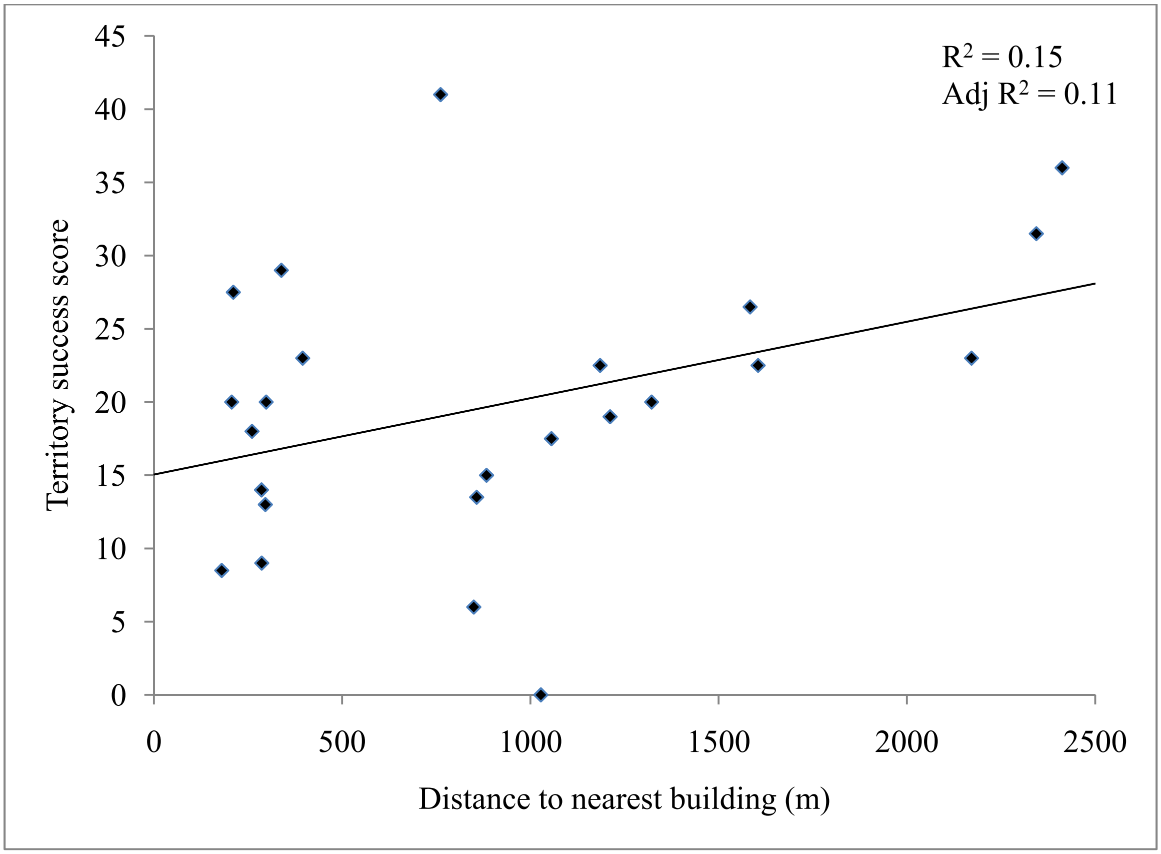


Figure 3.6. Potential nest site locations, in bold, based on classification tree analysis including human related and eagle related disturbance variables, Lake Umbagog National Wildlife Refuge.

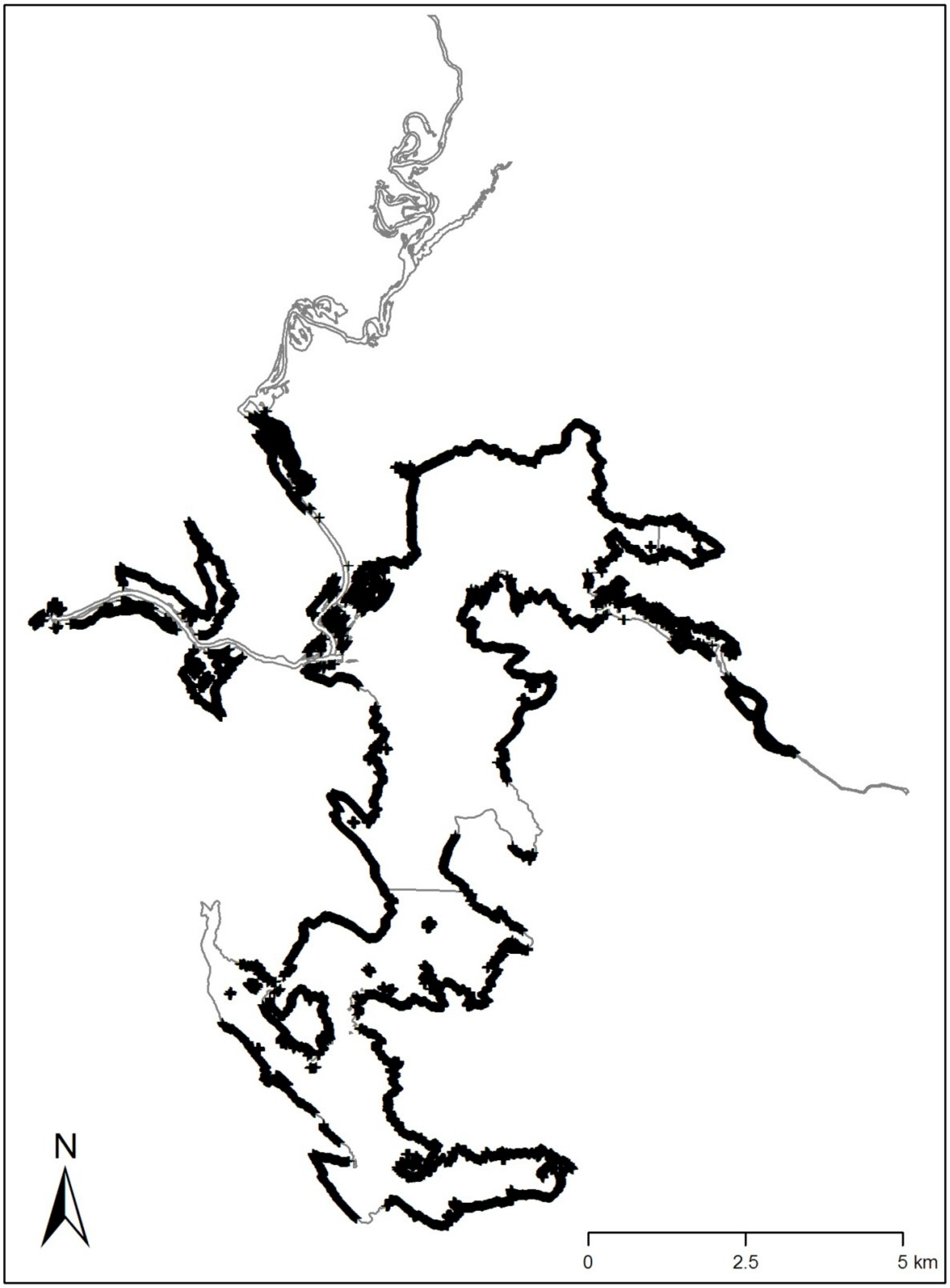


Figure 3.7. Potential nest site locations, in bold, based on classification tree analysis including only human related disturbance variables, Lake Umbagog National Wildlife Refuge.

CHAPTER 4

COMMON LOON BEHAVIORAL RESPONSES TO DISTURBANCE DURING BREEDING

Abstract

The common loon (*Gavia immer*) is experiencing declines at the southern extent of its range and is considered threatened or endangered in much of New England. One of many factors that could be affecting loon populations is the steady increase in recreational activity, as participation in ecotourism and other outdoor pursuits has increased significantly in North America. It has long been assumed that common loons will alter their behavior in response to human disturbance, but little has been done to quantify this effect. Additionally, natural disturbance events created by predators such as bald eagles (*Haliaeetus leucocephalus*) or intraspecific competition with other loons may alter breeding behavior, negatively affecting reproductive output. Through the use of behavioral observations and experimental manipulation we evaluated and quantified the behavioral effects of these various disturbance factors and discuss the potential risks of a distorted breeding activity budget. We found that loons significantly altered their normal behavior pattern in response to various forms of human recreation, bald eagle presence, and intraspecific competition at all stages of the breeding cycle. We recommend that with increasing recreational pressure and recovering eagle populations, disturbance mitigation strategies may be warranted for declining loon populations.

Introduction

The common loon (*Gavia immer*) is one of the great icons of the north, and there is strong sentiment for the species among various stakeholders throughout its range. Unfortunately, in recent years the southern range of the common loon has contracted (Piper et al. 2002), and in many areas there have been dramatic declines in the numbers of successfully breeding pairs. In New England, the common loon is now considered endangered in Vermont, threatened in New Hampshire, and a species of special concern in Massachusetts and Connecticut (Evers 2004). There is currently no protection under the federal Endangered Species Act, despite recent declines across their southern range (Piper et al. 2002). Numerous possibilities for these declines have been identified, including potential contamination with lead, mercury, and other pollutants (Evers 2001; Evers et al. 1998, 2003), as well as disturbance to breeding pairs by human activities, such as shoreline development, boating, and water-skiing (Evers 2004b). However, there has been no definitive identification of the causal agents, and alarming declines in the numbers of breeding loons throughout much of their range have continued.

The common loon is the largest of five species in the family Gavidae, the others being the yellow-billed (*G. adamsii*), Pacific (*G. pacifica*), Arctic (*G. arctica*), and red-throated (*G. stellata*) loons. Typical breeding habitat for common loons includes clear, oligotrophic lakes with adequate prey populations, located in forested, sub-arctic, and arctic regions across northern North America, as well as in Greenland, Iceland, and rarely, in Scotland (McIntyre and Barr 1997). Loons are primarily monogamous and pairs commonly remain together throughout the summer (McIntyre and Barr 1997). They fly inland from the wintering grounds on the coast from March to May, returning to the same breeding lakes year after year. Loons typically establish one nest each summer, but if their initial nest fails they may build a second nest. When successful, they usually hatch 1-2 chicks although clutches of 3 chicks have occasionally been observed (McIntyre and Barr 1997). Common loons typically migrate from the breeding grounds to wintering grounds between September-December, with the chicks leaving slightly later than the adults. The majority of individuals then winter in coastal marine areas, generally near shore, over shoals, and in sheltered bays, inlets, and channels (McIntyre and Barr 1997).

Common loons are a top predator, feeding mainly on a variety of fish species, and are therefore sensitive to abiotic and biotic factors associated with their breeding lakes (Badzinski and Timmermans 2006). As such, they are often considered as an indicator species for northern lake ecosystems. Their presence at healthy population levels indicates that the lower levels of the food chain are being sustained at adequate levels to support loon populations. Thus, efforts to maintain loon populations are thought to also support the underlying trophic levels. In addition to their value as an ecosystem indicator, loons are a valuable aesthetic resource whose presence adds a sense of excitement and character to natural areas (Titus and VanDruff 1981). As such, nearly every state and region within the breeding range of common loons has implemented extensive monitoring by state and federal biologists to assess the health of loon populations. In addition, there is a large faction of non-governmental organizations and citizen volunteers who actively monitor loon populations, provide artificial nesting platforms, safeguard nests, and band adults and chicks.

In recent decades, participation in ecotourism and other outdoor pursuits has drastically increased in North America and biologists have become interested in understanding the effect that these activities may be having on wildlife (Knight and Gutzwiller 1995). Additional disturbance studies have been done on a variety of species, including waterfowl (Henson and Grant 1991, Gill et al. 1996), shorebirds (Burger 1994, Gill et al. 2001), eagles and other diurnal raptors (Knight and Knight 1984; Vanderzande and Verstrael 1985; White and Thurow 1985; Fernandez and Azkona 1993; Steidl and Anthony 1996, 2000), owls (Swarthout and Steidl 2001, 2003), bats (Speakman et al. 1991, Mann et al. 2002), and other taxa (e.g., Bart 1977; Westmoreland and Best 1985; Skagen et al. 1991, 2001; Rodgers and Smith 1995).

It has long been assumed that common loons alter their behavior in response to human disturbance and competition (Ream 1976, Titus and VanDruff 1981, Jung 1987, Caron and Robinson 1994, Kaplan 2003). Perhaps one of the most widely recognized loon disturbance studies is Titus and VanDruff's (1981) research on the response of common loons to recreational pressure in the Boundary Waters Canoe Area of Minnesota. Canoes with motors showed a moderate effect on nest success and brood rearing, and caused more alert responses and flushing than canoes without motors (Titus and VanDruff 1981). Most of their data comparisons, however, showed that motorized recreational activity had little or no effect on loon productivity; no difference was seen vs non-motorized traffic, with some loons in high use areas even refusing to leave nests when approached by humans. However, loons on more remote lakes did have a higher hatch success rate, and those further from high levels of recreational use produced significantly more surviving young. Overall, Titus and VanDruff (1981) concluded that the common loon may be adapting and habituating to human disturbance, but also that heavy human use may be having negative effects on loons in the Boundary Waters Canoe Area.

In a study of common loon productivity in northern Minnesota, Ream (1976) looked at pesticide residues and recreational pressures. She found the increase in canoeing and recreational activities to be the likely cause of severe population declines. In northern Michigan Caron and Robinson (1994) found no significant difference between fledgling success on restricted-use and open-use lakes; however, they suggested that these results should not be extrapolated to lakes experiencing higher human use. Also in Michigan, Jung (1987) found that loons on high-use lakes exhibited significantly different behavior than loons on low-use lakes, although there was no relation of different behaviors to fitness level. Heimberger et al. (1983) observed a decrease in breeding success with an increase in the number of cottages close (<150 m) to nest sites, and Vermeer (1973) recorded an inverse relation between human disturbance and the number of breeding loons. Smith (1981) found that canoeing activities in the Kenai National Wildlife Refuge had not affected loon nest success. However, Kaplan (2003) compared loon nesting success to canoe and kayak activities in Isle Royale National Park and found that nest success decreased with an increase in paddling activity. This is important as, traditionally, these activities may have been considered to have low impact on wildlife populations.

Although there have been studies that addressed natural disturbance, there are indications that loons may also be largely affected by non-human disturbance factors. Bald eagles (*Haliaeetus leucocephalus*) are predators of incubating adult loons and loon chicks (Vliestra and Paruk 1997, Paruk et al. 1999, Richardson 2000, Evers 2004). Eagles are known to elicit extreme behavioral responses from nesting and brood-rearing common loons. Loons are also very territorial and both males and females engage in battles to protect or gain valuable territories from other loons (Piper et al. 2008).

Lake Umbagog National Wildlife Refuge (LUNWR) in northern Maine and New Hampshire historically hosts one of the largest breeding populations of common loons in New Hampshire (USFWS). In recent years, the refuge has become a popular site for wildlife-oriented recreation such as fishing, hunting, photography, and wildlife observation. As human use of the area has increased, there has been a concurrent decrease in the numbers of successfully breeding loon pairs, and concern has been expressed by refuge staff, biologists, visitors, and other stakeholders about biophysical and anthropogenic factors that may be affecting the status (numbers of breeding pairs) and fitness (reproductive output and fledgling success) of loons at the LUNWR.

The purpose of this study was to identify factors that may be affecting the breeding success and fledgling success of common loons at LUNWR, to assess the potential impact that disturbances may have on loon territory fidelity, breeding success, and fledgling success, and to determine management options that may eliminate or ameliorate disturbance to loons. We used both observational and experimental techniques to assess natural and anthropogenic disturbance at LUNWR during the 2007 and 2008 breeding seasons. Through repetition of our research at the nearby Aziscohos Lake in Maine, we are able to make inference and recommendations over a broader range of habitats and levels of human use. By increasing our understanding of the effects of natural and anthropogenic disturbances on common loon breeding behavior we hope to engender management strategies that will help limit the contraction of their southern range, and halt range-wide declines in the numbers of breeding pairs.

