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Spatial distribution of the common loon (Gavia immer) in New Hampshire

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SPATIAL DISTRIBUTION

OF THE COMMON LOON (*GAVIA IMMER*)

IN NEW HAMPSHIRE

BY

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DEDICATION

I dedicate this dissertation to my wife Debra and sons Joshua, Wesley and Adam for their patience, understanding and encouragement while mixing work, school and family life during the last few years.

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ABSTRACT

SPATIAL DISTRIBUTION

OF THE COMMON LOON (*GAVIA IMMER*)

IN NEW HAMPSHIRE

by

Mark W. Brennan

University of New Hampshire, May 2005

The Common Loon (*Gavia immer*) is located in many portions of North America. By the early 1970's the Common Loon population in New Hampshire had experienced a dramatic decline in historic numbers. In 1975, the Audubon Society of New Hampshire recognized this problem and established the Loon Preservation Committee (LPC). The intent was to collect information regarding the presence or absence of loons and loon productivity, and, educate the public regarding loon ecology and preservation. This dissertation represents the work completed to fulfill the requirements for the Doctor of Philosophy degree in Natural Resources Management at the University of New Hampshire. The research concentrated on analyzing georeferenced loon management data collected by LPC from 1980 – 2002 and understanding loon habitat occupancy. Specific objectives of this study were to: 1) investigate the colonization patterns of the Common Loon in New Hampshire, 2) identify and prioritize potential loon habitat in New Hampshire, and 3) develop and implement methods to be used by the Loon Preservation Committee for current and future loon management. Methods are described for converting and analyzing a 29-year historical database maintained by the Loon Preservation Committee located in Moultonborough, New Hampshire. Through this effort, techniques and results for: analog to digital data conversion, automating new data collection, and spatial analysis are discussed. Lake perimeter, lake depth, distance to lakes with and without loons, and lake elevation were identified as significant factors for determining loon habitat occupancy in New Hampshire. The results of implementing a GIS-enabled loon habitat occupancy model are presented.

CHAPTER 1

EXECUTIVE SUMMARY

In the early 1970's, the Audubon Society of New Hampshire conducted the first census of the loon (*Gavia immer*) in the state. Analysis of the data revealed that the loon population was declining and that some territories were abandoned. Previous reports by New Hampshire naturalists indicated that loons were on every lake with hundreds of nesting pairs. However, by 1976 only 21 lakes yielded successful nesting sites (Hammond and Wood, 1976).

In 1975, the Audubon Society of New Hampshire recognized the reduced loon population and established the Loon Preservation Committee (LPC). The original goal of this organization was to: 1) survey the loon population of the state and determine the cause of its decline, and 2) sponsor corrective measures for the protection of the species. Since its inception, LPC biologists have collected data for all known paired and unpaired loons on lakes within New Hampshire.

Until 1995, when this study commenced, little analysis had been performed using the LPC data. The purpose of this research was to: 1) better understand the spatial and dynamic distribution of loons in New Hampshire by analyzing LPC's extensive 29-year data repository, and 2) develop a model specific to loons that shows future occupancy or re-occupancy of lakes by loons within the state. Specific objectives of this research include:

- Determining loon colonization or re-colonization trends in New Hampshire.
- Identifying and prioritizing loon habitat for future occupancy.
- Developing a digital database to retain converted hardcopy data.
- Developing and implementing new methods for automating data collection, management and spatial analysis.
- Developing and implementing new methods for managing existing and envisioned LPC data.
- Educating the public regarding loon awareness and conservation.
- Coordinating with appropriate local and state agencies to obtain the data required for this study and providing results to these organizations to be used for long-term cooperative planning and preservation needs.

Loon specific biological data originally captured in hardcopy were converted to digital files. New semi-automated methods were developed and implemented for collecting and storing biological data in digital form. For example, the method for collecting nest site locations and associated attributes was modified to use handheld GPS units rather than USGS Topographic sheets and a pencil. A relational database specific to New Hampshire loons was developed and includes: 1) the location of reproductive loon nest sites and historic biology, productivity, and occupancy data, and, 2) associated physical and geospatial characteristics of water bodies occupied by loons.

Analysis of the loon database showed that the loon population in New Hampshire increased from 1980-2002 and that during the same period new habitat (water bodies) was occupied. This positive growth was probably due, in part, to continuous and effective loon management and protection, public education, and research efforts conducted by LPC. Further analysis focused on three regions of the state (north, central and south) and revealed that the southern region may represent the best potential for loon population expansion. One explanation is that historical habitat is filling up in the central and northern regions and younger loons returning to natal lakes are forced to establish territories on new lakes with lower occupancy and reproductive pressure. The following results support these conclusions:

- The total number of loons (defined as: total loons = paired loons + unpaired loons + immature loons) in New Hampshire experienced positive growth (F=370.81; p=0.000) during 1980-2002.
- Nesting pairs (a pair of loons that nest) and successful nesting pairs (nesting pairs that produce eggs) show significant increase during 1980-2002 (F=271.35; p=0.000; F=74.882, p=0.000; respectively).
- Chicks hatched (F=59.388, p=0.000) and chicks surviving (F=39.460, p=0.000) increased steadily from 1980-2002.
- The number of lakes with loon activity also increased 1980-2002 (F= 652.265, p=0.000).
- The southern region hatch rate is greater than central region hatch rate (t=4.28, p=0.000) and is greater than northern region hatch rate (t=3.64, p=0.000).

A habitat occupancy model was developed using historic loon presence and absence data on water bodies during 1980-1996. Four parameters – lake perimeter, lake depth, distance to a lake occupied by loons and lake elevation – were found to be significant (p=0.001) in determining loon occupancy. This model was tested using loon occupancy data collected during the 1997-2002 field seasons, yielding 78% accuracy. LPC biologists will benefit from this analysis by using a habitat occupancy map derived from the 4-paqramaeter model to guide monitoring efforts during subsequent field seasons. Continued validation is important for model refinement and will be achieved through feedback from LPC biologists after each field season.

Additional accomplishments and benefits of this research that support LPC's long-term mission of restoring and maintaining a healthy loon population throughout the state include:

- Integration of software tools within a loon management system that provide semi-automated geospatial analysis and graphical display of: 1) historical loon nest sites distribution, and 2) current and future loon habitat occupancy.

- Development of Standard Operating Procedures used to streamline and automate data collection and management processes.

- Establishment and maintenance of an LPC website (http://www.loon.org/) used for public outreach and education, and communication with the research community.

- Enhanced coordination among multiple loon management organizations (e.g., Biodiverstiy Research Institute, New Hampshire Fish and Game, U.S. Fish and Wildlife Service and Environmental Protection Agency) have contributed to new policy development and research extensions to other threatened species in New Hampshire.

This research presents a current view of the New Hampshire loon population which is increasing and occupying new habitat. Management and potential protection of existing and additional loon habitat will be required to sustain a healthy population in this state as well as other geographic regions that support loon populations. To address increased land use planning requirements, one future extension to this research is to develop a habitat planning and management modeling capability that will also account for human disturbances and changes in surrounding landscape in addition to loon habitat requirements. This will require increased coordination with resource management organizations at various levels of government. However, wildlife decision makers will be provided with an enhanced ability to develop management plans that are more closely aligned with local and state planning organizations.

The remainder of this document is organized as follows: Section 2 addresses loon management policy; database development is presented in Section 3; Section 4 discusses loon biological data and nest site analysis; habitat occupancy model development is found in Section 5; and conclusions, benefits and future research are presented in Section 6. Literature cited and appendices are included as separate concluding sections.

CHAPTER 2

COMMON LOON MANAGEMENT IN NEW HAMPSHIRE: A MULTI-ORGANIZATION APPROACH

2.1 INTRODUCTION

Accurate records prior to the 1970's are limited regarding Common Loon (*Gavia immer),* referred to as loon, populations in New England. However, some reports do indicate that the loon was prevalent in many open water bodies prior to the turn of the century. In the early 1900's the loon was regarded as a pest and threat to the local fisheries. At this time it was viewed as a species with little economic value and therefore was hunted without regard to the effect on the entire population.

Loons were finally protected from hunting under legislation known as the Migratory Bird Treaty Act of 1918 (U. S. Fish and Wildlife Service, 1918). This legislation protected loons as well as other migratory species from being hunted. In New Hampshire this law is credited for reducing the adult mortality to naturally occurring levels.

There is one localized account of attempts around 1950 by New Hampshire Fish & Game Department (NHFG) officials to reduce the loon population on one particular water body by shooting them ("shoot on site" order). They wondered why the population had not declined significantly and learned that the warden assigned to the lake was a bad shot and was not killing any birds (Wood, pers. comm.). This was an ill-implemented management technique that contributed to reducing the New Hampshire loon population to less than 40 breeding pairs by 1973 (Brennan, et al, 1998, Hammond and Rawson, 1976).

As a migratory species (U. S. Fish and Wildlife Service, 2002), the overall management authority for loons in any state resides with the U.S. Fish & Wildlife Service (USFWS). Unless on a federal property, the second largest organization in New Hampshire with loon management authority (as directed by USFWS) is the NHFG. In 1973, the Loon Preservation Committee (LPC) was formed because a trustee of the Audubon Society of New Hampshire (ASNH) reported that loon populations were drastically low[1]. Today, due to LPC's past success, NHFG works collaboratively with the LPC to manage loons in New Hampshire.

Since the early 1970's, other organizations (e.g., BioDiversity Research Institute) have also become involved with loon management. The increase in number of organizations and their goals for loon management presents new challenges in managing communication and coordination of activities among all organizations.

Specific objectives of this chapter include:

- Identify and describe dominant organizations involved with loon management in New Hampshire.
- Present the overall loon management policy development and implementation process in New Hampshire.

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[1] A trustee of the Audubon Society of New Hampshire noticed a significant drop in the loon population on Squam Lake where he was a summer resident. He organized a committee to evaluate current loon populations in comparison with historic levels. Hired biologists were able to document a decline in the historic number of loons, and in 1979, the Common Loon was designated as a state-listed threatened

- Provide an example of how new loon policy was developed in New Hampshire.

- Document the benefits of this work to loon management in New Hampshire.

2.2 METHODS FOR INFORMATION GATHERING

Content analysis is a method to systematically examine text information by identifying and grouping themes into categories. A simplistic set of five primary categories: loon biology, data collection, data management, data processing and geospatial analysis was used to organize relevant research documents.

2.2.1 Document Review

Documents of many types were obtained, reviewed and pertinent information recorded as part of this effort. Example documents include: journal articles, LPC technical, policy and annual reports; reports and wildlife management guidelines published by New Hampshire Department of Environmental Services (NHDES), NHFG, and bulletins and articles found in the news media and on the Internet (very few). Key words (e.g., loon, nest, cluster, and geospatial) were selected to identify documents potentially relevant to this study. Literature is cited for those documents from which information was extracted and used in this work.