Study Areas

Lake Umbagog National Wildlife Refuge is located in Coos County, New Hampshire and spans the New Hampshire-Maine border into Oxford County, Maine (Fig. 4.1). The refuge was established in 1992 with the primary purpose of protecting wetlands, wetland-associated wildlife, and migratory birds (USFWS 2006). The refuge includes more than 8,200 ha and incorporates extensive wetland complexes. Lake Umbagog historically hosted one of the largest concentrations of nesting loons in New Hampshire and supports numerous other waterfowl species including black ducks (*Anas rubripes*), ring-necked ducks (*Aythya collaris*), goldeneyes (*Bucephala clangula*), wood ducks (*Aix sponsa*), hooded and common mergansers (*Lophodytes cucullatus* and *Mergus merganser,* respectively), and mallards (*Anas platyrhynchos*) (USFWS 2006). Water quality in Umbagog Lake is ideal for warm-water fish species, and recent illegal introductions of bass have become established and now provide fisheries. Although populations of salmonids are present, they do poorly in the lake with heavy competition from many other species (Fisheries Report). Lake Umbagog is fed by 3 major rivers, the Magalloway, the Rapid, and the Dead Cambridge, and has one major output, the Androscoggin River. Outflow is controlled by a dam located in Errol, New Hampshire near the headwaters of the Androscoggin. The Lake Umbagog shoreline is populated by dozens of houses and camp sites, concentrated on but not limited to the southern portion of the lake. The United States Fish and Wildlife Service (USFWS) is actively purchasing developed land for restoration to natural habitat. There are multiple points of entry for recreational boating on the lake and adjoining rivers.

The Loon Preservation Committee (LPC), a New Hampshire-based private organization, has been documenting loon nesting and nest success on Lake Umbagog since 1976. Their research indicates that there has been a declining trend in numbers of nesting loon pairs and hatched chicks on Lake Umbagog since 1995, with severe drops in both 2002 and 2006 (Fig. 4.2; LPC 1995-2005). In 2003 and 2004, population levels and reproductive output increased slightly, although numbers were still below the level recorded in 2000.

Aziscohos Lake is a 2,700 ha water body formed by the construction of a dam on the Magalloway River, located 13 km north of LUNWR. (Fig. 4.1; Bonney 2002). It is long and narrow, with few coves and no floating bog complexes. Most loons nest on rafts placed by the Biodiversity Research Institute (Gorham, Maine) under contract with Florida Power and Light. Outflow from Aziscohos enters into Lake Umbagog via the Magalloway. The lake supports fisheries for both wild salmon and brook trout and overall runs considerably deeper than Lake Umbagog. The shoreline has limited development and there is less recreational use (pers. obs.).

Methods

Several different approaches have been used to assess human disturbance and its impact on common loons. Titus and VanDruff (1981) first located nests by extensive shoreline searches from canoe. Presence of young was assessed via spotting scope and binoculars, and reproductive success was determined by presence of young two weeks or older. To assess recreational impact they recorded recreational use on one leg of the daily nest surveys. The location of each observed recreational party was mapped and later the amount and type of use within 1.6 km of each nest was determined from these data. In one study year they spent 0.5 hours per visit in each territory to observe type and degree of recreational use. Nests were then ranked into high, medium, and low categories of recreational use, and assigned a rank of one to three in a human impact index based on the number of canoes recorded within 1.6km of the nest site, and on a disturbance potential index based on visibility from and distance to main travel routes. They also assigned a visibility index to each nest based on how conspicuous a loon sitting on the nest would be when a canoe passes 10 m from shore. Data were then analyzed using canonical correlation, discriminate analysis, and factor analysis. We chose to expand upon this methodology and used both observational and experimental methodologies to assess the impact of natural and anthropogenic disturbance on loon behavior at LUNWR.

Territory monitoring- Loon monitoring was conducted by the research team, the refuge staff, and LPC of New Hampshire and information on territorial pairs and nesting initiations was shared collaboratively. Prior to initiating pre-nesting surveys at LUNWR, all historical nesting territories were searched by the research team to locate territorial pairs. After survey efforts began, we continued to search periodically for new territorial pairs and include them into the sampling strategy. Nest sites were often observed when they were first initiated during pre-nesting surveys. Others were located by exhaustive shoreline searches using binoculars or through observation of pair behavior. Active nests were monitored daily to watch for nest-failure or hatching events. After hatching, brood rearing pairs were checked daily to document chick survival. If a nest failed, it was checked for evidence of the cause such as flooding, or animal predation. Our efforts on

Aziscohos were limited due to logistics, but when possible the nesting and brood rearing pairs were surveyed opportunistically. Territories on Aziscohos were not monitored daily by the research team and nest fate was often unknown.

Behavioral Observations- To facilitate the logistics of fieldwork, we divided the refuge into clusters of territories based on geographic location and sampled among those clusters. We strategically selected which cluster(s) to survey each day, the order that territories were observed within each cluster, and the time period during the day to ensure that each territory was sampled evenly over time. Loons were surveyed in 2007 and 2008 beginning with pre-nesting surveys in the first week of May and ending with brood-rearing surveys the second week of August. We used 100 minute time periods equally distributed within three time categories: (1) early morning (dawn to 10:00), (2) mid-day (10:00 to 15:00 hours), and (3) late afternoon (15:00 to dusk). A survey consisted of 100 instantaneous observations at 1-minute consecutive increments. Survey length was decreased if there was a lack of loon visibility or during extreme weather events, and increased in length if events of interest (e.g., boat arriving, eagle perched nearby) were occurring at minute 100. For each instantaneous observation, loon behavior was recorded, as were potential disturbance factors. We used a pre-determined list of potential loon behaviors based on descriptions by McIntyre (1988), and when needed, additional codes were created for unanticipated behaviors (Table 4.1). A coding scheme for potential disturbances was also developed and used to record all relevant details (Table 4.2). Apart from descriptive information of loon behavior and disturbance factors, we also recorded the position of loons and potential disturbances on area specific maps (100 m gridlines) at each one minute increment. This allowed the later measurement of the instantaneous distance between each loon and the disturbance and the subsequent comparison to observed loon behaviors.

To minimize any researcher effect on loon behavior, all surveys were conducted from concealed onshore locations that met two conditions: (a) the adult pair was unaware of researcher presence (no displayed behavior change), and (b) observers could record disturbance events at the nest and in the nest area. To meet (a) above, observers needed to access and exit survey sites with minimum disturbance to the breeding pair, to be able to conduct observations without being detected, and to have no influence on disturbance events. As such, researchers wore 3-dimensional (i.e., adorned with fake leafs) camouflage clothing to limit detection by both wildlife and humans. Additionally, survey efforts were kept confidential from the public so that the behavior of anglers and boaters was not affected (e.g., avoiding a particular cove, or changing their behavior once in the cove). In some rare instances, surveys were conducted from an unmarked boat when onshore locations could not provide clear visibility.

Observations were made using appropriate optics for the relative distance to loon or disturbance. We used Nikon Monarch™ 10x42 binoculars for near objects, Leica™ or Swarovski™ 20-60x spotting scope for far objects, and Nikon Stabileyes™ 14X40 binoculars from a boat. We used a compass and a Brunton™ laser-rangefinder to aid in accurately mapping locations of loons and disturbance factors. (Trade names do not imply endorsement by the federal government.)

Experimental Approach- To isolate the reaction of common loons to different types of recreational boating, we used a controlled experimental approach. Four different treatments were applied and replicated in random order on separate days to 4 nesting pairs at LUNWR in 2008. Each treatment was composed of a different boat-type slowly approaching a nest to 100 m, stopping for 5 minutes and then slowly departing along the same route. Loon behavior was also recorded for 10 minutes prior to boat entry and after exit. The four boat types used were canoe, kayak, skiff with gas motor, and skiff with electric motor. Approaches were completed in the mornings, under similar weather conditions with a general light breeze and mostly clear skies. A GPS unit was placed on each boat and set to record positions at 20 second increments. An on-shore observer synchronously recorded loon behavior at 20-sec intervals. We used a Brunton laser-rangefinder in the boat to maintain a position 100 m from the nest for 5 minutes. GPS locations were later compared to nest site coordinates in order to determine exact distance between the boat and the nest at each 20-sec interval.

Data Analysis- The spread of points in constrained ordination space suggested there was not a strong territorial pair effect and we felt that each survey was unique in its composition of disturbance factors. Thus, we chose to analyze each observational survey (100 min) as an individual sample unit. Behavioral data were collapsed from specific behaviors (~30) into relevant categories for pre-nesting, nesting, and brood rearing surveys. To assess the level of different disturbance factors in a given observational survey, we first measured the distance between each disturbance factor and each loon at every one-minute increment. To do this, paper maps with recorded locations were scanned into a digital format, and J Micro Vision image analysis software, with 100m gridlines as a reference, was used to measure each distance to the nearest meter. To account for variability in our ability to accurately map locations, particularly at increasing distances, we binned each specific minute of a disturbance observation into 1 of 6 distance categories: 0-75m, 75-150m, 150-300m, 300-600m, and 600 plus meters. Using these binned data, we assigned categorical levels to each survey for relevant disturbance factors, including motorboats, paddlers (canoes and kayaks), bald eagles, and non-pair loons. When disturbance factors were present in a limited number of surveys we only assigned levels of presence or absence. However, with well represented factors, such as motorboats, surveys were separated into more levels of relative disturbance. Some models were unbalanced when only a few surveys included a given disturbance factor. To account for this, we randomly selected an equal number of surveys without that disturbance factor for comparison. When we had multiple levels of disturbance we used non-parametric Kruskal Wallis to assess if levels of each disturbance type were correlated to percentage change in a loon behavior category. We used Wilcox statistical tests when only presence/absence was available for disturbance type. We calculated sequential Bonferroni (Holm 1979) significance levels for each group of tests that were drawn from the same data set. However, the use of Bonferroni procedures increases the risk of Type II error, accepting a false null-hypothesis, to unacceptable levels and their use is contradictory (Nakagawa 2004). To further elucidate specific associations between behaviors and disturbance factors, we used redundancy analysis with proportions of each behavior within a survey designated as the response variable and distance classified disturbances as predictors. We include the Bonferroni levels in our tabular data for the reader but advise interpreting standard p-values in conjunction with visual data representation from the redundancy analyses. Agreement between the redundancy analysis and univariate techniques suggests we are less likely to make a Type I error, rejecting a true null-hypothesis. Finally, we used analysis of variance techniques to analyze experimental data, looking at initial distance of behavioral response, departure distance at which loon returned to normal behavior, and total time of response behavior. All of the above analyses were performed in R statistical software. Data from Aziscohos was limited and we chose to compare it in tabular form, as statistical methods may have been invalid because of low sample sizes.

Results

Reproductive success- In 2007, 16 loon pairs established territories on Lake Umbagog and the nearby wetland and floating bog structures in the Magalloway and Androscogin rivers. Of these, 14 pairs attempted 18 nests (4 re-nesting attempts). Only 1 of the 18 nests successfully hatched 2 chicks, and all other nests failed. Within 5 weeks of hatching, both chicks from the only successful nest disappeared, leaving the total productivity of LUNWR at zero. In 2008, 17 pairs established territories at LUNWR. Of these, 9 pairs attempted 16 nests (7 re-nesting attempts) with 3 pairs successfully hatching 2 chicks each. Of the 6 chicks, only 1 survived to fledge. Four chicks were lost to unknown causes, and the fifth chick was observed being killed by an intruding male loon. These numbers follow the decreasing trend in productivity at LUNWR seen since the 2000 breeding season by refuge staff and reported in LPC annual reports (Fig. 4.3). Additional nests were located on nearby Long Pond (n = 1) and Round Pond (n = 1) in 2008 and included in the LUNWR dataset. The Round Pond nest was successful and fledged one chick, while the nest on Long Pond failed.

Survey effort- In 2007 we surveyed 16 territorial pairs for a cumulative total of 51 (3,605 min) pre-nesting surveys, 14 nesting pairs for 155 (14,846 min) nesting surveys, and one brood-rearing pair for 18 (1,718 min) brood-rearing surveys at the LUNWR study area and an additional five brood-rearing pairs for 32 (3,067 min) brood-rearing surveys on Aziscohos Lake. In 2008 we observed 16 territorial pairs for a cumulative total of 79 (7,298 min) pre-nesting surveys, nine nesting pairs for 57 (5,701 min) nesting surveys, and 4 brood-rearing pairs for 62 (6,040 min) brood-rearing surveys at the LUNWR study site. Additionally we observed four territorial pairs for a cumulative total of five (461 min) pre-nesting surveys, nine nesting pairs for 16 (1,602 min) nesting surveys, and 5 brood-rearing pairs for 11 (1,085 min) brood-rearing surveys on Aziscohos Lake. A total of 16 experimental nest approaches were completed in 2008. Additional experimental efforts were constrained by logistical difficulties in isolating territories from other disturbance factors during treatment (e.g., non-experimental entry of boats or bald eagles into the territory).

Pre-nesting behavior- Pre-nesting loons on Umbagog spent the majority of observed time foraging (49.0%) and drifting (23.5%). Of other observed behaviors, only swimming, preening, sleeping, and peering individually accounted for more than 0.5% of the pre-nesting loon's activity budget (Table 4.3). In surveys with motorboats present there was a significant ($W = 938$, $P = 0.077$) increase in the time a pre-nesting loon spent resting, a combination of the sleeping and drifting behavior (Table 4.4), but no difference ($P \geq 0.1$) in foraging, maintenance/preening, swimming, pair interactions, or response behaviors. When one or more non-pair loons were present in the survey we observed a significant ($W = 72$, $P = 0.035$) decrease in resting behaviors, and a highly significant ($W = 214$, $P< 0.001$) increase in response behavior (Table 4.5), but no significant ($P \geq 0.1$) change in foraging, maintenance/preening, swimming, or pair interaction behaviors. Redundancy analysis showed that the increases in alert posture, dive-swim, and swimming behaviors where associated with proximity of non-pair common loons, while drifting and sleeping where loosely associated with motorboat presence (Fig. 4.4). The spread of different territories within the redundancy data space suggests that there was not a strong territory effect on loon behaviors.

Nesting behavior- We focused on the primary nesting loon for nesting behavior analysis, meaning the loon that was actively nesting or at the closest proximity to its nest at any given time. During a survey, if the other adult switched positions with the primary nester we would note this in our survey and change focus to the new primary nesting adult. When possible, the secondary nesting loon's behavior was also recorded, but given the lack of time they spent within observational range, their behavior was not analyzed in conjunction with disturbance factors.

During observations at the LUNWR, the primary nesting loon spent an average of 67.3% of its time sitting quietly on the nest, 23.0% panting for thermoregulation while nesting, 2.8% off-nest drifting, 2.2% tending the nest (adding vegetation to the sides), and 1.0% rolling the eggs (Table 4.6). Other observed behaviors individually accounted for less than 1.0% of the primary nesting loon's activity. We only observed the secondary nesting adult 12.0% of total survey time. In that time they were primarily drifting, foraging, swimming, or preening (Table 4.7).

When 1 or more non-pair loons were present in the territory we observed a marginally significant increase in off-nest response (W = 168, P = 0.093) behaviors and a significant increase in off-nest relaxed behavior (W = 182, P = 0.031) (Table 4.8). We saw no difference ($P \geq 0.1$) in other behavior categories. When bald eagles were present in the survey we observed a significant (W = 115.5, P = 0.055) increase in off-nest response behavior and no difference ($P \geq 0.1$) in all other behavior categories (Table 4.9). We observed a significant ($P \leq 0.05$) increase in on-nest response behaviors under high levels of motorboat disturbance (Table 4.10). We found no difference ($P \geq 0.05$) in other behaviors at any level of motorboat disturbance. We observed a significant ($P \leq 0.05$) decrease in relaxed on-nest behavior, and a significant ($P \leq 0.05$) increase in on-nest response and off-nest response behaviors under high levels of kayak/canoe traffic when compared to no kayak/canoe traffic, but no difference between high to medium and medium to no kayak/canoe traffic levels (Table 4.11). We observed no difference ($P \geq 0.05$) in nest maintenance, relaxed off-nest, or foraging off-nest behaviors at any level of kayak/canoe disturbance.

Redundancy analysis showed a very clear separation of eagle, loon, and human disturbance factors (Fig. 4.5). All boats, including kayaks, canoes, fishing motor boats, and non-fishing motor boats, tended to be associated most with the on-nest head hung behavior. Intruding loons were associated with the swimming, drifting, wing-flapping, and alert posture behaviors, and bald eagles were associated with swimming, drifting, on-nest alert posture, and vocalizing wail behaviors. The spread of territories within the redundancy data space suggests that there was not a strong territory level effect on behavioral data.