2.2.2 Personal Interviews

A key source of information, often historical, is obtained through conversation with people who have held previous positions in organizations involved with the research

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species.

topic. For this project, Rawson Wood, John Lanier and Jordan Purdy provided valuable insight to previous loon management techniques dating back to the 1940s. Other individuals, mostly working with volunteer organizations, were also interviewed to gain knowledge of previous loon population dynamics through the years. Information obtained and used from personal interviews is referenced as personal communication.

2.2.3 Observation of Key Meetings

The LPC, Northeast Loon Study Working Group, Wildlife Society and American Society for Photogrammetry and Remote Sensing hold technical exchange meetings every six to twelve months. Through these meetings, information is gathered regarding other research activities being conducted around the state and country. The author sits on the LPC Technical Committee and through this exchange gained insight about management decisions and operations that otherwise would not be available. Meetings at LPC, Northeast Loon Study Working Group (NELSWG) and the American Society for Photogrammetry and Remote Sensing (ASPRS) were attended at which coordination with other researchers and or information was directly obtained. A list of meetings attended is provided in Appendix A.

2.3 Primary Organizations involved with New Hampshire Loon Management

The interface between wildlife and people requires proper management to ensure sustainability. Prior to civilization as we know it today, natural checks and balances presumably lent stability to wildlife populations. As the human population of the planet has increased, however, human predation and the demands on available habitat have increased and many wildlife populations have declined and/or are often forced to occupy other, and, sometimes less optimal habitat.

Humans recognize the benefits of wildlife resources often as food, clothing, tools, or aesthetics. Because of advances in civilization, methods for managing wildlife populations, and their surroundings, have evolved, sometimes with complicated ecosystem inter-dependencies. Aldo Leopold, often referred to as one of the fathers of wildlife management, recognized that careful management is critical to the long-term sustainability of wildlife resources. He established a foundation for wildlife management concepts and theories during the 1930's, and today, his doctrine still has an influence on management practices and strategies. His text, "Game Management" (Leopold, 1933), set the stage for wildlife managers to be good stewards, with the premise that the land should produce sustained annual crops of wild game for recreational use.

A key part of sustaining a population is to manage a wildlife resource while keeping in mind the entire ecosystem. The concept of ecosystem based management management, has played an important role in wildlife management for years (Allen and Hoekstra, 1992; Giles, 1969, Giles, 1979; Schemnitz, 1980). However, the dynamics of wildlife management are difficult to manage because an integrated solution composed of multiple technologies coordinated by many individuals and organizations is required to develop comprehensive ecosystem-based solutions rather than narrowly focused plans for an individual species. This approach yields another major trend in wildlife management, which is the use of interdisciplinary teams of people to provide complete management solutions. In turn, this requires the involvement of many different organizations in order to assemble a team with the desired scientific, engineering and management skills.

With regard to loon management in New Hampshire, a community-based team has matured to include the following organizations: federal, state and local governments, corporations (private or publicly owned) and non-profit organizations (NGOs). This interdisciplinary team now in place has evolved to accommodate changing loon management requirements, which the team identifies, analyzes and manages. Several of the organizations participating on this management team are discussed below.

2.3.1 U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service has responsibility for policy development and management implementation for migratory species. Regulations concerning the loons are documented in the Migratory Bird Treaty Act of 1918. For loons in New Hampshire, the USFWS office located in Hadley, Massachusetts is responsible for all permitting, policy development and implementation. LPC receives a special use permit and a special use possession permit each year from this office and in return provides reports to the USFWS regarding the loons in the state. The USFWS New England Field Office (NEFO) in Concord, New Hampshire concentrates on contaminant related issues (lead poisoning) and provides in-kind support to LPC such as field equipment, logistics and training. Less than 1 full-time person per year is assigned from the USFW to manage the loon efforts in New Hampshire (Taylor and Lanier, pers. comm., 1998).

2.3.2 New Hampshire State Government

2.3.2.1 New Hampshire Fish and Game Department (NHFG)

The NHFG, under the direction of the USFWS, is responsible for implementing loon management in the state. The Department headquarters office is located in Concord, New Hampshire and directs its conservation officers to enforce federal and state law, and coordinate loon management activities with other organizations.

The Non-Game Coordinator within this Department oversees LPC's activities related to loon management in the state. LPC is entrusted with this responsibility because of its previous success, mission and summer biologist staffing level. The NHFG Coordinator spends a minimal amount of time per year working directly with loons because LPC implements the majority of loon management techniques in this state (Taylor and Lanier, pers. comm., 1998).

Each year the LPC also obtains a permit from the state of New Hampshire to conduct their loon research. This permit is not required, but used as a mechanism for LPC to coordinate with the state regarding LPC activities.

2.3.2.2 Department of Environmental Services

Except for flight and time on the nest, loons spend all of their life on either fresh or salt water. Therefore, they seek to occupy bodies of water that are clean and good sources of food, protection and nesting opportunities. The importance of habitat quality has prompted DES to sponsor research focused on monitoring the effects of mercury and lead poisoning on the loon population. For example, Evers, et al., (1997) noted that death is the usual result of lead poisoning in loons, however, the presence of loons in relation to water quality was not examined in this study.

The NHDES performs water quality surveys on water bodies throughout the state during summer. This information (e.g., Secchi depth) is collected and distributed in various form and was evaluated in this study for use in assessing habitat occupancy as related to water quality. Unfortunately, the methods for sampling and the selection of water bodies for sampling is not consistent from year to year, so the lack of uniform data precluded its use to assess loon habitat occupancy. If the data exist, it could be valuable for addressing questions specific to individual water bodies for a particular year. LPC's interaction with DES in the past has been minimal with the exception of joint support activities during policy development of the lead sinker ban.

2.3.2.2.1 Wetlands Bureau

The Wetlands Bureau, under the NHDES, has the responsibility of enforcing the Comprehensive Shoreline Protection Act RSA Chapter 483-B (Springs, 1999). This office is also located in Concord, New Hampshire and it reviews all building permits located within or near wetlands. Specifically, a GIS is used to determine the distance from existing loon nesting sites in New Hampshire (stored as a separate theme within the GIS and updated on an ad hoc basis) to the proposed development area. That measurement is then compared to buffering and offset restrictions to determine final permit approval. LPC is allowed to comment on shoreline applications that have a potential to impact loon nesting or brooding sites. LPC also provides changes of loon nest site locations directly to NHDES. Other state agencies have access to this layer, however none have requested it most likely because they are not aware that it exists.

2.3.2.3 New Hampshire Geographically Referenced Analysis and Information Transfer System (GRANIT)

The state of New Hampshire maintains the Geographically Referenced Analysis and Information Transfer System (GRANIT http://www.granit.sr.unh.edu/). This office, located at the University of New Hampshire (UNH), is chartered to produce digital thematic layers for the entire state. The GIS layers are created at the UNH Complex Systems Center by importing and modifying 1:24,000 and 1:100,000 Digital Line Graph (DLG) data provided by the United States Geological Survey (USGS). Some of the ancillary layers produced by GRANIT (e.g., digital elevation data) were used extensively in the GIS analysis portion of this research as well as by the New Hampshire Department of Environmental Services Wetlands Bureau.

2.3.3 Marine Patrol

LPC coordinates and installs floating rafts that are used by loons as artificial nesting sites on many lakes. Part of this process requires roping off sections of water in an attempt to restrict boat traffic from nesting areas. LPC notifies the Marine Patrol of all enclosures that are floated and the length of restriction of time at a given area. Numerous rafts are installed each year under the Marine Patrol's permission and they help restrict people from the sites. The Marine Patrol is also contacted on nights when LPC biologists capture and banding loons because those operations are performed without running lights.

2.3.4 Local Government

Loon management at the local government level is usually conducted through city and town conservation commissions. These entities work with other city and town offices to coordinate activities that affect natural resource management within their local legal boundary, and sometimes across boundaries into other towns.

2.3.5 Local Organizations

Two of the local and regional organizations involved in monitoring loons of New Hampshire are the Squam Lakes Association (SLA) and the Lakes Region Planning Commission. The SLA is funded by the residents of Squam Lakes for the intent of preserving the beauty of Big and Little Squam Lakes. This organization plays an important role in educating visitors about loons. The SLA also provides housing for the LPC summer biologist that is dedicated to Squam Lakes and a mooring for the LPC boat used on Squam Lake. In return, LPC performs the loon management on Squam Lakes. Through these synergies, LPC and SLA maintain a cooperative relationship (Taylor, pers. comm., 1997).

The Lakes Region Planning Commission collects and maintains digital databases for the lakes region drainage basin. It generates digital data which, in some cases, is used to populate the state GIS layers retained at GRANIT. Although the Lakes Region Planning Commission does not have a directed loon management task, some of the GIS layers originally prepared through the Lakes Region Planning Commission were used in this research effort.

2.3.6 Private Sector Contributions

Corporations like to be associated with "green" activities because their participation demonstrates to the general public that the company cares about preserving our natural environment. Some of the companies involved with this research include Pacific Meridian Resources, Inc., ESRI, TASC, Emerge, and Gran-Net Innovative Technologies Group. Their participation ranged from tuition reimbursement to donations of hardware and software tools. Another example of sustained support is the "Adopt A Loon" program (http://www.briloon.org/Adopt/index.html). It is designed to provide contributors a mechanism for continuing annual support in return for being identified as participating in the management of a particular loon. This program allows contributors to feel more involved with loon management.

Corporate participation by individuals within a company can also be an important mechanism for securing sustained support for wildlife management projects. This has been beneficial to this research because it has brought people together who may know little about the research subject, but with strong technical training, bring new management ideas, into the process. This aids in stimulating new thinking and can lead to new ideas or ideas turning into a real asset sooner than anticipated. An example of this is a software engineer who provided guidance during the database design and GIS processing aspects of this project.

2.3.7 Non – Government Organizations (NGO)

There are many positive aspects of having NGOs involved in, and taking a very active role in wildlife management. First, people involved with NGOs often have the mindset that they will achieve their goal regardless of obstacles that arise. Second, NGOs have a different financial structure that allows them to stretch limited resources further. Third, NGOs have a strong mechanism for community outreach. Additional benefits of NGOs being involved with wildlife management include: 1) the grass roots association of an NGO, 2) smaller organizations often act more quickly than larger organizations, 3) autonomous existence, 4) extensive research programs, 5) provision of many individuals for – volunteer and part-time employees - to accomplish needed tasks, and 6) provide students with enhanced learning opportunities.