Nesting disturbance factors- Within LUNWR during the nesting time period, the relative percent of observed disturbance factors varied across different distance categories. Within 0-75m the bald eagles accounted for the highest percent of disturbance at 28.32 %, followed by fishing motorboats, moose (*Alces alces*), kayaks, and non-pair loons (Fig. 4.6). However, at the 75-150m distance, fishing motorboats become the dominant disturbance factor with 29.83% of the observed total (Fig. 4.7). At the 150-300m distance, non-fishing and fishing motorboats together accounted for more than 69% of the observed disturbance (Fig. 4.8). Over the course of the 2007 and 2008 nesting periods we observed daily variation in the number of non-fishing motorboats, fishing motorboats, and canoe/kayak disturbances (Fig. 4.9). Each of the disturbance types show an initial peak coinciding with the Memorial Day weekend. Non-fishing motorboats show an additional peak in mid-June and a sustained increase following the highest levels during the 4th of July weekend. Fishing motorboats showed a greater spread of peak times beginning the first week of June and tailing off after the 4th of July weekend. Kayak/canoe traffic maintained steady low-levels throughout the early season with a sharp rise during the 4th of July weekend and continuing into the second week of July.

Within a day there was a change in relaxed loon nesting behavior over time with a noticeable decrease during the morning to early afternoon, and the highest levels of relaxed nesting in the later evening (Fig. 4.10). Conversely there is a trend of increased levels of fishing motorboats during that time, and a more generalized spread of non-fishing motorboats through the middle of the day (Fig. 4.10). Kayak and canoe use had high peaks mid-morning and mid-afternoon (Fig. 4.11). Non-pair loon intrusions were highest in the mid-morning, also coincided with the decrease in relaxed nesting behaviors (Fig. 4.12). Finally, bald eagles had a staggered presence in the morning and early afternoon with a sharp peak near the end of the day (Fig. 4.12).

Brood-rearing behavior- We focused on the primary brood-rearing loon for behavior analysis, meaning the loon that was actively caring for the chicks or at the closest proximity to a chick at any given time. In brood-rearing surveys with no disturbance factors present, the primary adult loon spent the majority of its time foraging, 35.68%, and drifting, 20.41% (Table 4.12). In 20.35% of observations the parent had a chick riding on its back or under wing, but only 2.42% of the observations documented the adult feeding the chick(s).

When non-pair loon(s) were present in a brood-rearing survey, we observed a significant ($W = 229$, $P = 0.033$) increase in maintenance behaviors such as preening or bathing; a highly significant ($W = 278$, $P < 0.001$) increase in response behaviors; and a significant decrease ($W = 99$, $P = 0.062$) in brood care (Table 4.13). In surveys with bald eagles present there was a significant ($W = 50.5$, $P = 0.052$) increase in response behavior from the primary brood-rearing loon (Table 4.14). Other behaviors did not change significantly. The only significant ($p \leq 0.05$) difference noted with motorboats was an increase in chick feeding at high levels of disturbance (Table 4.15). No difference was noted in chick feeding between medium to nonexistent levels of disturbance, or across any level for other behavior categories. When canoes/kayaks were present there was a significant ($W = 366.5$, $P = 0.023$) increase in response behavior (Table 4.16). There was no difference ($p \leq 0.05$) in other observed behavior categories.

Redundancy analysis showed that the alert posture, dive swim, and bill dipping response behaviors were associated with close proximity of non-pair loon(s) (Fig. 4.13). There was a less clear association with these response behaviors and paddlers and bald eagles, as well as the peering behavior and the tremolo call. Motorboats were most associated with adult foraging and chick feeding behaviors. The spread of points representing territories shows some pattern, with many of the River Junction territory points associated with motorboat, paddler, loon, and eagle factors in the upper left quadrant. This suggests that there may have been a territory effect on these results with disturbance factors highly represented within one territory.

Aziscohos data: Tabular data from Aziscohos surveys showed similarities to significant results found at LUNWR. Nesting loons exhibited the nest head hung behavior in the presence of canoes, kayaks, and motorboats, and various response behaviors in the presence of bald eagles (Table 4.17). Brood-rearing loons showed some response to recreationists with vocal wails and alert posture. When non-pair loons were present they exhibited several response behaviors such as alert posture, bill dipping, splash dive, and yodeling. When eagles were near they again vocalized by wailing and displaying the alert posture (Table 4.18).

Experimental approach- In the experimental nest approaches we found a significant difference (F(3,10) = 51.87, P = <0.001) in initial response time between different nesting territories, but no difference (F(3,10) = 0.10, P = 0.96) based on boat type used (Table 4.19). We also found a significant difference (F(3,10) = 3.59, P = 0.05) in total time of behavioral response between different nesting territories, but no difference (F(3,10) = 0.32, P = 0.81) between boat type used (Table 4.20). However, the departure distance at which loons returned to normal behavior was significantly different between boat types (F(3,10) = 4.12, P = 0.04) but not between territories (F(3,10) = 0.75, P = 0.55) (Table 4.21).

Discussion

As recreational use continues to increase throughout the range of common loons, it has become imperative to assess the potential affect that this disturbance plays in the continuing decline of loon populations and productivity. Despite numerous research efforts to elucidate natural and anthropogenic disturbances of common loons, there has been little quantification of the resulting specific behavioral effects. Our detailed behavioral quantification of each stage of the breeding season will be helpful to managers attempting to develop best management plans to conserve increasingly threatened loon populations. The data from other lakes, while not abundant, allow us to infer a regional disturbance effect and generalize our recommendations to some degree.

As recreational activity at LUNWR and across all of New Hampshire has continued to increase (SCORP 2007), it is not surprising that both fishing and non-fishing motorboats were present at all stages of the loon breeding cycle. Our data show that the presence of these recreational vehicles is associated with significant loon behavioral changes. In the pre-nesting stage, the increase in time spent "resting" in the presence of motorboats reflects field observations that loons seemed to come to the surface and drift whenever a boat approached. Thus, we may not consider this actual rest even though we originally categorized drifting as resting. This behavior likely allows them to clearly assess the situation and determine if an evasive response is needed. Likewise, when nesting, loons most commonly lowered themselves into the "head hung over nest" position as motorboats approached. This was reflected in both the observational and experimental results. This behavior lowers their visibility, hiding their white breast, and also places them in a position to slide secretively into the water if needed without betraying the nest location (McIntyre 1988). This behavioral response to boats was seen in surveys on Aziscohos lake as well. The increase in chick feeding in the presence of motorboats is less self-explanatory. It is likely a coincidence between the timing of heavy recreational boat use and chick feeding, possibly influenced by a single pair (the River

Junction pair; Fig. 4.1) which saw significantly more boating during the brood-rearing stage, but also fed their chicks much more than other pairs. Anecdotally, we observed wheezing from these chicks on two occasions when close enough to hear them breathe. An illness may have caused them to eat less, leaving the parents presenting the fish for longer time periods. Although previous research indicates some amount of contradiction as to whether boating has a significantly negative effect on the productivity and population status of nesting common loons, and it is difficult to definitively identify the causative agents, our data indicate that at the very least recreational boating is significantly altering the behavior of loons at LUNWR.

Canoe and kayak traffic was less prevalent than motorized boats at LUNWR, but still associated with significant changes in loon behavior. Although present throughout the summer, the majority of paddlers used the lake during the first two weeks of July. This coincides with an active period of the breeding season, with some eggs from early nests beginning to hatch and other nests just being established. Although recreationists commonly think that canoe and kayak use is less disturbing to wildlife (pers. obs.), these data suggest otherwise. Not only was there an increase in on-nest response behavior, but also an increase in off-nest response. The increase in off-nest response behavior is particularly important because when adults are off the nest, loon eggs are easy targets for opportunistic predators (Evers 2004).

While anthropogenic disturbances are definitely altering the behavior of common loons at LUNWR, natural disturbances appear to have a significant effect as well. Loons are territorial and actively defend a nesting area. When non-pair loons are present in the territory, the behavioral differences are noticeable, with pre-nesting loons showing both an increase in drifting and response behaviors. This is typical in loon territorial defense with established pairs defending the limited nesting resources available (Piper et al. 2008). Non-pair loons continue to be an important disturbance factor in the nesting stage with increases in response behaviors and time off nest, as well as the brood-rearing stage with decreases in brood care and self maintenance, and an increase in response behaviors.

Bald eagles are a second source of natural disturbance at LUNWR. They are known to attack incubating loons (Miller 1988, Vlietstra and Paruk 1997; but see Evers 2004) and are considered a primary loon chick predator (Kenow et al. 2003, Evers 2004). Bald eagles generally elicit a vocal and agitated response from adult loons, especially those accompanied by chicks (Evers 2004), and in fact some of the most exaggerated responses exhibited by loons that we observed occurred when eagles were in the vicinity. This was evident in the data with the increased off-nest response behavior during the nesting period and the increase of response behaviors in brood-rearing adults. Response to numerous other bird and mammal species were observed, but were insignificant.

Although our statistical analyses are limited to the LUNWR, we feel that it is likely that similar behavioral responses occur on other lakes in the area. Tabular data from surveys on Aziscohos show that loons responded in a similar fashion to the LUNWR pairs. In our opinion, the loons on Aziscohos appeared to have more severe reactions to motorboats and paddlers, likely due to the limited traffic seen in comparison to Umbagog, and thus a lack of acclimation. Further research on lakes that vary in their levels of disturbance is warranted; however, our results suggest that behavioral responses may be similar, if of varying intensities. Currently we are implementing our research strategy on the Quabbin Reservoir in Massachusetts to assess behavioral responses and make comparisons to LUNWR and Aziscohos Lake.

Given the quantification of disturbance effects, the next logical step is to determine what those behavioral changes mean for loon populations. There have been numerous studies suggesting that water-related recreational activities cause waterfowl to use sub-optimal nesting habitat or to abandon nests after eggs have been laid (Anderson 1995). In an analysis of LUNWR's spatial disturbance factors, we validate this for the common loon, showing that nest site selection is influenced by human disturbance (McCarthy 2009). Here, however, we are viewing behavior patterns at a finite level, and interpreting the effect on loon productivity requires inductive reasoning.

The term 'ecology of fear' was formalized by Brown et al. (1999) to describe systems where populations maybe limited by the 'fear' of predation resulting in loss of feeding opportunities. In fact, non-lethal consequences have been described for predator-prey dynamics in birds as potentially having a greater negative effect than lethal events (Cresswell 2008). Studies of human disturbance to wildlife have also documented widespread non-lethal effects that result in avoidance (Sutherland 1996, Gill et al. 2001). One of the most important characteristics of these non-lethal effects is that they are not limited to the functional response of the predator (Creswell 2008). In our case, the "predator" is a role being filled either by a true predator such as the eagle, or by recreational boaters invoking anti-predator behavioral responses from loons.

In the present research, given an increase in atypical behaviors, we can safely say that there must be a subsequent decrease in typical behaviors. By engaging in anti-predator behaviors birds will often reduce their opportunity to engage in other activities

(Creswell 2008), which means that behavioral responses to predation risk will not change independently of foraging effort or fecundity, but, rather, there will be a trade-off effect. Although we have not specifically measured this indirect effect, it is likely playing a role in loon population dynamics at LUNWR and may be contributing to the local decrease in productivity.

In addition to the indirect effects discussed above, nesting loons suffer direct punctuated disturbance events in which a nest or young are abandoned. By a punctuated disturbance event, we mean periodic but relatively rare events that seemingly occur at random. These events can be intense enough to cause a major disturbance but may go undetected due to limited occurrences. During the course of our observations we witnessed several such events and, although they were too few to analyze statistically, they are well worth noting anecdotally. For example, one loon nest was observed being repeatedly approached by a fishing boat on which a large man was standing on the bow wearing a loose poncho that was flapping wildly in the wind. The loon finally left the nest and the territory, and in subsequent daily checks the loons were never observed in the vicinity of the nest. Two undamaged eggs were later found cold and undisturbed on the nest. In another instance an intruding adult loon was observed killing a small chick and subsequently taking over the territory. Finally, a remote video camera captured an immature eagle preying on an incubating egg while the adult loon repeatedly exhibited off-nest response behaviors while swimming back and forth in front of the nest (McCarthy in prep). Throughout the two field seasons, similar events were also commonly observed and likely led to direct nest failure or chick loss.

As a whole there appeared to be several synergistic disturbance factors at LUNWR acting to alter the behavioral pattern of nesting common loons, both anthropogenic and natural. Natural disturbance is perhaps most characterized by bald eagle interactions. Eagle populations are increasing throughout the northeast due to extensive recovery efforts, and currently four pairs have established nest sites around the lake. As a major predator of loons, the increasing numbers of bald eagles in the area may be related significantly to the ongoing decline of loons in the region. The intense behavioral response of loons to bald eagles indicated that at the very least, interactions with eagles are an increasing source of stress. The second source of natural disturbance at LUNWR is the apparent intensification of interactions with non-pair loons. With an increase in failed loon nests, there is evidence of an increase in the number of marauding loons entering established territories subsequent to the failure of their own nests. These loons are no longer defending their own territories and appear to be roaming widely around the lake. Nesting or brood-rearing loons are then forced to defend their chicks and territories. Anthropogenically, as a recently formed National Wildlife Refuge, LUNWR may be attracting more recreational boaters than were present before establishment. Our data suggest that both motorized and non-motorized recreational boats are creating significant behavioral changes among common loons. Further, according to local anglers, the fishery has changed from a salmonid to micropterus (bass) based system, necessitating a shift in techniques from deeper water fishing to near shore fishing. Finally, all of this means that nesting loons are concurrently experiencing an increase in both adult and immature eagles, more intrusions of non-pair loons, higher numbers of recreational boaters, and fishing at closer proximities.

Management Implications

There are two distinct groups of disturbance as presented: one is the human derived facet composed of recreational boat use, and the second is the natural component, composed of bald eagle presence and intrusion of non-pair loons. While these data cannot indicate that one or more of these factors is responsible for the population decline or decrease in productivity of loons at LUNWR, our data do indicate that there is a significant behavioral response and provide a starting place for managers in the development of initiatives to reduce the effect of disturbance on breeding common loons. In order to mitigate the effect of these disturbance factors, managers must attempt to limit the level of a given factor's presence within close proximity to loons during the breeding cycle. For non-pair loon intrusions this may be synergistic with an increase in breeding success, as loons would continue to defend nesting territories as long as their nests remain viable. Bald eagles are obviously a natural predator with which loons have evolved, but, with other pressures limiting loon success, it may be pertinent to limit the effect of increasing eagle pressure. This may necessitate the use of protective shelters over existing nests, or the use of nesting rafts with a protective mesh cover (Piper et al. 2002, DeSorbo et al. 2008). Perhaps most easily addressed are the anthropogenic disturbances. Based on our experimental results all 4 watercraft evoked initial behavioral response at a fairly standard distance. The average response distance of 218m from the nest may be a good starting point for limiting boat traffic through the use of signs and barrier floats. Given that the maximum response distance was 358m this would not preclude all response, but would limit the extremely close encounters in which a punctuated disturbance event might occur. If a 218m buffer had been placed around all active loon nests at LUNWR during the 2007 breeding season, it would exclude only 5.1% of the available water surface area from recreational use; a buffer of 358m would exclude 12.2% (Figure 14). Additional experimental approaches are warranted for lake specific determination of appropriate buffer distances in other areas. Buffering nests from recreational boating removes only a small portion of the lake from use, and will likely be easily accepted as eagle nests and some loon nest have been roped off previously.

Although the above results are aimed specifically at management for LUNWR, information incorporated from multiple lakes in the region allows these data to be applicable on a larger scale. While it appears that the declining population and productivity of common loons may not be attributable to a single factor; natural and anthropogenic disturbances have the potential to induce significant behavioral responses that may be detrimental to loons during the breeding season. As recreational use of protected areas expands in North America, managers will increasingly be faced with decisions as to how to maintain wildlife populations and balance interactions with recreators. The present data provides basic guidelines as to major disturbance factors for common loons, and suggestions for their amelioration.

Table 4.1. Behavioral categories, codes, and descriptions used to explain observed common loon behavior on LUNW R and Azicohos lake, ME.

Category	Code	Description
Foraging	AF	Adult Foraging
	CF	Chick Foraging
	PE	Peering (head in water, body above water)
Maintenance	PR	Preening
	BT	Bathing (beyond simple preening, flipping upside down etc)
Resting	DR	Drifting
	FW	Foot is above water and shaken
	WF	Wing Flap Body raised and wings extended
	YA	Yawning (extending neck with bill opening and closing while pointing skyward)
Swimming	SW	Swimming
Response on-nest	NH	Nest Sitting / Head Hung Over in Low Position
	NA	Nest Sitting / Alert Posture (neck extended)
	ND	Nest Departure / Loon leaves nest in response to intrusion
Response off-nest	PD	Penguin Dancing (body vertical, wings tucked, bill ahead or down

	RU	Rushing (moving rapidly across water using wings and feet)
	AP	Alert Posture (Neck extended up, high in water)
	SD	Splash Dive (kick upward while diving creates splash / intrusion response)
	DS	Dive swim (loon quickly dives and resurfaces in response to disturbance)
	BD	Bill Dipping (bill dipped rapidly in water and then flicked to one side)
	HS	Head Shake (back and forth movement of head more than one time)
	HR	Head Rub (rolling top of head)
	VW	Vocalizing Wail
	VT	Vocalizing Tremolo
	VY	Vocalizing Yodel
Brood-rearing	BB	Back Riding (adult is attending young with chick(s) on back
	BU	Brooding Chicks Under-wing (adult is attending young with chick(s) under-wing)
	BS	Brooding while Swimming (adult attending young / adult and chicks are swimming)
	BD	Brooding while Drifting (adult attending young / adult drifting)

	BP	Brooding while Preening (adult attending young / adult preening)
Chick Feeding	FC	Adult Feeding Chick(s)
Pair interactions	CS	Courtship (synchronous formalized bill dipping)
	VH	Vocalizing Hoot
Relaxed on-nest	NC	Nest Sitting Content
	NP	Nest Sitting / Panting (thermoregulation)
	NS	Nest Sitting / Sprawl (sprawled low for thermoregulation)
Nest maintenance	NB	Nest Building
	NT	Nest Sitting / Tending nest (rearranging nest material)
	NE	Nest egg rolling

Table 4.2. Disturbance codes, and descriptions used to explain observed disturbance on LUNW R and Azicohos lake, ME.

Code	Description	Code	Description
Human Disturbances		**Wildlife Disturbances**	
FM	Fly Fishing Motor Boats	AC	American Crow
FK	Fly Fishing Kayaks	CR	Common Raven
FC	Fly Fishing Canoes	RG	Ring-billed Gull
SM	Spin Fishing Motor Boats	BE	Bald Eagle
SK	Spin Fishing Kayaks	OS	Osprey
SC	Spin Fishing Canoes	OA	Other Avian Species
NM	Non-Fishing Motor Boats	RC	Raccoon
NK	Non-Fishing Kayaks	FX	Fox
NC	Non-Fishing Canoes	MK	Mink
SC	Sport Watercraft	OM	Other Mammal
MV	Motor Vehicle		
AT	All Terrain Vehicle		
AP	Airplane Overhead		

Table 4.3. Common loon pre-nesting territorial pair behavior in the absence of disturbance factors on Lake Umbagog NWR.

Behavior	Percent Observed
Foraging	48.99%
Drifting	23.53%
Swimming	6.89%
Preening	6.73%
Sleeping	6.27%
Peering	4.18%
Alert posture	0.46%
Courtship	0.46%
Head rub	0.46%
Nest initiating	0.39%
Foot waggle	0.31%
Wing flap	0.31%
Dive swim	0.15%
Nest building	0.08%
Rushing	0.08%
Vocalizing wail	0.08%

Table 4.4. Behavior profile of pre-nesting territorial loon pairs in the presence and absence of motorboat traffic on Lake Umbagog NWR.

	Motorboats Absent	Motorboats Present	Wilcox W n1=n2=39	Wilcox p-Value	Sequential Bonferroni
Foraging	56.44%	49.47%	628	0.187	0.02
Maintenance/preening	6.26%	6.28%	847.5	0.379	0.025
Resting	22.30%	28.90%	938	0.077	0.017
Swimming	17.69%	11.45%	681	0.427	0.033
Pair interactions	0.23%	0.15%	743.5	0.739	0.05
Response behavior	10.06%	3.75%	776	0.878	0.1

Table 4.5. Behavior profile of pre-nesting territorial loon pairs in the presence and absence of non-pair loons in surveys on Lake Umbagog NWR.

	Loon Absent	Loon Present	Wilcox W n1=n2=16	Wilcox p-Value	Sequential Bonferroni
Foraging	49.25%	35.79%	89.5	0.152	0.033
Maintenance/preening	8.51%	4.95%	121	0.804	0.1
Resting	29.37 %	17.45%	72	0.035	0.02
Swimming	18.42%	25.06%	160	0.234	0.05
Pair interactions	0.12%	1.03%	153	0.144	0.025
Response behavior	3.55%	15.72%	214	0.001	0.017

Table 4.6. Behavior profile of primary nesting common loon from in absence of disturbance factors onLake Umbagog NWR.

Behavior	Percent Observed
On-nest quiet	67.33%
On-nest panting	23.02%
Drifting	2.76%
Nest tending	2.23%
On-nest egg rolling	1.03%
On-nest sleeping	0.70%
Nest building	0.64%
Nest alert	0.52%
Foraging	0.52%
On-nest head hung	0.52%
Swimming	0.19%
Preening	0.17%
Nest departure	0.11%

Table 4.7. Behavior profile of off- nest common loon from nesting pair (visible 12% of total survey time) on Lake Umbagog NWR.

Behavior	Percent Observed
Drifting	33.83%
Foraging	17.08%
Swimming	17.08%
Preening	13.07%
Sleeping	4.14%
Peering	3.93%
Nest building	2.27%
Alert posture	1.70%
Dive swim	1.65%
Head rub	1.32%
Wing flap	0.79%
Bill dip	0.62%
Bathing	0.45%

Table 4.8. Nesting loon behavior profile (proportion of time spent) when non-pair loon(s) are present and absent in surveys on Lake Umbagog NWR.

	Loon Absent	Loon Present	Wilcox W n1=n2=16	Wilcox p-value	Sequential Bonferroni
Relaxed behavior on-nest	87.13%	81.58%	73.5	0.041	0.02
Nest maintenance behavior	4.52%	2.73%	130	0.955	0.5
Relaxed off-nest behavior	1.72%	5.56%	182	0.031	0.017
Foraging off-nest	0.19%	1.76%	163	0.113	0.033
Response behavior on-nest	4.13%	4.90%	127	0.985	0.1
Response behavior off-nest	0.31%	1.95%	168	0.093	0.025

Table 4.9. Nesting loon behavior profile with eagle presence and absence in surveys on Lake Umbagog NWR.

	Eagle Absent	Eagle Present	Wilcox W n1=n2=39	Wilcox p-value	Sequential Bonferroni
Relaxed behavior on-nest	84.60 %	77.61%	67	0.382	0.033
Nest maintenance behavior	4.23%	10.23%	76.5	0.689	0.1
Relaxed off-nest behavior	1.15%	2.77%	98	0.415	0.05
Foraging off-nest	0.08%	0.31%	104	0.156	0.02
Response behavior on-nest	3.08%	5.31%	102.5	0.361	0.025
Response behavior off-nest	0.15%	2.54%	115.5	0.055	0.017

Table 4.10. Nesting loon behavior profile in the presence of high, medium, low, and no motorized boat traffic on Lake Umbagog NWR.

	High		Medium		Low		None	
	n =33		n = 42		n = 46		n = 86	
Relaxed behavior on-nest	82.81%	a	88.27%	a	83.94%	a	85.58%	a
Nest maintenance behavior	3.01%	a	4.20%	a	6.51%	a	4.21%	a
Relaxed off-nest behavior	3.70%	a	2.44%	a	2.95%	a	3.19%	a
Foraging off-nest	0.45%	a	0.40%	a	0.61%	a	0.42%	a
Response behavior on-nest	7.40%	a	2.72%	b	4.00%	b	2.17%	b
Response behavior off-nest	0.90%	a	1.03%	a	0.60%	a	0.82%	a

Different lower case letters indicate significant difference based on Kruskal Wallis test.

Table 4.11. Nesting loon behavior profile in the presence of high, medium, and no kayak/canoe traffic on Lake Umbagog NWR.

	High n = 22		Medium n = 20		None n = 165	
Relaxed behavior on-nest	73.55%	a	78.97%	ab	87.55%	b
Nest maintenance behavior	6.20%	a	7.14%	a	3.94%	a
Relaxed off-nest behavior	7.01%	a	3.07%	a	2.56%	a
Foraging off-nest	1.16%	a	0.90%	a	0.32%	a
Response behavior on-nest	6.91%	a	4.43%	ab	3.10%	b
Response behavior off-nest	1.97%	a	0.73%	ab	0.69%	b

Different lower-case letters indicate significant difference based on Kruskal Wallis test.

Table 4.12. Common loon primary brood-rearing adult behavior in the absence of disturbance factors on Lake Umbagog NWR and nearby Round Pond.

Behavior	Percent Observed
Foraging	35.68%
Drifting	20.41%
Chick on back	15.50%
Swimming	12.74%
Chick under wing	4.85%
Peering	3.72%
Feeding chick	2.42%
Sleeping	1.80%
Preening	1.35%
Wing flap	0.39%
Wail	0.28%
Tremolo	0.23%
Foot Waggle	0.17%
Foot waggle	0.11%

Table 4.13. Primary brood-rearing loon behavior profile (proportion of time spent) when non-pair loon(s) are absent and present in surveys on Lake Umbagog NWR.

	Loon Absent	Loon Present	Wilcox W n1 =n2 = 18	Wilcox p-value	Sequential Bonferroni
Foraging	42.67%	37.78%	132	0.351	0.025
Maintenance	2.09%	3.42%	229	0.033	0.03
Resting	18.56%	22.28%	182	0.542	0.05
Swimming	16.42%	14.64%	150.5	0.729	0.1
Response	2.10%	11.95%	278	< 0.001	0.014
Brood care	26.88%	4.28%	99	0.021	0.017
Chick feeding	2.98%	4.86%	183.5	0.506	0.033

Table 4.14. Primary brood-rearing loon behavior profile with eagle presence and absence in surveys on Lake Umbagog NWR.

	Eagle Absent	Eagle Present	Wilcox W n1 =n2 = 8	Wilcox p-value	Sequential Bonferroni
Foraging	31.15%	37.53%	39	0.505	0.025
Maintenance	3.35%	2.09%	27.5	0.673	0.033
Resting	22.12%	21.48%	34	0.879	0.1
Swimming	11.49%	12.76%	34	0.878	0.05
Response	2.61%	7.56%	50.5	0.052	0.014
Brood care	32.90%	10.65%	19	0.148	0.02
Chick feeding	2.82%	7.65%	48	0.105	0.017

Table 4.15. Primary brood-rearing loon behavior profile in the presence of high, medium, and no motorboat traffic on Lake Umbagog NWR.

	High		Medium		None	
Foraging	39.13%	a	24.77%	a	37.92%	a
Maintenance	1.92%	a	2.90%	a	2.26%	a
Resting	23.58%	a	19.02%	a	21.43%	a
Swimming	9.75%	a	11.61%	a	14.93%	a
Response	5.22%	a	3.86%	a	3.87%	a
Brood care	11.30%	a	34.89%	a	15.73%	a
Chick feeding	8.35%	a	2.18%	b	3.30%	b

Different letters within rows indicate significant difference based on Kruskal Wallis test.

Table 4.16. Primary brood-rearing loon behavior profile with canoe/kayak presence and absence in surveys on Lake Umbagog NWR.

	Paddlers Absent	Paddlers Present	Wilcox W n1 =n2 = 23	Wilcox p-value	Sequential Bonferroni
Foraging	36.62%	32.83%	244.5	0.668	0.025
Maintenance	2.35%	2.25%	235.5	0.524	0.02
Resting	21.74%	20.48%	254	0.826	0.033
Swimming	12.95%	13.93%	232	0.482	0.017
Response	3.12%	6.67%	366.5	0.023	0.014
Brood care	19.00%	17.87%	270	0.901	0.05
Chick feeding	3.65%	5.15%	266.5	0.974	0.1

Table 4.17. Total minutes in specific behaviors of primary nesting loons in the presence of disturbance factors on Aziscohos Lake, ME.

Behavior	Bald Eagle n = 7	Common Loon n = 4	Canoe/Kayak n = 42	Motorboat n = 40
Nest alert	2	-	-	-
Nesting content	4	1	13	15
On-nest head-hung	-	-	13	17
On-nest panting	-	3	14	8
Rush	1	-	-	-
Swim	-	-	2	-

Table 4.18. Total minutes in specific behaviors of primary brood-rearing loons in the presence of disturbance factors on Aziscohos Lake, ME.

	Bald eagle n = 28	Common loon n = 131	Canoe/ kayak n = 49	Motorized boat n = 279
Foraging	3	2	7	29
Alert posture	5	17	1	7
Chick on back	6	7	6	34
Bill dipping	0	15	0	2
Bathing	0	0	0	2
Chick under wing	0	0	0	4
Drifting	7	31	12	92
Dive Swim	0	17	0	0
Feeding chick	1	1	1	9
Foot waggle	0	0	0	1
Head rub	0	0	0	2
Peering	0	2	1	13
Preening	0	0	0	19
Swimming	0	32	17	57
Rushing	0	1	0	0
Splash dive	0	2	0	0

Tremolo	0	0	1	2
Wail	6	0	3	3
Yodel	0	2	0	0
Wing flap	0	2	0	3

Table 4.19. Initial behavioral response distance in meters of nesting common loons to experimental approaches on Lake Umbagog, NWR. Each approach consisted of slowly moving to within 100 m, stopping for 5 min, then slowly departing.

	Nesting Territory				
Treatment	Stateline	Upper Magalloway	Leonard Inlet	Bear Island	Mean
Gas Motor	315	no response	183[b]	94	197
Electric Motor	324[a]	308	99	no response	244
Kayak	296	272	177	90	209
Canoe	358	266[b]	162	101	222
Mean	323	282	155	95	218

a Loon left nest at end of treatment

b loon left nest during treatment

Table 4.20. Total behavioral response time in 20 second increments of nesting common loons to experimental approaches on Lake Umbagog, NWR. Each approach consisted of slowly moving to within 100 m, stopping for 5 min, then slowly departing.

	Nesting Territory				
Treatment	Stateline	Upper Magalloway	Leonard Inlet	Bear Island	Mean
Gas Motor	35	no response	33[b]	21	30
Electric Motor	49+23[a]	20	20	no response	37
Kayak	35	19	34	20	27
Canoe	34	25[b]	32	20	28
Mean	44	21	30	20	30

a on-nest response time + off-nest time

b loon left nest during treatment

Table 4.21. End behavioral response distance in meters of nesting common loons to experimental approaches on Lake Umbagog, NWR. Each approach consisted of slowly moving to within 100 m, stopping for 5 min, then slowly departing.

	Nesting Territory				
Treatment	Stateline	Upper Magalloway	Leonard Inlet	Bear Island	Mean
Gas Motor	459	no response	602[b]	358	473
Electric Motor	316[a]	196	213	no response	242
Kayak	325	189	235	169	230
Canoe	273	404[b]	294	101	268
Mean	343	263	336	209	295

a Loon left nest at end of treatment

b loon left nest during treatment

Figure 4.1. Lake Umbagog and Aziscohos Lake, study areas for analysis of common loon behavior in response to disturbance.