There can also be negative aspects associated with NGOs involved in wildlife management. For example, if funding is too limited then it can become a major problem and drawback. Many times NGOs rely on fundraising activities to generate the revenue that supports the budget required to employ their staff and conduct business activities. Unstable organizations can lead to low morale and depending on the situation, employees may consider leaving the NGO to obtain employment with more security or higher wages. If word gets out that the NGO is having funding problems, then the general public may become concerned and vital donations can be negatively affected. Given that NGOs rely on volunteers and paid wages are usually lower, the general turnover rate from year to year can be higher than that in corporate or government organizations. Large turnover rates can become a data quality issue if the collection consistency from year-to-year is not sustained. Additionally, institutional memory is lost through each individual that leaves the organization.

Data quality, consistency and timeliness of data availability threaten some NGO's. Mitigation strategies for maintaining high quality standards include providing training programs to develop competent staff and providing work environments and tasks that keep staff interested and focused on their work.

Technology is also a driving force that is shifting the way NGOs are involved with wildlife management. The use of new technologies is changing wildlife management strategies and NGOs are required to accommodate the new methodology through additional training or hiring of new staff. For example, remote sensing, land use / land cover change detection, advanced computing (including the internet) and GIS technologies have made it easier, faster and less expensive to collect, organize and process data for wildlife management decision making. Use of new technologies to advance the understanding of wildlife populations and implementing strategies is a major emphasis of the current research.

2.3.7.1 Loon Preservation Committee (LPC)

By the early 1970's the loon population in New Hampshire had experienced a dramatic decline. In 1975, the ASNH recognized this problem and established the LPC as a self-funded project. Located in Moultonborough, New Hampshire, the LPC's main mission has been, and still is, the conservation of the loon in New Hampshire through research, management and education. The intent of creating the LPC project was two fold: 1) to collect information regarding the presence, absence and productivity of loons in New Hampshire, and, 2) to educate the public of New Hampshire regarding loon ecology and preservation.

During the last 28 years, LPC has successfully monitored all known territorial pairs of loons in New Hampshire and compiled an extensive database that includes location, occurrence, reproduction and productivity[2]. As a result, LPC is playing a vital role in New Hampshire loon management and is now recognized as a leading authority in the world for loon research. In this state, NHFG is ultimately responsible for loon

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[2] Baseline data were also collected on two lakes in 1974, one year prior to LPC's existence. Therefore one additional year (29 total) of data is contained within the database.

management. However, they delegate much of their authority to LPC because of its consistent and successful research, management and education programs. LPC's success is attributed to sustaining a solid scientific foundation while also interacting and coordinating efforts among all the other wildlife management organizations, and the general public. This is the longest continuous effort of its kind in the United States. Requests for information about LPC and its procedures are received from organizations across North America (Taylor and Lanier, pers. comm., 1998).

LPC recognizes that analysis of this loon database is essential to best guide their future management and data gathering activities. Using the loon database, Brennan, et al. (1998) noted that the loon in New Hampshire experienced positive population growth each year since 1980. In 1995 there were approximately 122 loon territorial pairs within the state of New Hampshire, versus 62 in 1977. This increased population growth is, in part, due to the efforts of the LPC through monitoring programs, surveys, legislative support, and educating the public. The LPC employs 4 full-time people and 8 summer biologists (paid interns) to implement the loon management program. Each year the priorities of the organization are reviewed and adapted from the knowledge gained from the data collected the previous year.

LPC conducts a three-day training course for its biologists at the beginning of each season. Selected documents from this training are provided in Appendices E, F, G. The senior biologist holds coordination meetings once per week for the first two weeks of the season (every other week thereafter) with the biologists to provide additional training and rectify problems, if any. Written reports are required weekly during the entire season. Daily field reports and weekly reports include common Metadata to simplify the task of collecting repetitive information and time series analysis.

LPC is partially funded through a contract with USFWS. Communication between the two organizations is accomplished by regular technical and policy meetings. Contract fulfillment requires that data collected and results obtained during the previous year be shared through year end reports and meetings such as the LPC Technical Committee meetings and conferences.

2.3.8 Volunteers

Volunteers are a critical element to all aspects of wildlife management. Historically, the field of wildlife management has paid lower wages than other disciplines, which makes it difficult to retain good people with required skills. Therefore, many wildlife managers will factor in a percentage of volunteer effort into their programs to accomplish their goals. Individual volunteers are usually enthusiastic about participating because they appreciate the wildlife resource and feel part of the process. They may also see the benefits of their contribution directly through one of their next outings such as bird watching or fishing.

In New Hampshire, loon management would not be in its current condition without volunteer participation. In particular, volunteer labor is required to: perform the annual loon census, assist with collecting biological data, distribute literature, float rafts, house biologists and organize social events.

Volunteers with bird watching experience are selected to conduct the annual loon census from 0800-0900 EDT on the third Saturday of July. Their training is limited to how to fill out a form and where to return it at the end of the day. Many of these volunteers return each year to assist with the census, which yields in an increased year-to-year data consistency.

2.3.9 Organizations Located Outside of New Hampshire

There are a few organizations existing outside of New Hampshire that contribute to the loon research conducted within the state. These include: Biodiversity Research Institute located in Falmouth, ME, Tufts University located in Grafton, MA, and the North American Loon Fund (NALF). These organizations continue to contribute significantly to New Hampshire loon research through the participation of their employed scientists, volunteers and students.

The BioDiversity Research Institute, Tufts University and the U.S. Fish and Wildlife Service formed the NELSWG in 1994. In 1996, LPC became involved and the membership and participation in loon research expanded to include about 25 professionals from across the northeast United States and Canada. Individual contributors have various backgrounds and the original intent of the organization was to study the effects of mercury on loons; it has now extended to discussing the effects of lead and general loon management issues. Even though this group meets only once or twice per year, there is more communication and coordination within this group than among previously mentioned groups. LPC staff who attend the meetings capture feedback from this organization and present it to the LPC technical and policy committees, who, consider it for guiding implementation of monitoring and/or management strategies. Feedback from NELSWG has influenced this project by suggesting methods for analyzing the loon data.

2.4 LOON MANAGEMENT POLICY DEVELOPMENT AND IMPLEMENTATION PROCESS IN NEW HAMPSHIRE

2.4.1 Federal and State Role

The U. S. Congress is responsible for all migratory species policy development in the United States. The Migratory Bird Treaty Act developed in 1918 (http://laws.fws.gov/lawsdigest/migtrea.html) is the legislation that protects loons from being hunted. Although the policy oversight responsibility resides at the federal level, state and local organizations have a great influence on this process. Findings or recommendations from a research study, or an idea or concern stemming from the general public can initiate a new policy development cycle (e.g., LPC research supported lead sinker ban legislation).

Because loons are a federally protected migratory bird species, their status is listed according to individual states. The listing process allows for states to be accountable for their protected wildlife resources and to prioritize management efforts accordingly. Loons are listed as a threatened species in New Hampshire, an endangered species in Vermont, a species of special concern in Massachusetts. They are not a listed species in Maine.

Once policy is developed and approved by the USFWS, individual states accept much of the responsibility for its successful implementation. Regarding loons in New Hampshire, NHFG has the overall state implementation authority, and oversees LPC's activities. Figure 1 shows the flow of information and responsibility for organizations involved with the loon management policy development and implementation process.

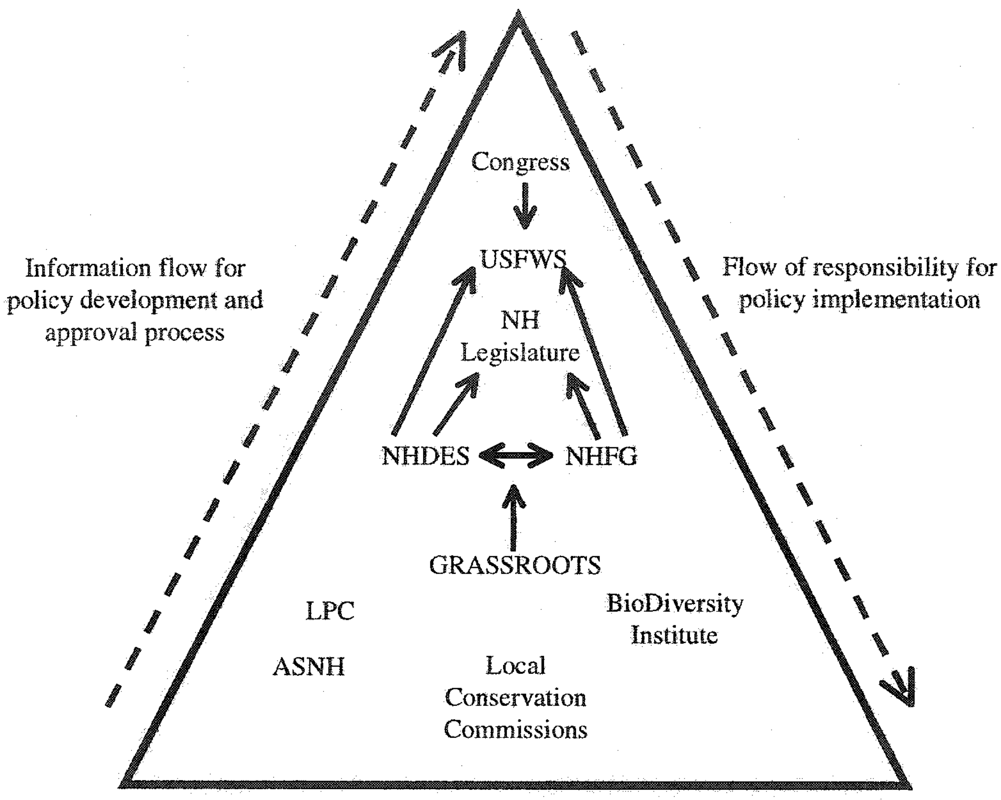


Figure 1. Loon management policy development and implementation process flow.

Legislation that affects loons indirectly may also be invoked at the state level. In this situation, a concern or idea is brought forward and a bill is proposed within either the New Hampshire Senate or House of Representatives. Once it is approved then implementation and enforcement is handled by appropriate state agencies.

2.4.2 LPC Role

The ASNH, Office of State Affairs, monitors current legislation that may affect loons and the surrounding ecosystem. When and if the LPC feels that policy should be altered or new legislation constructed, then it consults with its own policy and technical committees to generate their own recommendation. Next, the LPC coordinates with appropriate local and state agencies and politicians to support the approval process. The LPC is the largest political force for loon management in the state and influences many issues that cross local, state and federal political boundaries.

A recent and local example of LPC's participation in policy development revolves around Squam Lake. Activities on this lake are influenced strongly by the governing SLA and the local residents believe that they should control all aspects of the lake and its resources. The struggle with this control strategy is that it makes it very difficult when the LPC or other organizations attempt to recommend or implement loon management strategies that are not aligned with the Association's charter.