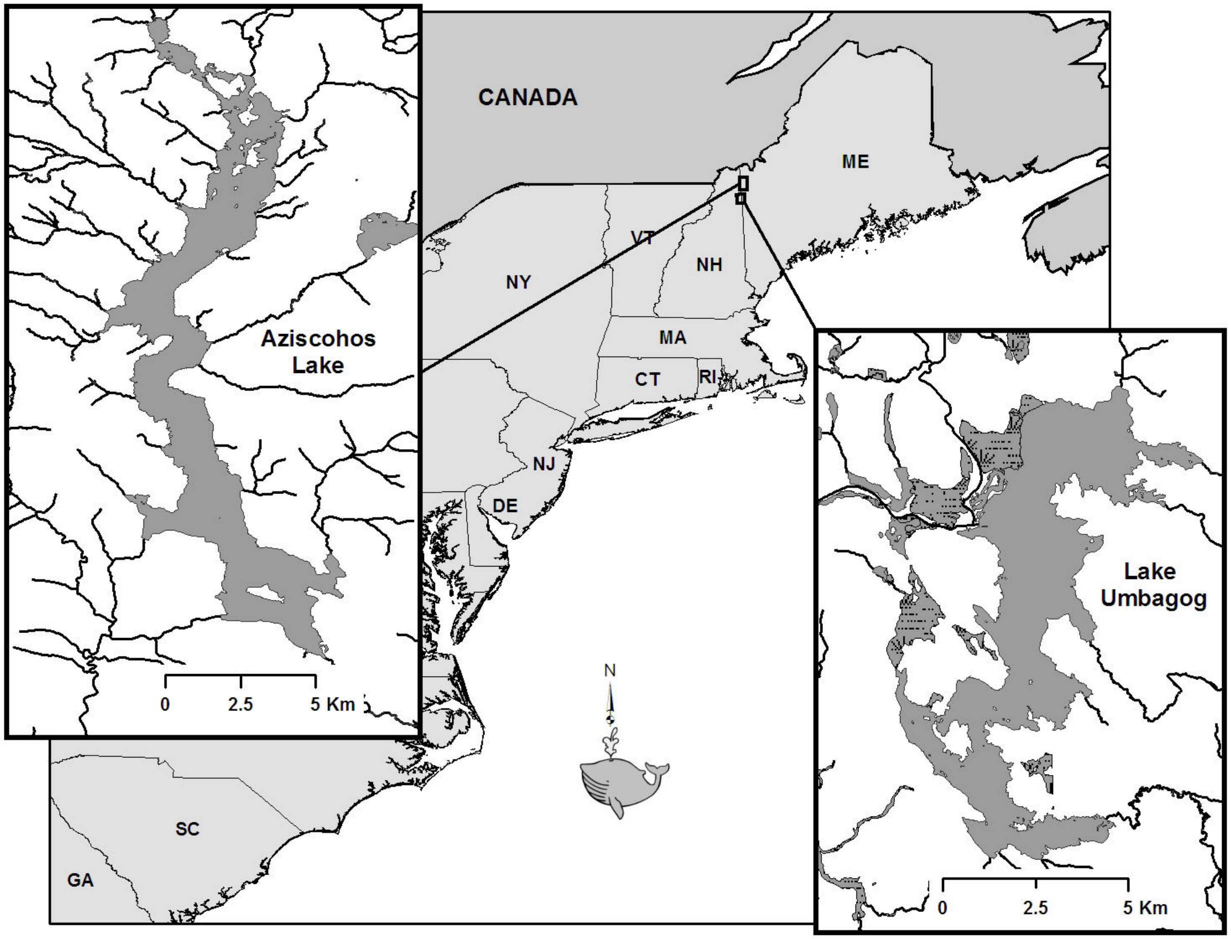


Figure 4.2. Observed nesting pairs and chicks hatched on Lake Umbagog, from 1995 – 2006. Data from the Loon Preservation Committee’s annual “Lake Umbagog Loon Population and Management Report” and from Lake Umbagog National Wildlife Refuge.

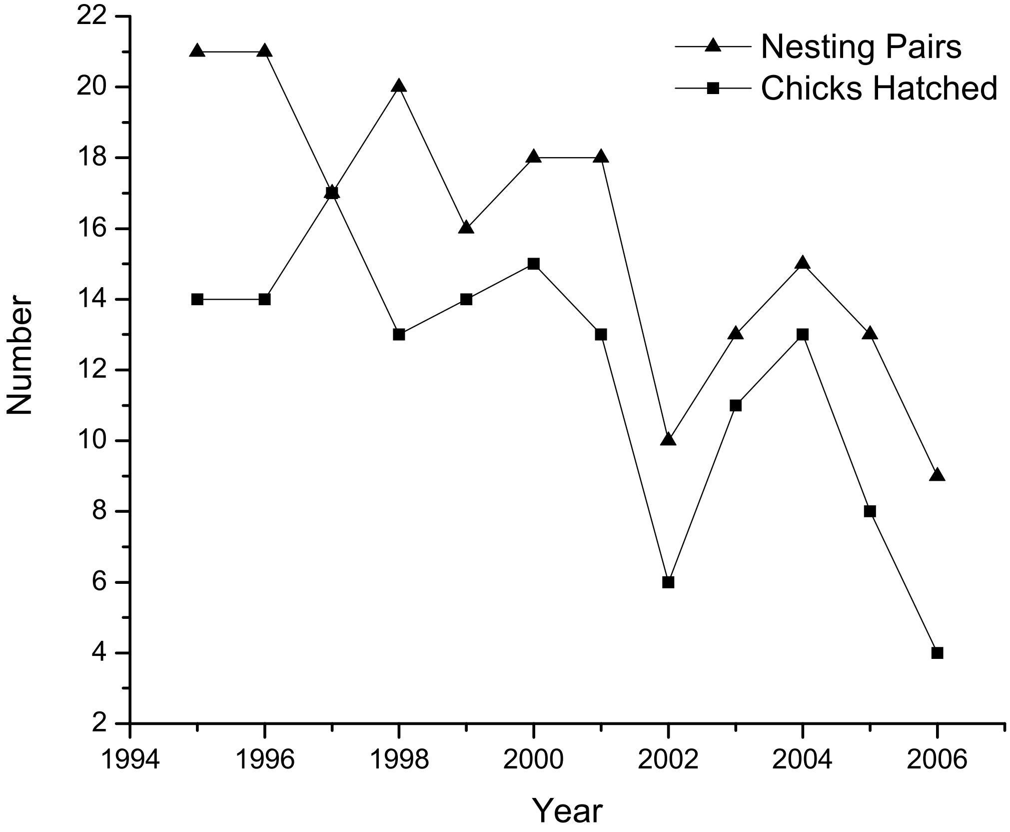


Figure 4.3. Historical breeding status of the common loon on Lake Umbagog from 2000 to 2008. Data from the Loon Preservation Committee's annual "Lake Umbagog Loon Population and Management Report" and from Lake Umbagog National Wildlife Refuge.

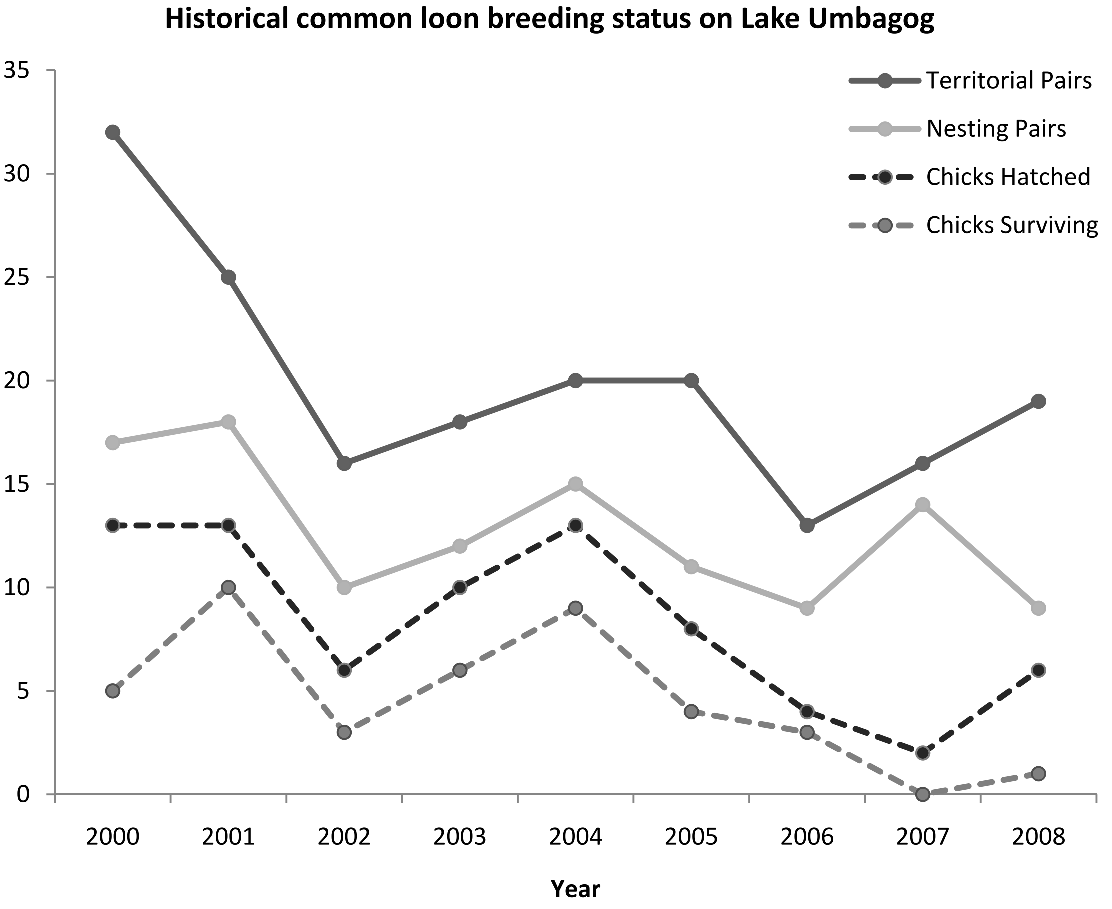


Figure 4.4. Redundancy analysis tri-plot with significant overall model (p = 0.02) showing first two gradients, RDA1 and RDA2. Survey sites are separated by territory via color. Behavior variables SW = swimming, DR = drifting, AF = foraging, PR = preening, AP = alert posture, SL = sleeping, BD = Bill dip, and DS = dive swim. Other behaviors are insufficiently separated to assess effects. Disturbance variable MB = motor boat, CL = common loon. Postscripts A, B, C, and D indicate distance bins of 0-75m, 75-150m, 150-300m, and 300-600m respectively.

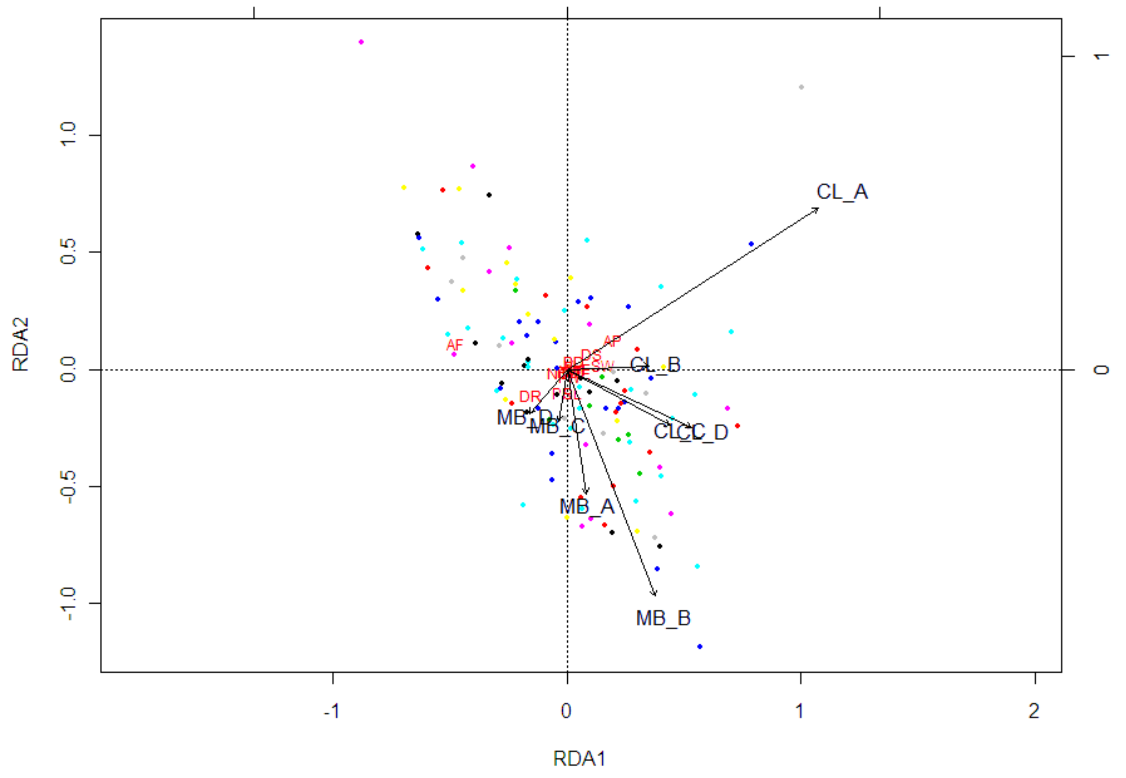


Figure 4.5. Redundancy analysis tri-plot with significant ($p < 0.05$) axes 1 and 2. Survey sites are separated by territory via color. Behavior variables SW = swimming, DR = drifting, NH = nest head hung, NA = nest alert, VW = vocalizing wail, AP = alert posture, WF = wing flap, BD = Bill dip, and DS = dive swim. Other behaviors are insufficiently separated to assess effects. Disturbance variable BE = bald eagle, CL = common loon, SM = fishing motor boat, NM = non-fishing motor boat, NK = Kayak, and NC = Canoe. Postscripts A, B, and C indicate distance bins of 0-75m, 75-150m, and 150-300m respectively.

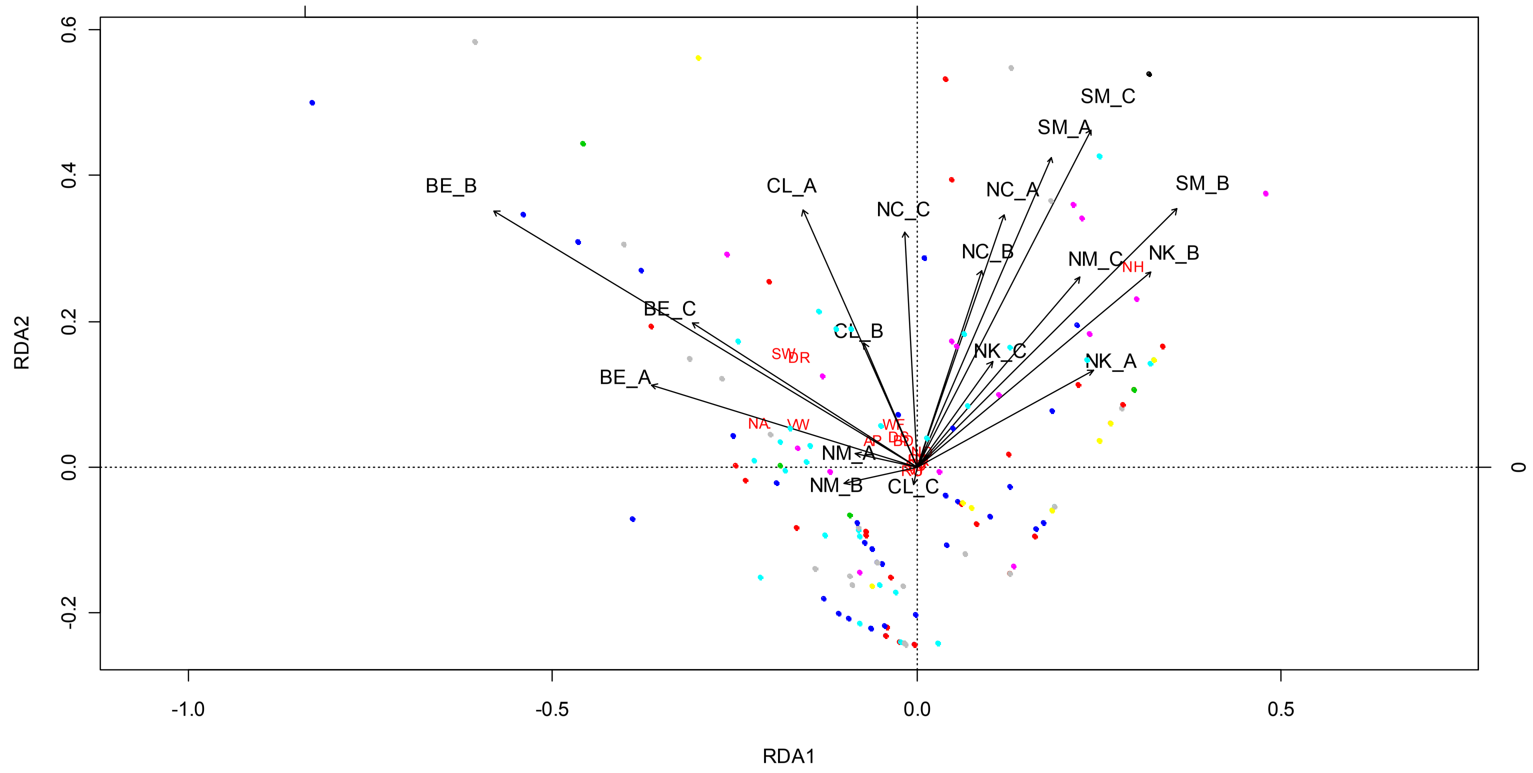


Figure 4.6. Percent disturbance type observed within 0-75 meters of nesting loon, 512 total observations, Lake Umbagog NWR.