In particular, a conflict arose in which the SLA supported the closure of the one and only public access boat ramp that is used by the public. The NHFG proposed alternative sites to locate a public ramp, which the LPC was asked to review. Some of the sites were acceptable, however, the residents around the lake pooled their money, purchased the land for the proposed new sites and forced a decision to retain and redesign the existing public ramp. During this process LPC was also invited to present information at a local hearing regarding the impacts to LPC's research and development efforts, which have been ongoing on this lake for more than 28 years.

The banning of lead sinkers on New Hampshire's lakes and ponds is another recent example of LPC's engagement with policy development in New Hampshire. Lead sinkers are the most significant contributor to adult loon mortality in New England (Pokras, et al., 1992; Miconi, 2001). A press release was issued by LPC regarding this finding and Rep. Jeb Bradley developed and introduced a bill to ban the sale and use of lead sinkers in New Hampshire. This bill was tabled because the Environmental Protection Agency was developing similar, and more restrictive, legislation that would have overridden the New Hampshire bill.

Three years passed and no legislation had been developed so the LPC issued another press release which Rep. Bradley saw again and consequently resurrected his original bill. He failed to communicate to anyone the development of this bill resulting in little support from any organization. In particular, the NHFG decided to oppose the bill because they wanted a voluntary policy towards lead and were not included in the policy development process.

New Hampshire Senator Carl Johnson Sr. (LPC policy Board member) became aware of the lead sinker bill and decided to support it. He along with others rallied support for this bill from other organizations including WalMart, ASNH, Trout Unlimited and finally the NHFG. LPC became involved with supporting this bill by analyzing the loon database, preparing maps showing the locations of loons affected by lead poisoning, outreach activities (e.g., distributing literature at boat launches) and testifying before the New Hampshire Marine and Wildlife Resources Committee.

Separate versions of the bill were passed through both the New Hampshire House of Representatives and then the New Hampshire Senate with amendments. Because of this, a special committee of conference comprised of equal numbers of members from the New Hampshire House of Representatives and the New Hampshire Senate were required to evaluate, modify and provide final approval. The final legislation restricts the use but not the sale of lead sinkers of one ounce or less and lead jigs of one inch or less on lakes and ponds in New Hampshire, but not rivers (RSA 211:13-b).

2.4.3 Successes and Challenges within New Hampshire Loon Management Structure

In 1975, LPC was formed as a self-funded organization within the ASNH. This occurred because the loon population in New Hampshire was depressed due to poor management practices prior to the early 1970s. The charter of this committee was to monitor the loon population and educate the public regarding the preservation of the remaining population. It has turned out to be a tremendous success and is now recognized as a leading authority on loon research in the country. The success of LPC is based on: 1) collecting data in a consistent manner from year to year despite changes in seasonal staff, 2) concentrating efforts on educating the public, and, 3) communication both internally and externally (between ASNH & LPC) with other organizations participating in loon management.

Since the inception of the LPC, other organizations have become involved with loon management practices. They are of varying size, corporate structure and have different institutional missions that affect the loon population, whether directly or indirectly. Communication and coordination of activities among all the different entities conducting loon management in New Hampshire has been, at times, frustrating. This situation is attributed largely to a lack of time for representatives of each organization to visit with each other on a regular basis and coordinate activities.

Efforts to expand external coordination were enhanced in the early 1990s when the LPC expanded its program. This provided more people to conduct research and interact with outside organizations. An example of the expansion is the research reported in this dissertation, which is a cooperative effort with the University of New Hampshire. Another example is highlighted through the lead sinker ban policy development process. During this process communication with the general public was enhanced because staff associated with multiple organizations cooperated with each other to distribute information to the public regarding the effect of lead poisoning on loons.

The Northeast Loon Study Working Group (NELSWG) is the newest organization to form (Fall, 1993) and is another success story. Its charter is to provide a forum within which practitioners in loon research and management can coordinate loon activities across the northeast United States and exchange information about their work while protecting the privacy of individual research in a non-threatening manner. The NELSWG meets twice per year. Approximately 40 people from the northeast and Canada attend each meeting. NELSWG members who participate from New Hampshire are from the LPC and USFWS only, so the benefit to New Hampshire is for these organizations to see what is happening in other states. The response to the formation of this organization is good and it is anticipated to continue for the next few years.

2.5 FINDINGS

2.5.1 Results of Current work on loon Management in New Hampshire

Results from this portion of the research are specific to either LPC or organizations external to LPC. They are operational and organizational in nature and enabled by results from other portions of this research, e.g., loon database development.

2.5.2 LPC Specific Results

LPC has monitored loons in New Hampshire for 28 years and amassed a large biological database during that time. Through this study, operational and organizational needs were identified including:

- A digital database by converting biological records from paper to a digital format to support answering biological related questions.
- Refinement of data collection methods and parameters collected by summer biologists.
- Enhanced outreach to the general public.
- Implementation of mapping functionality for analyzing and displaying spatially related data.

A loon database, which is queried regularly to answer biologically related questions, now exists on-line at the Loon Center headquarters in Moultonborough, New Hampshire. During the last 3 years the database has been analyzed to address loon management questions such as: is the loon population in New Hampshire increasing through time.

Geospatial technologies including GIS tools were installed at LPC to provide biologists with mapping capabilities using the data stored within the loon database. Using hand-held GPS technology rather than estimating nest locations from a USGS topographic map enabled the addition of a reliable spatial component to loon database.

Standard Operating Procedures (SOPs) were developed for collecting field data, handling and transporting injured birds, and floating rafts to be used as artificial nesting sites. The field data collection protocols were updated so that additional information would be collected to support future analyses, and to improve data collection consistency among biologists, and from year to year. A combination of collecting revised data and storing it within the loon database has led to a streamlined process for producing year-end status reports.

Two other results derived from this research are the establishment of an LPC website (www.loon.org) and enhanced communication with the general public. The website was created in 1997 and has provided a mechanism for Internet savvy individuals to learn more about LPC and to communicate remotely with the organization. It has proven to be an extremely important and useful tool because messages can be sent 24 hours per day while the Loon Center is open from 9-5 daily. To date, four messages concerning stressed loons have been received and acted on outside of normal Loon center hours. The website receives other requests for information concerning the Loon Center, research activities, how to become a volunteer, social calendar and membership.

Educational programs have also been enhanced through this research effort by providing new information and technology for use in special programs and general distribution to the public. In particular, a computer based Geographic Information System (GIS) is used extensively for analyzing and viewing the spatial relationships of data within the loon database. This system resides on a desktop computer allowing the results of map queries to be viewed on a large monitor. This tool has been instrumental in showing groups of people maps of loon nest site locations and how their distribution around the state has changed through time.

2.5.3 Local, State and Federal Organization Specific Results

Results of this research have had positive impacts to local, state and federal government organizations. For example, portions of the data contained within the loon database (developed through this study) were analyzed by LPC and used to support the development of the policy on banning lead sinkers in New Hampshire lakes and ponds. Specifically, reports on loons that died from lead poisoning were extracted from the database for review and a map was prepared showing the locations of affected birds. This demonstrated the point that lead poisoning was a widespread rather than localized problem. The LPC was also responsible for coordinating and interacting with individuals from other organizations including politicians, NHFG, USFWS and Tufts University.

The nest site location GIS layer, also created through this research, is used by the New Hampshire Department of Environmental Services Wetlands Bureau to check compliance with the New Hampshire Shoreland Protection Act. They use the digital layer in their GIS for reviewing and approving building, or other shoreline improvement permits that are located within, near or adjacent to wetlands. The layer that was created through this research has been supplied to the NH Wetlands Bureau so that they have the most recent information for their approval process. The layer that they were using contained approximately 60% of the true nest locations in the state.

2.5.4 Community Based Management Strategy

Current resource managers are under greater scrutiny to achieve sustainability than their predecessors. There has been a conscious shift from the reactive/crisis management style to the proactive approach that strives for ecological balances. The higher demand on managers is in part a result of educational efforts during the 1970's that raised the awareness of conservation issues to the general public. Also, in the 21st century, professionals have a more active management role, and the general public is participating more in activities that help achieve and sustain biodiversity.

Hybrid wildlife management approaches are also beneficial when staff resources or budgets are constrained. This approach combines multiple management approaches to provide the most efficient solution for the current management issue. One hybrid method involves a community-based ecosystem approach in which a group of individuals and organizations cooperate to manage a system of resources for sustainability (Salafsky, 1995; Robinson and Redford, 1994). The assumptions associated with a successful community-based ecosystem management style are to: 1) strive to preserve the variety and variability among living organisms and the ecological complexes in which they occur (biodiversity); 2) maintain ecological processes and support systems (sustained development); 3) understand ecological limits and opportunities; 4) identify and recognize needs and rights of people involved; and to ensure that 5) resource management regulations are coordinated with respect to effects on the rest of the ecosystem (Salafsky, 1995).

The current management of loons in New Hampshire is an excellent example of a wildlife resource that is governed by a successful community based ecosystem management technique. It represents the culmination of numerous concentrated efforts by multiple organizations over the last 28 years. Although successful, this management style is not widely recognized by all of the contributors, and coordination among individuals has been difficult.

The successful management of loons in New Hampshire is due largely to the efforts of the LPC. The full time staff and summer loon biologists are very dedicated individuals who are responsible for seasonal data collection and interact with the public. Currently, research and education efforts that involve monitoring and studying all aspects of the ecosystem and sub-systems which are critical to the survival of the loons in New Hampshire are ongoing. Some of these sub-systems, the organizations involved, and management responsibility are found in Table 1.

Table 1. Organizations involved with loon ecosystem management.

System/Resource	Managing Organization	Management Responsibility
Open water	NHDES; UNH Lay Lakes Monitoring Program	Quality of water and fishery
Lands adjacent to loon habitat	Local Conservation Commissions; Private Landowners; Local Associations, Society for Protection of New Hampshire Forests	Runoff, shoreline development, nest site quality and quantity, habitat protection
Shoreline Development	NH Wetlands Bureau	Quality and quantity of nest sites, reducing erosion and contaminants due to runoff
Fisheries	NHFG	Quality and quantity of food source, lead sinker ban enforcement
Common Loon	USFWS; NHFG; LPC	Species preservation

A large interdisciplinary team, now vital to sustaining the loon population in New Hampshire, includes private citizens, engineers, and scientists. This group is largely volunteer based, but allows for paid staff to update previous management plans, and strategies. The biggest problem faced by this community based management structure is the coordination of organizations that manage different ecosystem components. The NELSWG is the first attempt to coordinate management activities on this level for the northeast region of the United States and Canada. It is viewed as a success because researchers from multiple states and provinces are collaborating on research efforts, sharing information openly and addressing loon management requirements across larger ecosystems rather than small independent regions. Fortunately, some of the leaders of this organization are from New Hampshire and the benefits from NELSWG are transferred directly to those involved with loon management in this state via established co-working relationships and the internet.