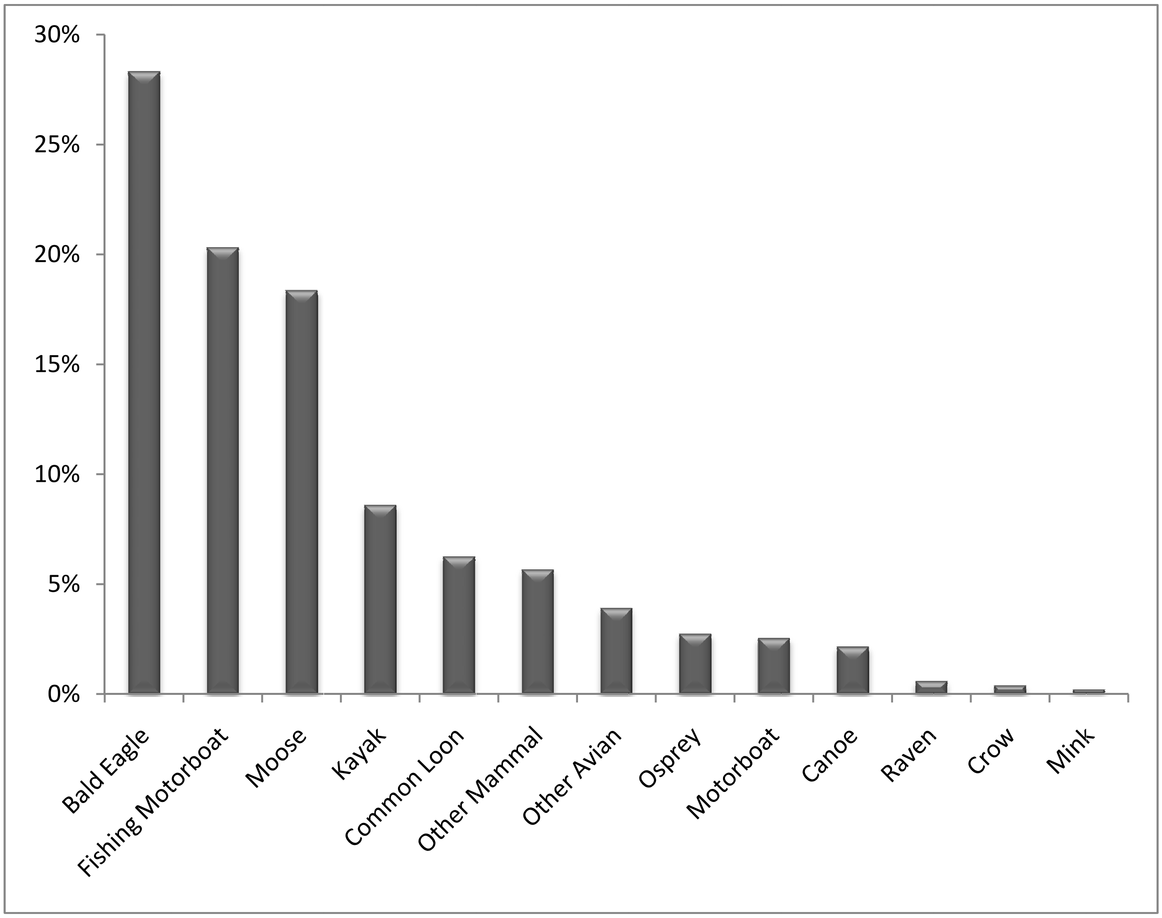


Figure 4.7. Percent disturbance type observed within 75-150 meters of nesting loon, 476 total observations, Lake Umbagog NWR.

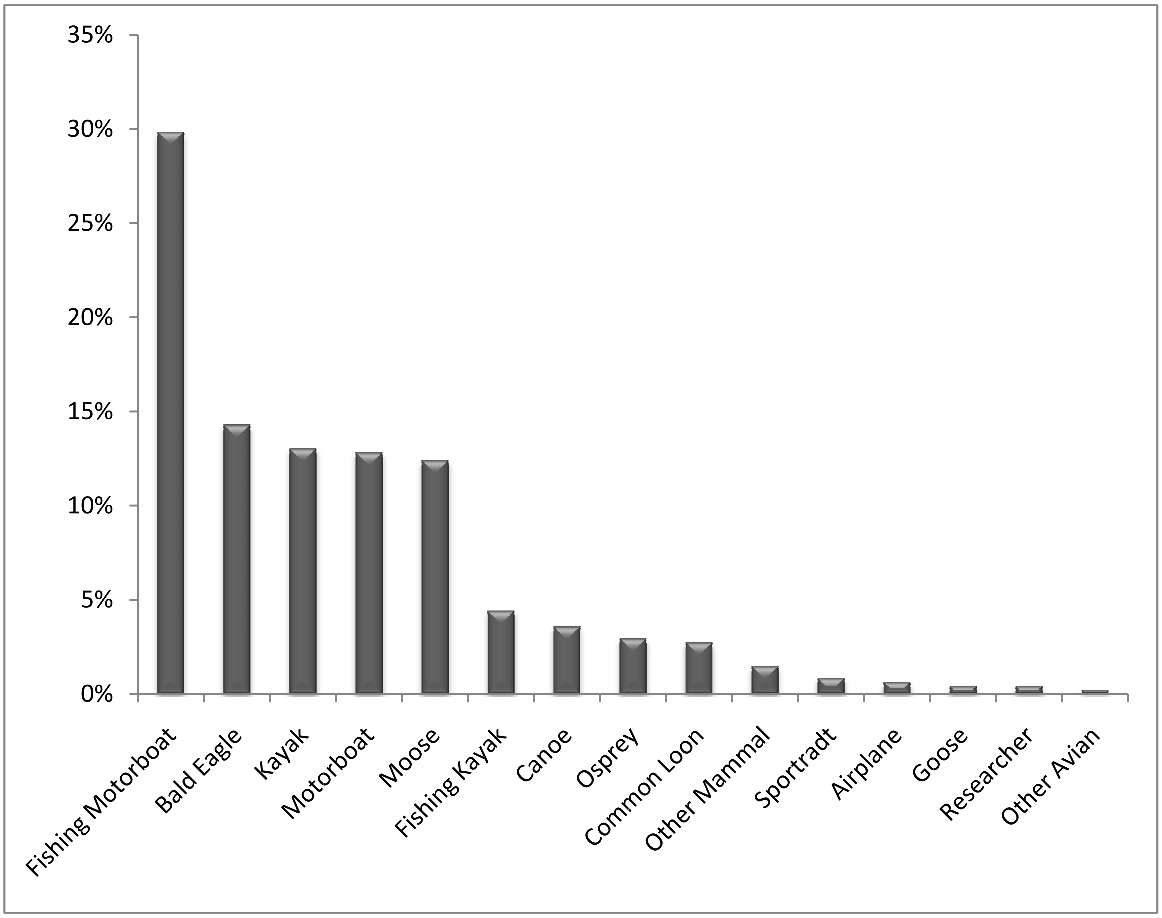


Figure 4.8. Percent disturbance type observed within 150-300 meters of nesting loon, 958 total observations, Lake Umbagog NWR.

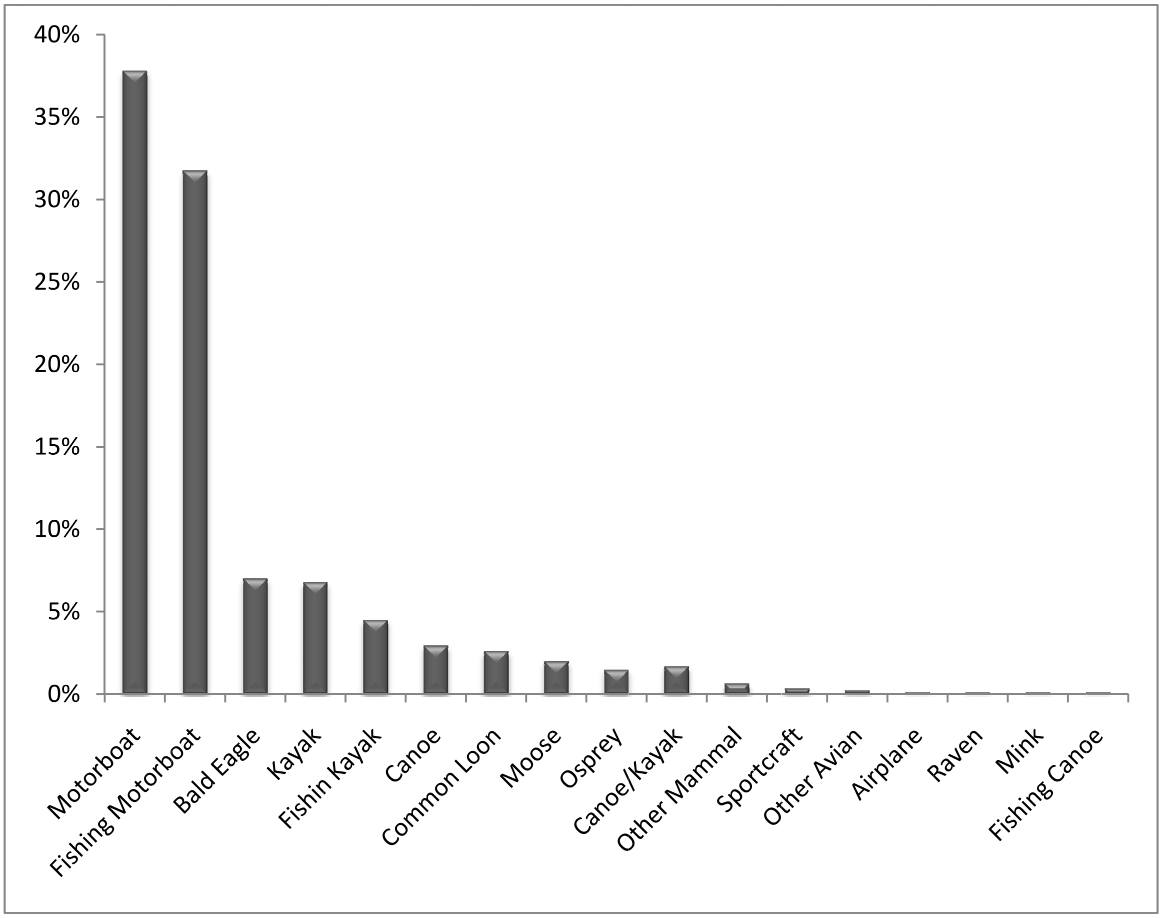
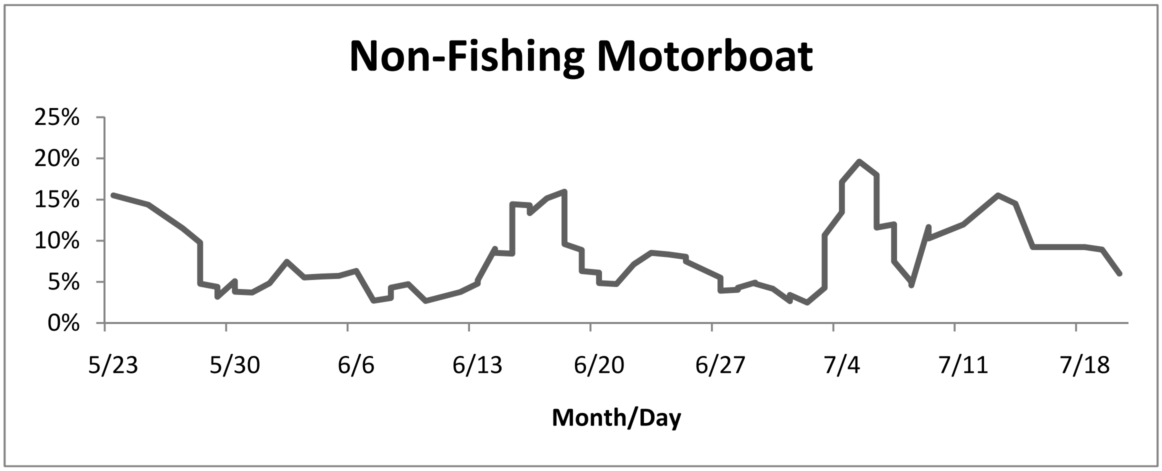
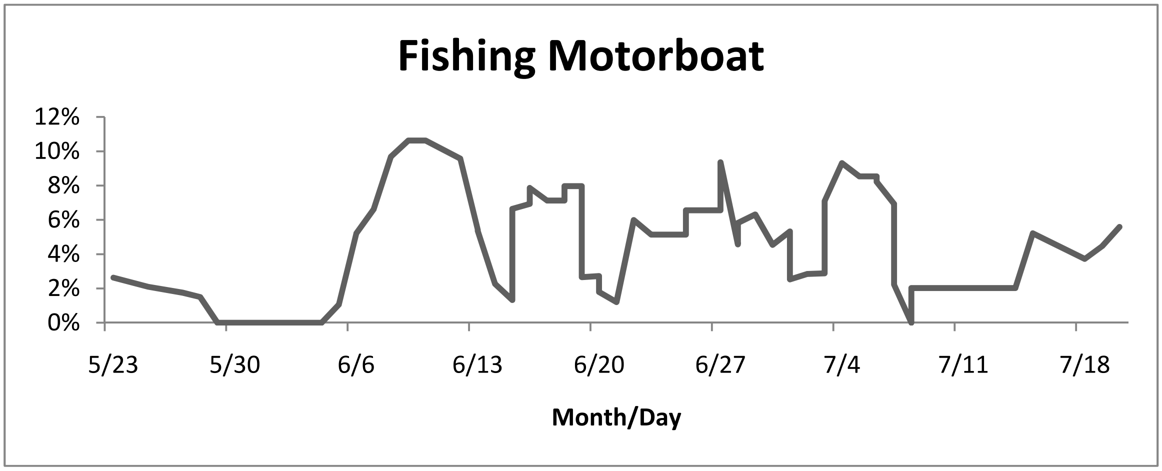


Figure 4.9. Percent observed non-fishing motorboat, fishing motorboat, and canoe/kayak use during common loon nesting surveys on Lake Umbagog NWR. Lines smoothed using 7-day moving window analysis for average and adjusted for daily survey effort.





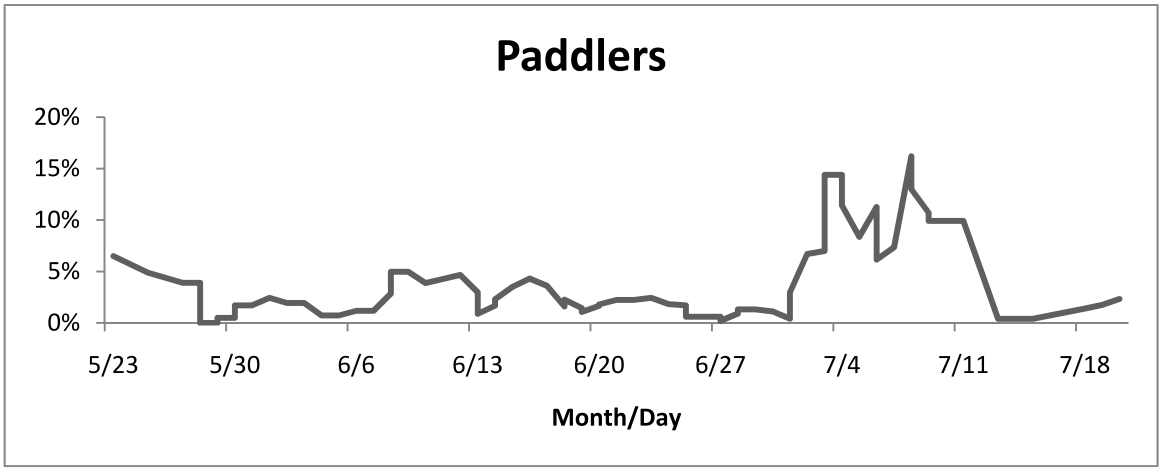


Figure 4.10. Percent relaxed nesting and percent motorboats observed based on survey start-time, adjusted for survey effort.