The hybrid community based management approach used in New Hampshire has contributed to the success of returning the loon from the grips of population collapse to a near sustainable condition. In concert with this, development of conservation policies such as the banning of lead sinkers have also played a major role in implementing this recovery. Further analyses of the loon database created throughout this dissertation effort may be required to support the creation of additional loon management policies as needed.

2.6 CONCLUSIONS

The work performed under this research has positively impacted loon management in New Hampshire. Some of the notable achievements are:

- LPC's education program is enhanced by providing new information that is used in special naturalist programs.
- A digital database containing loon biological data is resident at LPC headquarters and is used for extracting information in responses to general questions and new policy development both internal and external to LPC.
- A Geographic Information System (GIS) is located at LPC and used for showing digital maps and animations during special programs.
- The digital loon database was used to support the development and approval

of a bill to ban lead sinkers on New Hampshire lakes and ponds.

- The New Hampshire Wetlands Bureau uses the digital loon database extensively for shoreline building permit approval.

2.6.1 Future Research

The future of the loon in New Hampshire is determined largely by the efforts of the LPC. Wildlife managers associated with other organizations such as the Lakes Region Water Commission, NHFG and USFWS will also continue to have a positive impact on loons in New Hampshire through their data collection and public education efforts. An important element to the preservation of loons in this state will be more and frequent communication among all loon mangers in New Hampshire and other states with significant populations (e.g., Maine, Michigan, Wisconsin and Minnesota).

Ideas for future work include:

- Creating one loon management organization that is designated with directing loon management in New Hampshire. This could be achieved by restructuring an existing organization, such as the LPC, or by creating a new organization. The new organization might report to USFWS to promote consistent management practices and eliminate redundancy of efforts, which are currently caused by miscommunication and political differences.

- Further evaluate portions of the spatially related loon database to determine new policy needs. An example of this would be to review the database to determine if a need exists for developing and enforcing a bill that restricts aquatic recreational traffic within formal specific nest site buffer areas.

- Monitor through time the potential loon habitat identified in this research to see if predicted water bodies are being used, and if so develop legislation to protect selected land or coordinate with land trusts and other organizations to obtain conservation easements.
- Establish formal procedures to distribute portions of the loon database to requesting organizations for research use.
- Integrate additional GIS tools for future analysis and presentations.

CHAPTER 3

LOON DATABASE AND MANAGEMENT SYSTEM DEVELOPMENT

3.1 INTRODUCTION

The Common Loon (*Gavia immer*), referred to as loon, is a migratory species that will travel hundreds of miles between summer and winter ranges (Kerlinger, 1982). In New England, this species uses fresh water bodies for summer habitat and reproduction, and often travels a relatively short distance to the nearby North Atlantic coast to winter (Blair, 1992; Evers, 2003). Through limited banding recovery efforts, it is known that some loons from New England travel to the Gulf of Maine, and some winter along Long Island Sound.

Understanding the population characteristics and spatial distribution patterns of loons is necessary prior to generating models that describe its current or future habitat trends. This study is focused on understanding the population and colonization patterns associated with its summer range found within the state boundary of New Hampshire.

The remainder of this chapter reviews: 1) loon characteristics, 2) data requirements for exploring the summer range colonization patterns of loons found in New Hampshire, 3) a system designed for managing and analyzing loon data, and, 4) general observations derived from initial analysis. Specifically, the following areas are discussed:

- Loon characteristics including lineage, physical features, habitat and survival.

- Development of a loon database and management system.

- Field methods for collecting loon biological data associated with individual loon nesting sites in New Hampshire during the 1976 - 2002 field seasons.

- Conversion of all manually collected biological data to a geo-referenced digital database.

- Procedures for geo-referencing all nest sites.

- Strategy for collecting and creating ancillary geo-referenced data layers to be used in ESRI ArcView GIS.

Specific objectives of this research include:

- Developing a digital database by: 1) converting hardcopy data collected by LPC staff back to 1974, and 2) acquiring new data sets required for additional analysis.

- Developing and implementing new methods for automating data collection, management and spatial analysis capabilities.

- Developing and implementing new methods for managing existing and envisioned LPC data.

3.2 LOON CHARACTERISTICS

A relatively large amount of literature exists concerning loon biology and management. Much of this work has occurred in the north central portion of the United States including Minnesota, Wisconsin and the Great Lakes region (McIntyre, 1979, 1988). Few papers are available in the open literature that address loon populations in

New Hampshire (Sutcliffe, 1978 and 1980; Blair, 1992; Brennan and Congalton, 1999). Substantial literature is available from publications of specialized organizations such as Audubon Society, Minnesota Department of Natural Resources, The Loon Preservation Committee (LPC) and the North American Loon Fund (NALF). The following review of loon characteristics is required to determine the appropriate data to be collected and analysis procedures.

Loons belong to the Gavidae family (Welty, 1975). A common trait of all gaviid species is that they breed on freshwater water bodies and spend part of their life along coastlines (Kerekes, 1990). Five species of loons are recognized: the Red-throated Loon (*Gavia stellata*), Arctic Loon (*G. arctica*), Pacific Loon (*G. pacifica*), Common Loon (*G. immer*), and Yellow-billed Loon (*G. adamsii*). The Common and Yellow-billed Loon diverged from a common ancestor during the Pleistocene glacial period when North America was divided by a barrier. Breeding habitat was suitable north and south of this barrier. Differences exist among the species as to the time spent between fresh and salt water regimes, the size, configuration and location of each occupied site, and plumage.

Common Loons are found in Alaska, Canada, northern United States, Greenland and Iceland (Evers, 2003). In the northern U. S. and Canada, although normally associated with rural, isolated water bodies, shoreline development has forced behavioral adaptation by loons to maintain breeding on many types of lakes, including those with increased human disturbance (Palmer, 1962). Alvo, 1981; Christenson, 1981; and McIntyre, 1988 have noted that some loons use less favorable nest sites (e.g., marshes) in response to human disturbance. In New England, loons are found on freshwater lakes during the summer where they sleep, eat, protect territory, and raise young (Kerekes, 1990; McIntyre and Barr, 1997). They spend the winter near bays and harbors along the north Atlantic coast.

The loon's life span is approximately 25-30 years (Evers, 2003). Its breeding plumage consists of glossy black head and neck, white neck collar, checkered black and white back, and white underparts. Winter plumage is dark gray for the head, neck and back, with white cheek, throat and underparts (Peterson, 1961; McIntyre and Barr, 1997; Evers, 2003;). Adult loons have at least 13 rows of white spots on their scapulars and flight feather shafts are black. Its bill is also black and has a slightly decurved culmen (McIntyre, 1988; Kerekes, 1990; McIntyre and Barr, 1997; Evers, 2003). To the untrained observer, loons are sometimes mistaken as Cormorants (*Phalacrocorax* sp.).

The weight of a loon differs geographically and the average is approximately 3.64 kg (8 lbs), some reaching 5.91 (13 lbs) (Klein, 1990). In New England, the average weight for a female is 4.63 kg (10.2 lb) and 5.89 kg (13 lb) (Evers, 2001). Due to its large body size and slow wingbeats, long distances are required for take-off. In flight, loons have a sagging appearance due to drooping neck and feet, but can reach high speeds; migrating birds have been measured at 173 km/h (108 mph).

The loon swims low in open water with a stout dagger-like bill leading its way. It is larger than most ducks with a long body, thick neck and webbed feet. Its overall profile, webbed feet, and strong leg muscles allow it to be an efficient predator and an elusive prey. Typically the loon submerges itself in search of food. It swims fast enough to catch its prey, which consists of small fish and aquatic animals. Sometimes it swims with only its head above water. Loons often dive to approximately 15 m (50 ft), although depths to 61 m (200 ft) have been recorded (Klein, 1990).

The loon is generally silent during winter months. At other times, however, it uses four basic calls: tremolo, wail, yodel and the hoot. According to Barklow (1979), the tremolo call is used to signal alarm or greeting with greater intensity levels indicating higher anxiety. The call is often used when young are threatened. The tremolo is the only call that loons can elicit during flight, and therefore, is used for in-flight communication with other loons. The wail is used to contact other loons and is given in series of five to twenty calls. The call is often used to request a mate to exchange place on the nest. It is also used during night chorusing (Barklow, 1979). The yodel is produced only by the male and is used to control territories. The one-note hoot call is the primary communication between adults and young, for example, to summon chicks to feed (Barklow, 1979).

New Hampshire loon populations winter along the coast from the Gulf of Maine to the Long Island Sound. They return to summer range (breeding areas) usually between 4 and 30 days after ice out (Sutcliffe, 1980). In New Hampshire, summer range for the loon is found on various sized ponds and lakes. However, they prefer larger, open water areas (Lakes > 24 ha) to establish a territory that includes all the requirements for nesting, foraging and chick rearing, and to allow enough space for lengthy landings and departures (Olson and Marshall, 1952; Sutcliffe, 1980; Strong and Bissonette, 1987; McIntyre, 1988).

Christenson (1981) found that one-chick broods in New Hampshire experienced higher survival rates (1.6 chicks/pair) than two-chick broods in Maine. This rate was more than twice the rate (0.75 chicks/pair) measured earlier in New Hampshire by Sutcliffe (1980). McIntyre (1975) found that nearly all chicks fledged regardless of brood size in Minnesota. Analysis of data collected in New Hampshire from 1977-2002 on 86 lakes and ponds shows a mean chick survival rate of 76% (Taylor and Vogel, 2003). Through this analysis it was also noted that lakes greater than 405 ha had significantly more non-reproductive adults (48%), and a significantly lower survival rate than lakes less than 405 ha (3%). The range of lakes examined was 14-18,043 ha.

Predation, water level fluctuation, human disturbances, habitat reduction and toxic poisoning (Longcore, 1990) are the main causes of chick mortality. The raccoon (*Proycyon lotor*) is a predator of loon nests, and their population increases with increased human population and development. Other predators include skunks *(Mempitis memphitis*), mink (*Mustela vision*), common crow (*Corvus brachyrynchos*), herring gulls (*Larus argentatus*), ring bills (*Larus delawarensis*) and ravens (*Corvus corax*). Ream (1976) reported that massive die-offs occurred during 1963-1965 because of pesticide residues. Specifically, adult loons died of high contamination levels and hatching success declined because of eggshell thinning.