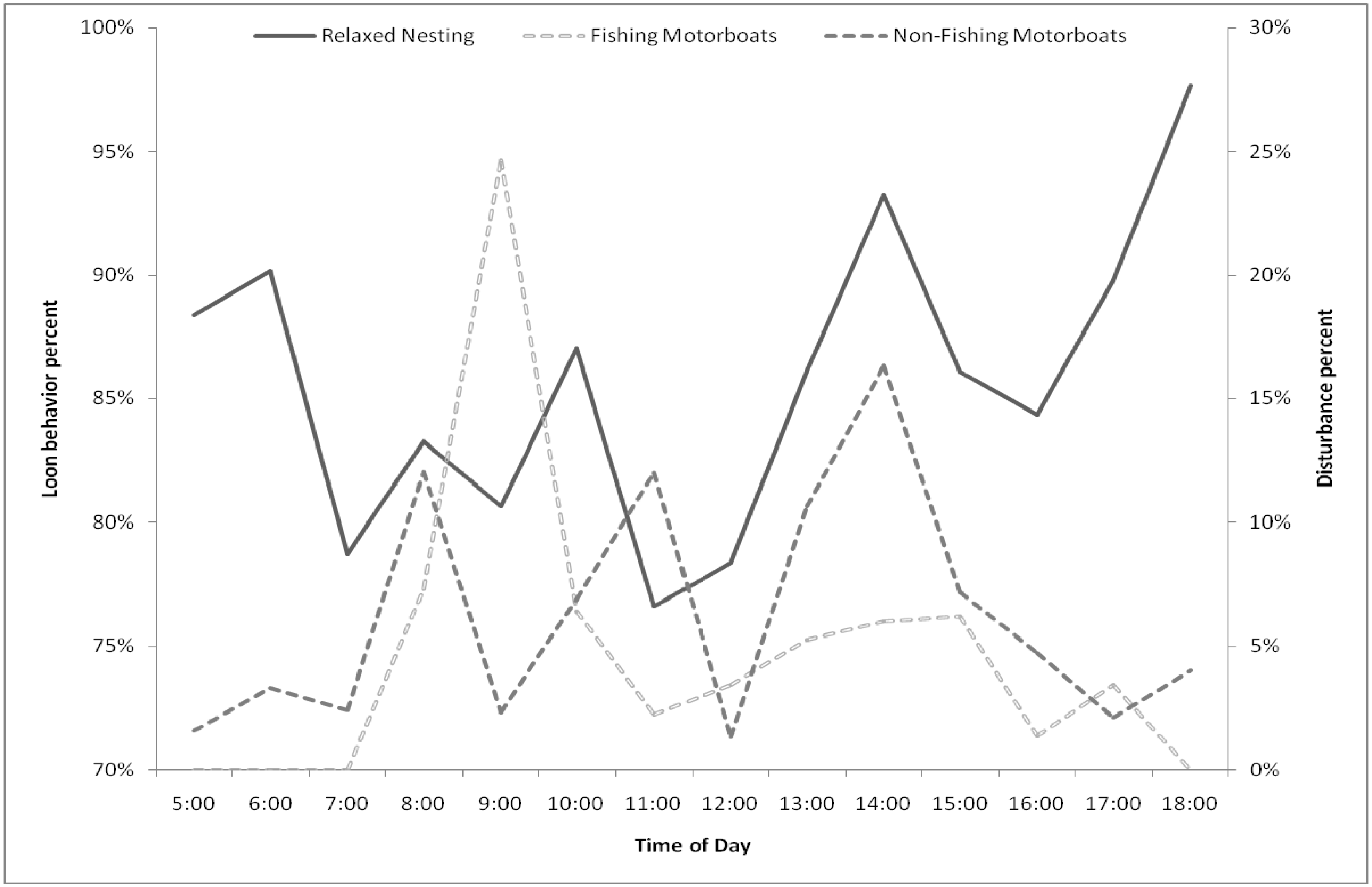


Figure 4.11. Percent relaxed nesting and percent paddlers observed based on survey start-time, adjusted for survey effort.

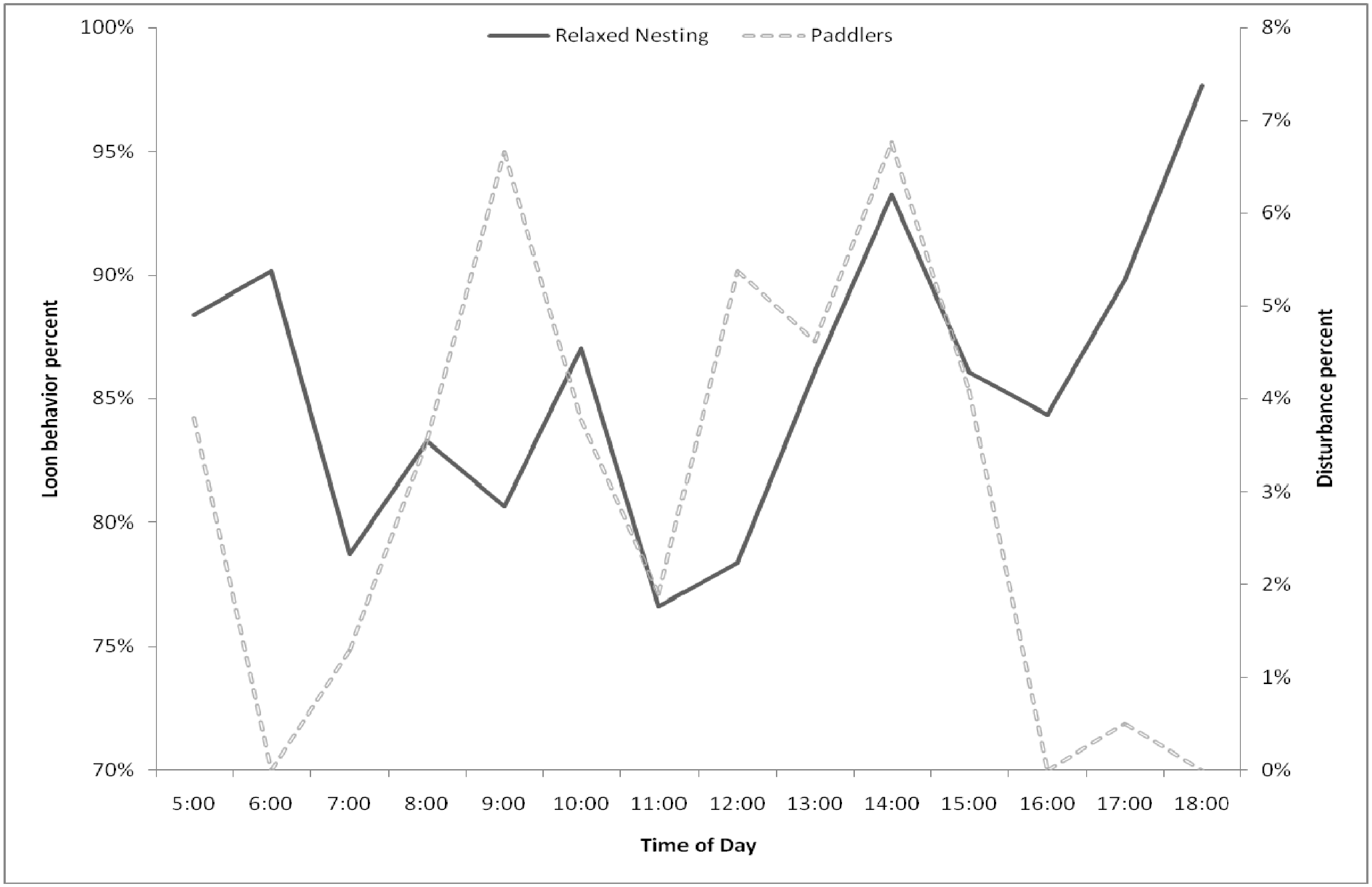


Figure 4.12. Percent relaxed nesting and percent eagle and non-pair loons observed based on survey start-time, adjusted for survey effort.

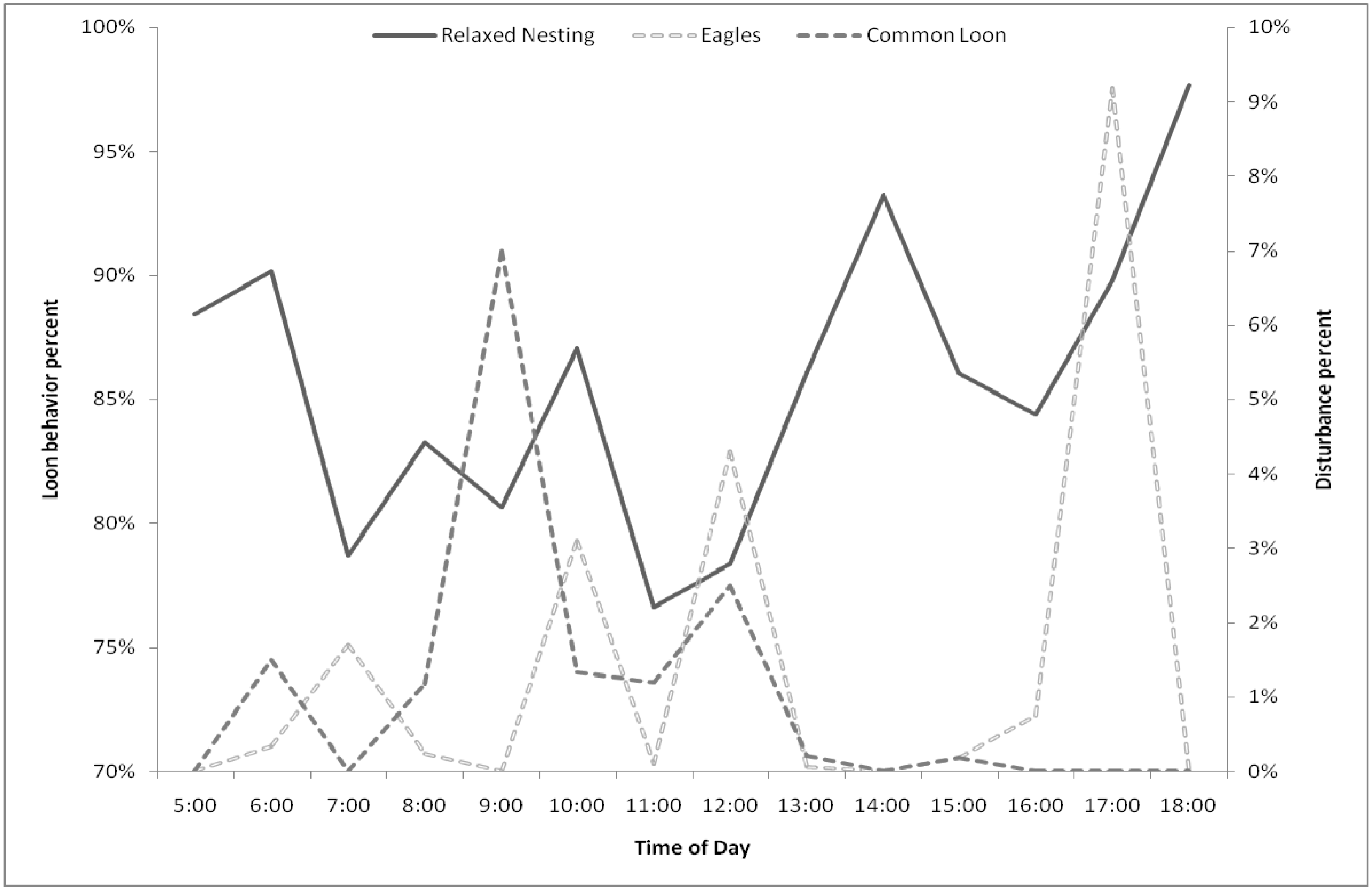


Figure 4.13. Redundancy analysis tri-plot with significant ($p < 0.05$) axes 1. Survey sites are separated by territory via color. Behavior variables AF = foraging, FC = feeding chick, BU = chick under wing, BB = chick on back, AP = alert posture, BD = bill dip, and DS = dive swim PE = peering, VT = tremolo. Other behaviors are insufficiently separated to assess effects. Disturbance variable BE = bald eagle, CL = common loon, MB = motorboat, PD = canoe/kayak. Postscripts A, B, and C indicate distance bins of 0-75m, 75-150m, and 150-300m respectively.

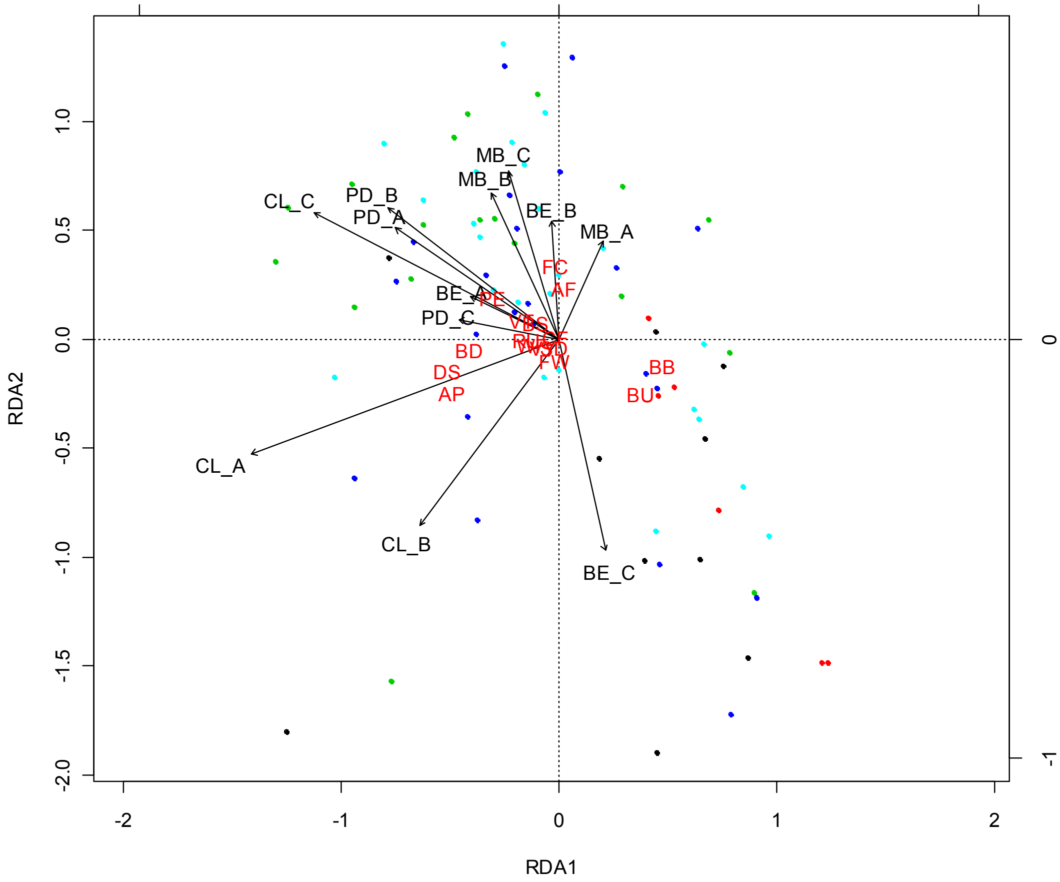
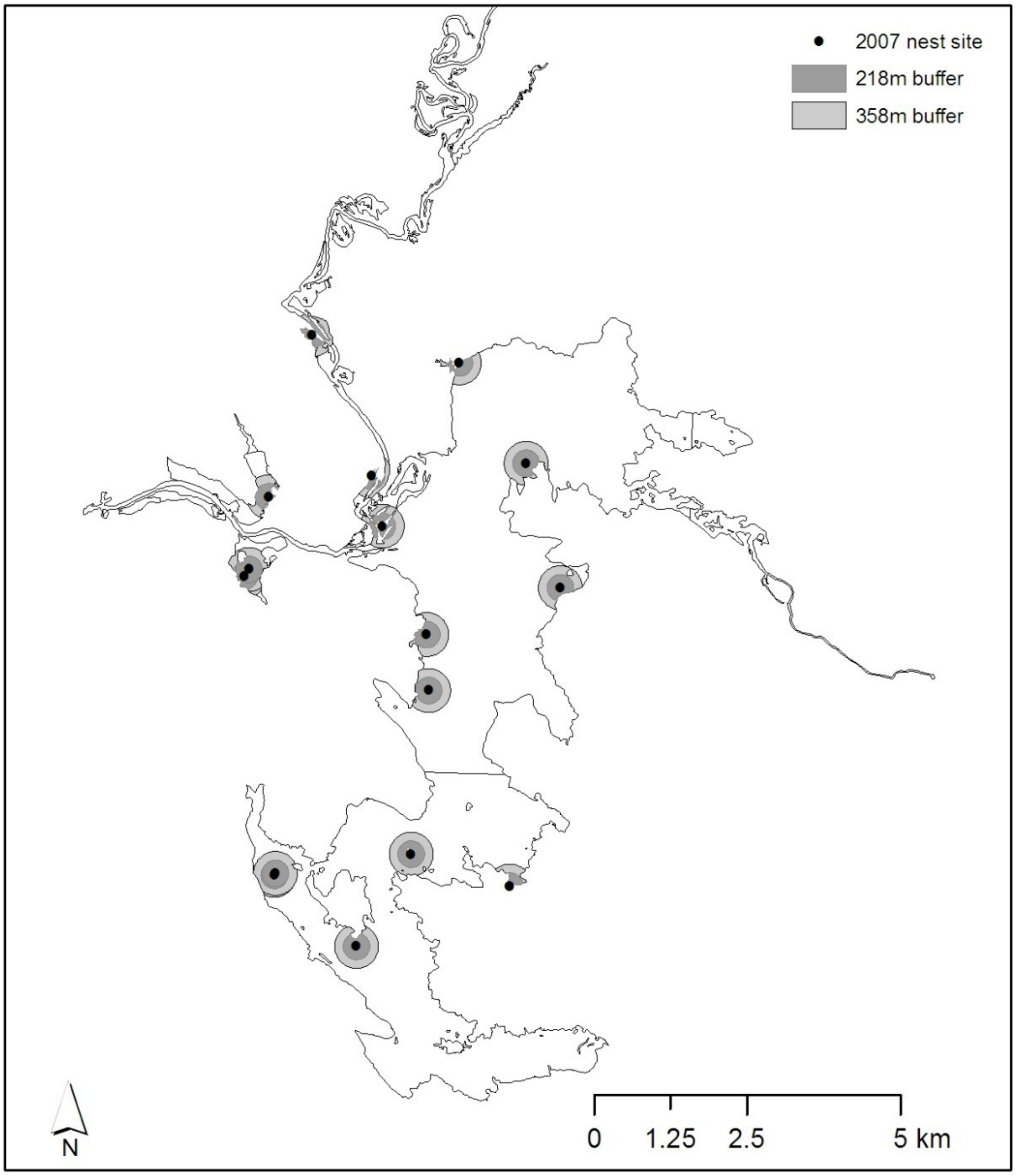