Human disturbance can contribute to nest failure. Increased shoreline development has presumably forced loons to nest in lower quality habitats (Alvo, 1981; Christenson, 1981; McIntyre, 1988). Fair (1993) found that water level fluctuations due to hydroelectric plants reduced nest success. However, Sutcliffe (1980) believed that loons can adapt to human disturbance, and, Caron and Robinson (1994) found that increased human disturbance did not influence productivity. Ream (1976) reported that loons are more inclined to abandon nests when disturbed early in the nesting season. Fishing season openings and scheduled water releases can force loons off the nest. Artificial nests (rafts) are used successfully in New Hampshire to offset human disturbance (Wood et al., 1986).

3.3 Study Area

For wildlife applications, study areas are selected based on characteristics of an animal, and the questions being asked about it. Consequently, the parameters to be collected and used for analysis are in part a function of the chosen study area. Therefore, the study area used in this research is limited to the summer range of loons found within the state boundary of New Hampshire. This geographic area was selected because: 1) a substantial amount of biological data dating back to the mid 1970's had been collected for loons in New Hampshire, and 2) a geographic limitation had to be established to perform the geospatial analysis and develop a habitat occupancy model.

New Hampshire is located in the northeast portion of the United States and the climate in this area is moderated by the Atlantic Ocean. Average total precipitation is approximately 106 cm, with approximately 152-203 cm of snowfall (Geraghty, et al., 1973). Significant increases in rainfall during the breeding season can flood nests and result in higher chick mortality.

The elevation in this state ranges from sea level near the coast to 1916 m (6288 ft) on top of Mt. Washington located in the White Mountains National Forest. The average elevation in the state is 342 m (1122 ft) with the highest areas concentrated in the northern portion of the state. Most of the upper elevations are gently rolling hills because they were smoothed over during the last glacial periods.

New Hampshire water bodies are principally fresh water and used by loons during the summer for territory establishment and breeding. This study is confined to examining the occupied loon habitat associated with summer range found on open water bodies within New Hampshire (Fig. 2).

In the higher elevations of the state, it is noted that the density and size of fresh water bodies is reduced. Consequently, loons seeking optimal habitat are usually found in lower elevations. Figure 3 shows the loon nest sites recorded in 2002 overlaid on top of the elevation data for New Hampshire.

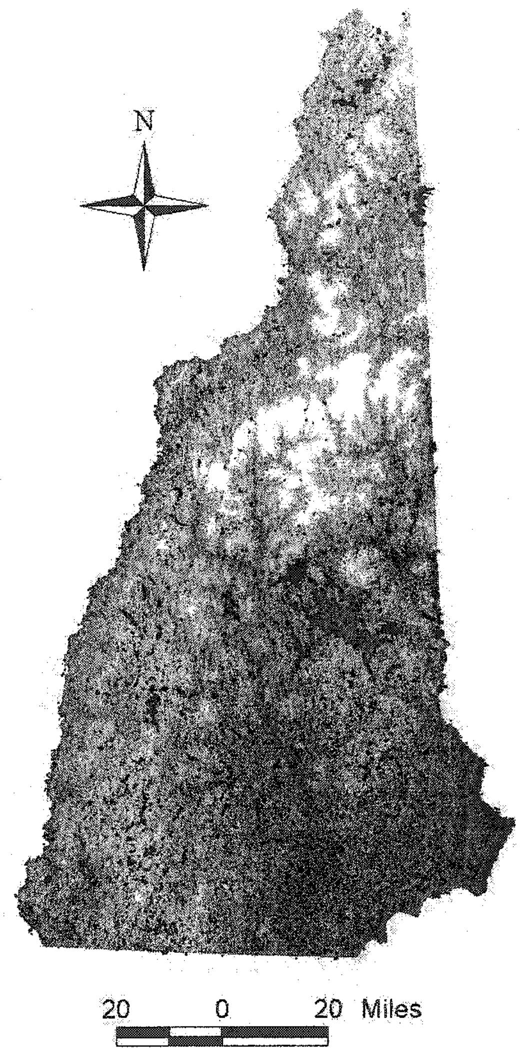


Figure 2. New Hampshire topography with fresh water body overlay (dark areas are lowest elevations and white areas are highest elevations).

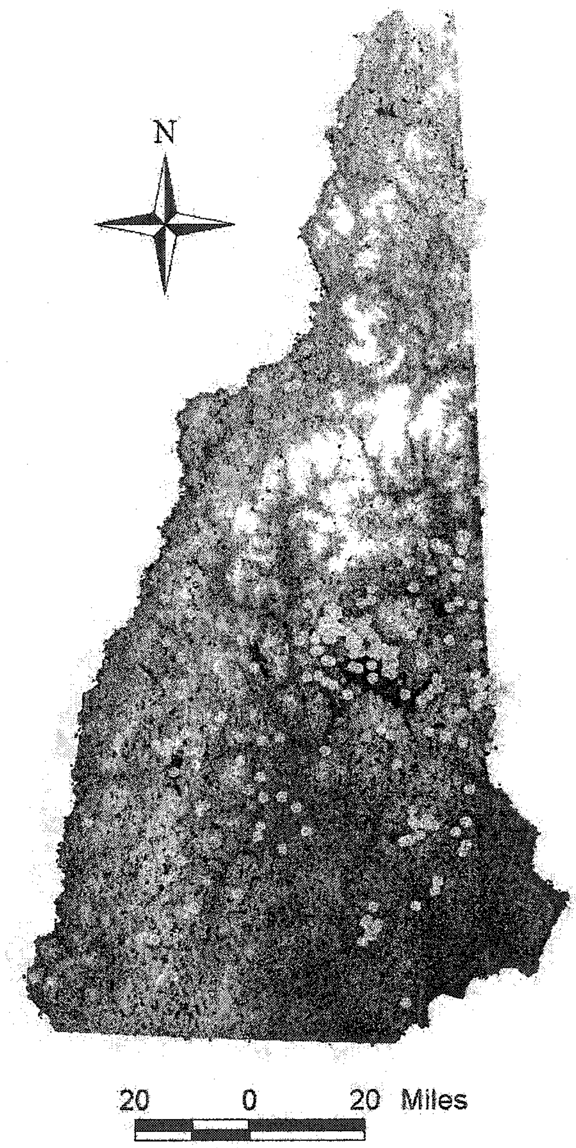


Figure 3. New Hampshire topography with 2002 loon nest sites.

3.4 LOON DATABASE DEVELOPMENT

This section presents a discussion of the data required for this study and the development of a GIS system designed for managing and analyzing these data. Names for specific data tables and variables within the tables are indicated by capital letters (e.g., LAKESIZE).

3.4.1 Biological Data

Each summer since 1974, LPC biologists have collected data associated with territorial loon pairs in New Hampshire. A territorial pair is defined as: a pair of loons defending a territory for at least four weeks and have the potential to breed (Evers, 2003). Field biologists collect information concerning each pair along with other information such as brooding site locations, nest descriptions, disturbances, intrusions, and return rates of banded birds. These data were originally recorded in a field notebook and later transferred to a seasonal *Biological Data Report* form (Appendix B). At the completion of the field season, a *Loon Data Summary Report* (also Appendix B) was compiled to provide seasonal summary statistics.

Currently, data are collected in the field using a *Site Survey Report* form (Appendix C) and then entered into an on-line database using new forms developed within Microsoft Access®. A complete list of all parameters collected for each territorial loon pair is provided in Appendix D. The methods followed for collecting each of the parameters is presented in Appendix E. Appendices F and G describe procedures followed (when appropriate) for handling sick/injured loons, and artificial nesting island (or "raft") protocol, respectively.

In an effort to ease collection and management burdens, the state is broken into eight regions, of which four of the regions are single lake territories. Eight field biologists are hired for 12 weeks beginning the 3rd week in May and are responsible for collecting data in a designated region. Biologists visit the lakes and ponds representing water bodies where loons have either been sighted or maintain a consistent presence. Although the number of staff and number of water bodies monitored has increased with the expansion of LPC's monitoring and management program, present territory delineation and staffing profiles have remained stable since 1991.

Additionally, an annual statewide loon census provides a mid-season check on the productivity of loons around the state. Volunteers are distributed around the state and collect data from 0800-0900 EDT on the third Saturday of July. The data collected during this event are used to supplement the data collected by biologists during the field season. One risk of using this dataset, however, is that it may contain additional errors due to inexperienced volunteers and, therefore the census data are not not included in biological summaries or reports.

3.4.2 Biological Data Conversion

LPC biologists record field data during the field season using the *Site Survey Report* form. Up until 1996, these data were stored on paper only and retained in a filing cabinet. Through this effort, all data recorded from 1974-1996 were entered into a Microsoft Excel® spreadsheet (originally compiled in a proprietary database and FoxPro) and verified to allow for easy maintenance and analysis and retained on a computer workstation available to multiple LPC staff.

3.4.3 Lake Data

Information about fresh water bodies in New Hampshire is fragmented and resides with various agencies. Two primary sources of information used to create the Lakes data for this work are: 1) New Hampshire Department of Environmental Services (NHDES) lake data (Varney, et. al., 1994), and 2) a lakes GIS layer obtained from the Geographically Referenced Analysis and Information Transfer System (GRANIT http://www.granit.sr.unh.edu/ described in section 3.4.6).

The NHDES retains an official list of approximately 732 publicly owned water bodies in New Hampshire (Varney, et. al., 1994). These water bodies are identified as natural lakes or natural lakes raised by damming, and must be at least 4.1 ha or larger. According to New Hampshire RSA 4:40-A, NHDES also defines a great pond as a public water body of more than 4.1 ha (Springs, 1999). However, the great pond definition can include artificial impoundments that are not included in the official list of public waters.

NHDES also collects biological (microorganism levels, e.g., zooplankton), chemical (chemical analysis, e.g., nitrate level), and morphological (physical attributes of the water body, e.g., depth) data for selected lakes, some dating back to the 1970's. Up to thirty-six parameters are collected for each lake. A Microsoft Excel® table (LAKES) was created to capture selected NHDES water body parameters (Appendix H).

3.4.4 Fishery Data

The Loon feeds on fish as its main source of food. Information regarding fish species for selected lakes in New Hampshire was retrieved from the New Hampshire Fish and Game Fishing Guide (NHFG, 1999). Presence and absence information for seventeen fish species, and four lake accessibility codes was entered into a Microsoft Excel® table. A complete list of the fish parameters obtained for this study is provided in Appendix I.

3.4.5 Nest Site Locations

LPC plots the locations of all nest sites on 1:24,000 USGS topographic maps. An initial attempt to digitize all the known nest sites was accomplished by the New Hampshire Wetlands Bureau located in Concord, New Hampshire. This resulted in an ESRI shapefile that included one hundred sixty three nest sites and is used by the wetlands bureau to review building permits that are located near known loon territories and brood sites.

This shapefile was obtained from the Wetlands bureau and used as the initial set of nest site locations for this study. Through this work handheld GPS technology was used to update the locations of existing sites and collect new sites.

3.4.6 Thematic Layers

Digital thematic layers for the entire state of New Hampshire were obtained through the state of New Hampshire Geographically Referenced Analysis and Information Transfer System (GRANIT). These GIS layers are created at the University of New Hampshire's Complex Systems Center by ingesting and modifying 1:24,000 and 1:100,000 Digital Line Graph (DLG) data provided by the United States Geological Survey (USGS). These layers are provided to the GIS user community in an ESRI shapefile (.shp) format at little cost and can be directly imported as a theme into ESRI

ArcView® GIS software.

The layer themes obtained for this research include: open water, streams, topography and transportation. The open water layer is used for referencing all other digital data and contains a table with multiple attributes. The primary attributes used most extensively in this study are: LAKEID, NAME and SIZE. Information within the LOONDATA and LAKES tables are linked to the lake polygon layer using LAKEID as the common parameter.

3.4.7 Loon Data Management System

LPC has collected and retained loon data in hardcopy format since the mid 1970's. Much of this data resides in file cabinets and is distributed among numerous organizations within the state. A major part of this effort was to convert existing analog sources to digital format, and to create new digital data to be used for loon management decision-making.

A large volume of converted and new digital data was generated through this study. Therefore it was necessary to develop a system with the following general data functionality: storage and retrieval, management, analysis and product generation. Through the use of a GIS, wildlife managers find it easier to manage large georeferenced databases that are required for long-term wildlife management applications (Stoms et al., 1992). The application of a GIS for loon management is ideal because it provides the necessary data management and analysis functionality associated with georeferenced loon data.

Microsoft Excel® and Access® were integrated and used exclusively for data entry, organization, maintenance and initial/low-level queries. These tools were selected because: 1) they are easy to use, and 2) widely accepted and available to wildlife biologists. Excel® was used for some basic statistical procedures, however, MathSoft's® S+Plus® and S+SpatialStats® packages were used for the geo-statistical analysis. ESRI's ArcView® served as the GIS engine for this project because of its powerful spatial processing and display capabilities, ease of use and market presence. This tool provides the functionality for creating all the geo-referenced layers and determining loon habitat occupancy.

3.5 RESULTS & DISCUSSION

The following describes the results obtained in compiling the data and developing a GIS based management system for managing loons in New Hampshire.

3.5.1 Biological Data

During 1974 to 1996, field biologist collected loon specific data at 2991 locations. A *Biological Data Report* form, 3 pages in length and containing 46 parameters, was completed at each location. The next task involved entering the data from each form into a Microsoft Excel® table. A quality control check was performed by double-checking all entries to verify that data were transferred correctly and to correct any problems with individual data records. This effort took approximately six months to complete and resulted in a table titled "LOONDATA".

Biologists still use the paper form (*Site Survey Report*) to collect data in the field. However, easy to use forms have been developed to allow the transfer of data directly into the LOONDATA table at any time during the field season. This reduces the risk of data loss and errors that can occur by having someone else transfer the data at a later date. Additionally, report forms have been developed to automate some of the standard end of year reports.

The LOONDATA table includes information that allows for referencing all data to a unique TERRITORY ID, which is related to the GIS nest site layer containing proper geographic locations. Of the 46 parameters identified in Appendix D, the primary parameters that are used for analysis and habitat model development were:

- LAKE ID - identification number of each lake.
- PAIR NUMBER - identification number for each nesting pair for a given water body.
- TERRITORY ID - unique identification number for each loon territory (may or may not include a nest site) located in New Hampshire. This is a new parameter created through this research because PAIRNUMs are not unique. For example, the value of PAIRNUM for the first loon pair identified for every lake is equal to 1, whereas, the value of TERRITORY ID for each is unique. Therefore, the TERRITORY ID scheme has no restrictions and can be used internationally.
- YEAR - year that data were collected.
- NESTED – indication of nesting attempt (yes or no).
- ATTEMPT - nesting attempt number (1, 2, or 3).

- NUMEGGS - number of eggs produced per nesting attempt.
- NUMHATCH - number of chicks hatched.
- NUMSURV - number of chicks that survived for at least six weeks of age.

3.5.2 Lakes Data

Information for 756 water bodies were captured in a Microsoft Excel® table titled "LAKES" (Appendix H). Each entry in the table has eighteen parameters that were compiled based on data obtained from the NHDES official list of public waters and from the open water GIS layer obtained through GRANIT.

The biological, morphological and chemical data collected by NHDES were used on a limited basis to augment the LAKES table. Specifically, values for lake size, mean depth, and elevation were extracted, and for selected lakes used to replace missing values. The remaining data (primarily chemical and biological) were not used in this study because the lakes that are sampled vary annually, and samples are not necessarily collected at the same location on each individual lake.

The parameters used for subsequent analysis and habitat model development in this study were:

- LAKEID - Identification number for the lake.
- LAKENAME - Name of the lake.
- LAKETOWN - Town in which lake is located.
- LAKECOUNTY - County in which lake is located.

- LAKEACRES - Size of the lake in acres.
- SHORELENGTH - Distance in feet around the shore.
- ELEVATION - Elevation of lake.
- MEANDEPTH – Mean depth of lake.
- WATERSHED - Total area (acres) that drains into the lake.
- NUMTERRS - number of loon territories found on lake; this is a new parameter based on information contained in the LOONDATA table.
- PERIMAREA - Perimeter / area ratio; this is a new parameter calculated using SHORELENGTH / LAKEACRE.
- CENTERLAT – Latitude at center of water body.
- CENTERLON – Longitude at center of water body.

3.5.3 Fishery Data

A Microsoft Excel® table (FISH) was developed and includes presence and absence for 17 fish species and four lake accessibility codes. Data were captured for 341 of the lakes contained within the LAKES table. This was a lengthy task and required 75 hours to enter the information into the table from the paperback version of the New Hampshire Fish and Game Fishing Guide (NHFG, 1999). These data are used in Chapter 4 to determine if presence or absence of individual fish species on specific lakes is related to presence and absence of loons.

Three metrics (TOTAL FISH SPECIES, TOTAL WARM SPECIES, TOTAL

COLD SPECIES) were derived to represent the total number of fish species in a given lake, total number of warm water fish species in a given lake, and total number of cold-water fish species in a given lake. This information is analyzed in Chapter 4 for its importance in determining presence and absence of loons at specific lakes.

3.5.4 Nest sites

The locations of loon nest sites within New Hampshire are recorded on USGS 1:24,000 maps. This process is subject to error through the process of locating the nest site on an unstable paper media and pencil. Beginning in summer 1998, the location (latitude and longitude) of each past nest site was also recorded digitally using handheld Global Positioning System (GPS) technology, as were the locations of all occupied nest sites during the 1998 and 1999 field seasons.

A Garmin 45XL handheld GPS unit was used to collect the nest site locations. The manufacturer's specification of accuracy associated with these instruments is approximately +/- 100 meters (Garmin International, 1998) with Selective Availability turned off. To improve on the relative positional accuracy, the position of each nest location was recorded once per minute for a total duration of 15 minutes, and then the average latitude and longitude position was calculated and recorded as the final nest site position. Using this procedure, the relative accuracy is approximately +/- 15 meters, which is sufficient for use with all the GIS data layers obtained through the GRANIT program.

A total of 293 nest site locations were recorded and retained in a Microsoft Excel® table titled "NESTS". These sites were split into two groups, primary and historic, to identify them as being currently used, or used as an alternate site (used if a failure occurred at initial nest site). A nest site location shapefile titled "LOON NEST SITES" was created to show the location of all nest sites within New Hampshire. This was accomplished using ESRI ArcView to ingest the latitude and longitude coordinates for each nest site contained in NESTS. All coordinates were re-projected into New Hampshire State Plane NAD83 (feet) to be compatible with other GIS layers used in this study.

The LOON NEST SITE shapefile was compared to the shapefile created by the New Hampshire Wetland Bureau. As expected, the locations of nest sites did not agree because: 1) the difference in total number of nest sites locations, and 2) differences in positions derived from USGS 1:24,000 maps versus those derived using GPS technology. The final nest site location layers generated through this research were transferred to the New Hampshire Wetland Bureau to update their mapping database.

3.5.5 GRANIT Data

The final open water shapefile (LAKES) was created by importing the open water layer provided by GRANIT and then comparing its contents to the water body information obtained through NHDES. Through this process, parameters (including name spelling and LAKE ID) for approximately 60% of the lake polygons had to be adjusted. This task required approximately 80 hours of labor. The final LAKES shapefile contains 756 lakes and is used within ESRI ArcView to link the LOONDATA, FISH, and the LAKES tables. The LAKEID parameter is the common field used to link the data tables.

Additional layers obtained from GRANIT include: elevation, roads, streams, and political boundaries. The elevation grid served as a quality control source to DES elevation data prior to developing the loon habitat occupancy model (Chapter 4). The political boundary, roads and streams shapefiles are used for visual reference only.

3.5.6 Loon Management System

Historically, all data collected through LPC efforts was retained on paper, stored in file cabinets, and often distributed among numerous organizations within the state. The following describes a management system designed to address LPC's need for data storage, retrieval, analysis and management of loon data within a digital environment.

Figure 4 shows a conceptual diagram for an LPC Loon management system. The GIS engine is the central part of this system and relates all the data tables previously described. Data tables highlighted in blue are tables that are envisioned based on tangent research activities either external to LPC or in preliminary stages. These tables, and others not designed yet, will be integrated once their data formats are mature.

This system is used primarily for managing data collected by LPC, performing complex spatially dependent analysis, and as a decision support tool to allow biologists to better manage the loons within New Hampshire. For example, Using ArcView, LPC biologists can display all the nest sites on a lake, and then query the data to identify the nests occupied in a particular year. Software tools integrated within this system include: ESRI ArcView, Spatial Analyst; Microsoft Excel®, and Microsoft Access®. One specific output from this system is the ability to generate loon habitat occupancy maps as described in Chapter 5.