Figure 4.14. Map of Lake Umbagog and river confluences with common loon nest sites from the 2007 breeding season. Each nest is buffered by 218m and 358m, the average and maximum distance a response was evoked under experimental treatment with canoe, kayak, gas motor on skiff, and electric motor on skiff. No statistical difference was detected between boat type.



CHAPTER 5

BALD EAGLE PREDATION ON COMMON LOON EGG

Abstract

We document the predation of an active common loon (*Gavia immer*) nest by an immature bald eagle (*Haliaeetus leucocephalus*) on Lake Umbagog National Wildlife Refuge, Maine. It is likely that with an increasing trend in eagle populations in New England and many other parts of the range where bald eagles and loons overlap, there will be subsequent increases in bald eagle predation on common loon nests. Based on egg shell fragments we suggest that other egg depredations by bald eagles may be misclassified as potential mammalian predation events under current loon monitoring practices.

Introduction

The common loon (*Gavia immer*) must defend against many potential egg predators during incubation including American crows (*Corvus brachyrhynchos*), common ravens (*Corvus corax*), herring gulls (*Larus argentatus*), raccoons (*Procyon lotor*), and mink (*Mustella vison*) (McIntyre 1988, Evers 2004). Bald eagles (*Haliaeetus leucocephalus*) have been documented as predators of both adult common loons and their chicks (Vliestra and Paruk, 1997, Paruk et al. 1999, Erlandson et al. 2007, Piper et al. 2008). However, although opportunistic egg predation has been associated with bald eagles, specific predation events have yet to be documented (Evers 2004). Here we describe the first documented observation of predation on a common loon egg by an immature bald eagle as captured by a nest surveillance video-camera on Lake Umbagog National Wildlife Refuge (LUNWR) in Maine. Further, we discuss the evidence remaining at the nest site and how it would have been classified as potential mammalian predation lacking video evidence.

Methods

As part of an ongoing study of loon behavior and population demographics at LUNWR managers placed time-lapse (1sec frame rate) remote surveillance cameras opportunistically at nest sites. There was no sound recorded. The camera was placed to provide a view of the nest and the immediate area surrounding it. In conjunction with the remote cameras, nest sites were checked daily to determine if the loon pair was still incubating. If the loons were no longer incubating the nest site was visually assessed to determine nest fate and any egg shell remains were collected. Upon nest failure, video footage was reviewed to determine cause of egg loss.

Results

The common loon pair nested on 19 June 2008 on a small floating mat of vegetation. This was their second nest attempt and only one egg was observed. Remote video-cameras were placed on 20 June by refuge personnel to observe the nest. On 3 July at approximately 8:00am the nest was found abandoned and only a portion of crushed egg shell was visible. A section of the nesting substrate was pulled up and folded over the shells as if digging had occurred. Based on the state of the egg shell and the nesting substrate it was recorded as a potential mammalian predation, but without corroborating evidence such as mammalian tracks no definitive cause was identified (Fig. 5.1). This was in accordance with the standard method for categorizing nest failures currently used by refuge personnel, adapted from Loon Preservation Committee techniques for surveys throughout New Hampshire and Maine (Loon Preservation Committee 2007).

Subsequent review of the video footage provided a detailed account of the nest fate. The incubating adult was seen to be resting on the nest for >1 hour before quickly departing the nest at 19:07:06 on 2 July 2008. The loon swam out of view until 19:50:47; it then began swimming back and forth in front of the nest. Based on body posture it appeared to vocalize at 19:52:24. It then rushed towards the nest a brief distance at 19:52:27 at which point an immature bald eagle landed directly on the nest. While the eagle was on the nest the loon appeared to wail repeatedly and exhibited two seconds of penguin dancing, a behavior in which the loon folds its wings against its body and swims upright in the water. At 19:53:28 the bald eagle flew off of the nest and the loon continued swimming back and forth in front of the nest site. At 19:56:51 the eagle returned to the nest and began eating the egg. The eagle remained on the nest eating for 17min and 42sec before departing at 20:14:33. Meanwhile the loon continued to vocalize and swim repeatedly back and forth in front of the nest. The loon remained in view for about 15min but did not approach the nest before departing the area.

Discussion

It is unknown whether this predation event was incidental or the act of an individual specializing in egg predation. In either situation it is important to note that eagle populations across New England are increasing and predation events are likely to follow the same trend. In New Hampshire the number of nesting bald eagle pairs has risen from 1 pair in 1990 to 12 pairs by 2006, 3 of which nest on LUNWR (Martin 2006).

In 2008 a new eagle pair nested near the Rapid River on LUNWR bringing the total to 4 pairs (U. S. Fish and Wildlife Service, unpub. data).

It is troubling that the egg remains where classified as potential mammalian predation but later proved to be the result of bald eagle predation. It is possible that several other bald eagle predation events on LUNWR have gone undocumented and the cause incorrectly identified as potentially mammalian. In the future, when assessing predation events on nest sites, managers should use caution when classifying the results as mammalian. Unless direct evidence such as obvious tooth marks, feces, or spoor are observed (as recommended by LPC protocol) then classification should include the possibility of bald eagle predation.

Figure 5.1. Common loon egg shell remains after predation by immature bald eagle, Lake Umbagog National Wildlife Refuge, 2008.

CHAPTER 6

COMMON LOON NEST DEFENSE AGAINST AN AMERICAN MINK

Abstract

We describe a successful nest defense strategy of an adult common loon (*Gavia immer*) during an attempted predation event by an American mink (*Mustela vison*) at Lake Umbagog National Wildlife Refuge, New Hampshire. It is suspected that mink occasionally predate common loon nests but defense strategies have not previously been described. Our observed nest defense behavior is likely the result of co-evolution in the historical predator-prey dynamic between the American mink and the common loon.

Observation

As a novel predator to the British Isles, it is suspected that American mink (*Nevison vison*) has wreaked havoc among shore nesting bird species after its intentional introduction for the fur trade (Nordström et al. 2002). However, in North America where the mink is a native species, prey species have theoretically adapted to deal with mink predation via co-evolution as described for species in general by Vermeij (1987). One potential prey species, the common loon (*Gavia immer*), is suspected to be the occasional victim of egg predation by the American mink, but little documentation of such events exists (Fox et al. 1980, Evers 2004). Here, we provide a detailed account of an attempted egg predation event by an American mink on a common loon nest at Lake Umbagog National Wildlife Refuge (LUNWR), New Hampshire. Our observations allow us a glimpse of an evolved predator defense mechanism and promote discussion on the topic of the mink-loon predator-prey relationship.

Lake Umbagog National Wildlife Refuge is located in Coos County, New Hampshire and Oxford County, Maine. Established in 1992, the primary purpose of the refuge is to protect wetlands, wetland associated wildlife, and migratory birds (USFWS 2006). The common loon is considered a focal species of the refuge and its status and reproductive success are a key component of a recently established ecosystem study. As part of this ongoing study of loon behavior and population demographics at LUNWR, we observed loon nesting behavior via high powered spotting scopes from hidden shore-based locations. Observation periods lasted 100 minutes with all behaviors and disturbance events being recorded. The nesting territory discussed here was located within Harper's Meadow. This is a floating bog and wetlands complex that was designated as the Floating Island National Natural Landmark in 1972 by the Secretary of the Interior. The nest was located on a floating bog mat, approximately 70 m from the nearest land; however, contiguous floating vegetation allowed terrestrial access. Our observations were conducted from within a stand of evergreen forest >200 m from the nest.

On 19 June 2008 at 8:36am a solitary adult mink was seen swimming along a shoreline about 350 m from the observed loon nest at Harper’s meadow. The mink was being mobbed by red-winged blackbirds (*Agelaius phoeniceus*), and a black duck (*Anas rubripes*) swam aggressively towards it, perhaps defending a nest site. The mink then exited the water and disappeared into the grass. The Harper’s Meadow loon showed no reaction to the mink’s presence and likely did not see it. The following day during nest observations several mink calls were heard behind the observer. At 12:53pm the observer identified the origin of the calls and found a mink den within 300 m of the loon nest. Several kits and an adult mink were observed at the den site.

On 21 June 2008 at 8:44am, after 20 minutes of quiet nesting behavior (i.e., the loon sat on the nest with no disturbance or outside activity influencing its behavior), the Harper's loon (female) suddenly dove off its nest. Simultaneously an adult mink pounced onto the nest from behind the loon. As soon as the loon left the nest it turned in the water, rose into the penguin dance posture (McIntyre 1988) and began stabbing at the mink with its beak (Fig. 6.1). The mink quickly returned to the water and swam out of sight while the loon continued to penguin dance, a behavior in which the loon folds its wings against its body and swims upright in the water, around the nest. The loon traversed the water around the nest four times while penguin dancing and occasionally plunging its beak into the water. The mink was not observed after the initial dancing and stabbing motion and the egg remained untouched on the nest. Within one minute of the initial attack, the loon returned to the nest, adjusted two eggs with its beak, and resumed incubating. The loon was now facing in the direction of the original mink attack and maintained an alert nesting posture for approximately two minutes. The loon then rolled the eggs and returned to a quiet nesting posture. Throughout the whole interaction there were no audible vocalizations from either the loon or the mink; however, the splashing of the penguin dance was very loud.

On the 25 June, 8 days after initiation and 4 days after the mink attack, the Harper's Meadow nest was found predated. The remains of the 2 eggs indicated a potential mammalian predation event, but no tracks could be found to indicate a specific species (LPC 2007). This was the second and final nest attempt of the year for this loon pair. The first nest failed after 2 days for unknown causes; no egg remains were found. It was located outside the inlet of Harper's Meadow about 700m from the mink den.

Loons often leave their nests unattended during territory defense or when disturbed, making them more vulnerable to predation (Evers 2004). However, it is apparent that when present, the loon has developed an aggressive nest defense strategy to deter American mink. It is hypothesized that the intensity of nest defense depends on the maximization of net fitness benefits (see Montgomerie and Weatherhead 1988). This means that brood survival and accrued fitness costs are balanced against the probability of the parent surviving to breed again. Therefore, in the case of the observed common loon, the benefit of protecting its eggs outweighed the risk of serious injury. This behavior is likely a trait evolved over time, as the loon and mink have competed in the predator-prey evolutionary interactions as described by Vermeij (1987).

Figure 6.1. Illustration of common loon nest defense against predating American mink. Composite of public domain photographs rendered using Jasc Paintshop Pro™.

APPENDIX A. GROUPING USED TO CATEGORIZE INDIVIDUAL COMMON LOON PRE-NESTING BEHAVIORS.

Foraging	Maintenance	Resting	Swimming	Response	Pair Interactions
Adult Forage	Bathing	Drifting	Swimming	Alert Posture	Courtship
Peering	Foot Waggle	Sleeping		Bill Dip	Hoot
	Preen			Dive Swim	
	Wing Flap			Head Rub	
	Yawn			Rush	
				Splash Dive	
				Tremolo	
				Wail	
				Yodel	

APPENDIX B. GROUPING USED TO CATEGORIZE INDIVIDUAL COMMON LOON NESTING BEHAVIORS.

On-nest relaxed	Nest Maintenance	Off-nest relaxed	On-nest Response	Foraging	Off-nest response
Nest Content	Nest Tending	Drifting	Nest Alert	Adult Foraging	Alert Posture
Nest Panting	Egg Rolling	Swimming	Nest Head-Hung	Peering	Nest Departure
Nest Sleeping	Nest Building	Preening	Nest Sprawl		Dive Swim
Nest Preening		Sleeping			Wail
		Wing Flap			Head Rub
		Foot Waggle			Bill Dip
		Bathing			Rushing
					Penguin Dance
					Splash Dive
					Yodel

APPENDIX C. GROUPING USED TO CATEGORIZE INDIVIDUAL COMMON LOON BROOD-REARING BEHAVIORS.

Foraging	Maintenance	Resting	Swimming	Response	Brood Care	Chick Feeding
Adult Forage	Bathing	Drifting	Swimming	Alert Posture	Chick On Back	Chick Feeding
Peering	Foot Waggle	Sleeping		Bill Dip	Chick Under Wing	
	Preen			Dive Swim		
	Wing Flap			Head Rub		
	Yawn			Rush		
				Splash Dive		
				Tremolo		
				Wail		
				Yodel		

APPENDIX D. INITIAL LIST OF POTENTIAL DISTURBANCE EVENTS TO RECORD DURING OBSERVATIONS

HUMAN DISTURBANCES

#FM – Number Fly Fishing Motor Boats (replace # with number of boats present)
#FK – Number of Fly Fishing Kayaks (replace # with number of boats present)
#FC – Number of Fly Fishing Canoes (replace # with number of boats present)
#SM – Number Spin Fishing Motor Boats (replace # with number of boats present)
#SK – Number of Spin Fishing Kayaks (replace # with number of boats present)
#SC – Number of Spin Fishing Canoes (replace # with number of boats present)
#NM – Number of Non-Fishing Motor Boats (replace # with number of boats present)
#NK – Number of Non-Fishing Kayaks (replace # with number of boats present)
#NC – Number of Non-Fishing Canoes (replace # with number of boats present)
SC – Sport Watercraft
MV – Motor Vehicle (Car or Truck)
AT – All Terrain Vehicle
AP – Airplane Overhead

WILDLIFE DISTURBANCES

CL – Common Loon (territorial disturbance)
AC – American Crow
CR – Common Raven
RB – Ring-billed Gull

BE – Bald Eagle

OS – Osprey

OA – Other Avian Species (name bird in comments)

RC – Raccoon

FX – Fox

MK – Mink

MO - Moose

OM – Other Mammal (Name mammal in comments)

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