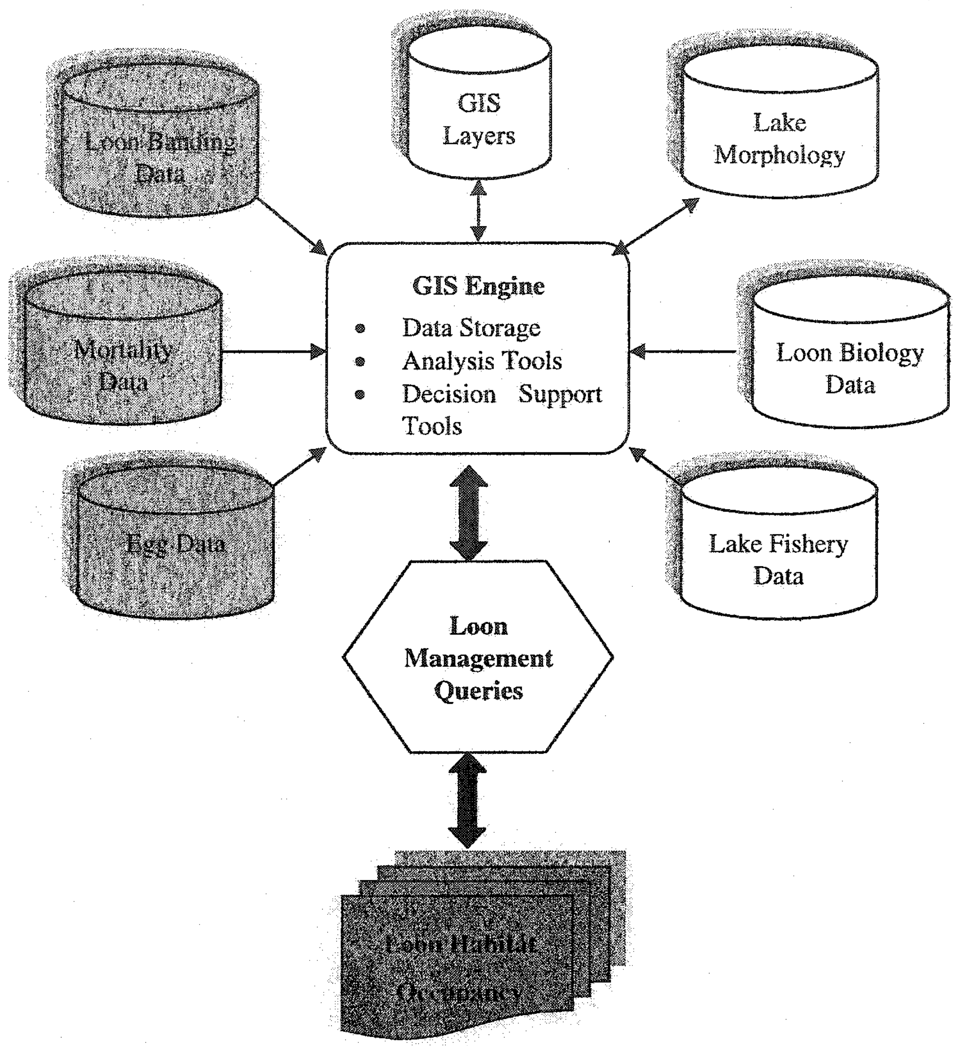


Figure 4. LPC Loon management system conceptual diagram.

3.6 CONCLUSIONS & RECOMMENDATIONS

Data that are required for loon management were obtained, organized and consolidated into one management system. The data were collected by multiple organizations (e.g., LPC, USFWS, BioDiversity) for a variety of reasons dating back to 1974. This effort required many labor hours to obtain the information and convert it from hardcopy format into a common digital format. A significant portion of this effort was dedicated to converting: 1) the biological data collected by LPC over a 29-year period, and 2) the newly acquired data that was only available in hardcopy (e.g., fishery data).

A data management system designed for managing and analyzing loon specific information was also developed through this research. This integrated system is composed of software tools that provide a GIS engine, data management and analysis capabilities. One outcome from the development of this system is that wildlife biologists are equipped with more data and analysis capabilities which allow for making better decisions concerning loon management in New Hampshire. The system is located at the LPC main office in Moultonborough, New Hampshire.

LPC and the Univeristy of New Hampshire sponsored this work. However, the benefits of this work extend far beyond these organizations including: NHDES Wetlands Bureau, NHFG, USFWS, the Northeast Ecosystem Research Group (NERC) and BioDiversity Research Institute (a non-profit organization, based in Maine conducting loon research in North America). Specific benefits realized through this work include:

- Standard operating procedures have been developed for capturing field data at LPC.
- Standard methods are implemented for storing and managing data within a digital environment.
- Standard quality control procedures have been developed for collecting field measurements, verifying field data and checking it after entry into the loon database. Methods for accomplishing this are incorporated in revised data collection forms and operating procedures documented in Appendices

B, C, E, F, G.

- The loon management system was designed with an open concept to address new data and processing requirements.
- Data within the loon management system were extracted, queried and the results used in policy development to ban the use of lead sinkers within New Hampshire.
- Georeferenced digital data layers are updated during each field season and made available to other organizations.
- New research activities have already spun off, and will continue to spin off, from this effort to address new management requirements (e.g., mercury impacts on loons and for developing a loon recovery plan for New Hampshire).

Recommendations for future work include:

- Complete the Loon Management System framework and implement the banding, mortality and egg databases.
- Develop semi-automated methods for data entry and standard end of year reporting.

CHAPTER 4

LOON BIOLOGICAL AND NEST SITE DATA ANALYSIS

4.1 INTRODUCTION

Early reports by New Hampshire naturalists prior to the 1970's indicate that loons (*Gavia immer*) occupied every sizeable lake and there were hundreds of nesting pairs. Loons were so prevalent in the state that seven water bodies are named either Loon Lake or Loon Pond. In 1976 however, only 84 lakes were reported with any loon activity, and of these, only 21 had successful nests (Hammond and Wood, 1976).

In the early 1970's volunteers assisted the Audubon Society of New Hampshire in conducting the first loon census in the state. The reporting mechanism was informal and did not provide sufficient data to produce an accurate census. However, analysis of the data revealed that the New Hampshire loon population was declining and certain territories were unoccupied. Loon populations in states from Maine to Minnesota also experienced declines during this timeframe, with some related to increased human use of lakes (Hammond and Wood, 1976).

In 1975 the Audubon Society of New Hampshire formed the Loon Preservation Committee (LPC) in response to the dramatic decline in historic loon numbers. The original intent of this organization was to: 1) survey the loon population of the state and determine the cause of its decline, and 2) sponsor corrective measures for the protection of the species (Hammond and Wood, 1976). Since its inception, LPC has collected information regarding the presence or absence of loons and loon productivity, and educated the public regarding loon ecology and preservation.

4.2 Objectives

Since 1975 the LPC has collected a great amount of ecological data in New Hampshire, unanalyzed until this research effort. One by-product of this effort was the creation of a digital database where characteristics of the loon population and associated habitat were stored for easy access and analysis. The objectives of this study were to: 1) describe and evaluate the loon population and its colonization patterns associated with its summer range within New Hampshire, and 2) determine the optimal habitat parameters associated with summer range occupancy in New Hampshire. This work supports LPC's original intent of sponsoring corrective measures for the protection of loons.

4.3 Background

A reduction in available habitat induced by human disturbances (e.g., shoreline development) has resulted in the decline of some wildlife species populations (Alvo, 1981; Murphy, 1988). Adjusting for reduced or fragmented habitat as a management technique requires the analysis of geospatial, biological, and habitat specific data for the particular species and its surroundings. Using qualitative and quantitative analysis methods are critical to developing an understanding of the dataset and yielding statistically valid results.

One step in project design is to determine the types of data to be collected and appropriate analysis tools. Initial data used in this research represents a combination of continuous and categorical responses dating back to 1976. Starting in 1996, hand-held

GPS units were used to collect the position (latitude and longitude) of all nest sites while simultaneously collecting biological data at the same location. This new spatial data component permitted the development of a georeferenced database and the application of geospatial analyses that are important to understand spatial relationships. Spatially related data are segmented into three recognized classes: geostatistical, spatial point and lattice patterns (Kaluzny, et al., 1998). Various components of the loon database accommodate these classes and are discussed in conjunction with appropriate analysis methods.

Geostatistical data consist of measurements that are collected at predetermined fixed locations. They may be continuous such as rainfall collected at weather stations or discrete, such as the number of bears captured in a specific culvert trap. For these data it is the variable collected at each location that is of interest for analysis. In this research, the number of loon chicks hatched and the number of chicks surviving to the end of the summer at each nest site represented such data because they provided an annual indication of population health. Variogram, covariogram and correlogram analysis (Isaaks and Srivastava, 1989) were methods used to investigate the potential interactions of distance and direction on chick hatching and survival.

Point pattern data consist of a finite number of locations observed within a spatial region. The location of the point itself is the variable of interest rather than the attribute information that is referenced to the point. In this study, complete spatial randomness computations were used to evaluate clustering of lake centers and individual nest site locations in the state.

Lattice data are regularly or irregularly spaced measurements that are associated with a spatial region. Examples of these data are image layers produced with airborne and satellite remote sensing systems. These data are often subjected to neighborhood analysis to determine relationships between and among spatial regions. Because the locations of loons are irregularly spaced within the boundary of New Hampshire, the Moran statistic was used to evaluate nest site spatial autocorrelation.

Qualitative and quantitative spatial analyses are used to describe relationships of spatially related events through space and time (Cressie, 1993). These methods are powerful for comprehending spatial distribution trends and demonstrating the ability to analytically describe spatial patterns associated with conservation biology, climate change, habitat, or wildlife management (Kaluzny et al., 1998). Guisan and Zimmerman (2002) recognized that predictive statistical techniques were useful for developing habitat distribution models. However, Store & Kangas (2001) and Rossi et al. (1992) preferred the coupling of spatial statistics and visualization tools for planning, managing and displaying geospatial results. The use of combined geostatistical and visual analysis tools is rising because they are effective and convenient for integrating spatially enabled empirical models, and presenting results of species distribution analysis in relation to their present environment (Store and Jokimaki, 2003).

A Geographic Information System (GIS) is an example of a combined qualitative and quantitative spatial data analysis tool. The power of a GIS is demonstrated by its use in many disciplines (e.g., urban planning, emergency response, and wildlife management) for analyzing spatial data relationships and providing advanced decision-making capabilities (Burrough, 1986; Maguire, Goodchild and Rhind, 1991; Congalton and

Green, 1992). An example is the use of GIS tools for preserving wildlife populations by implementing habitat occupancy or preference models (Agee, et al., 1989; Gagliuso, 1991; Perira and Iami, 1991; Ringelman, 1992; Congalton et al., 1993). Many local, state and federal organizations find it easier to use GIS to manage large georeferenced databases required for sustaining long-term wildlife populations (Stoms, et al., 1992).

Geospatial trend analysis is another important technique for exploring data relationships over time with both qualitative and quantitative approaches. One prerequisite is that data be collected with temporal structure. This is easily achieved by using GPS technology that enables the collection of geographic location with each data entry. In this study, GIS-based trend analysis software provided a qualitative method for evaluating georeferenced nest site, water body parameters, and nest site occupancy through time.

Ordinary regression analysis offers a quantitative alternative for trend analysis. It is used to determine a function that relates a continuous outcome variable (dependent variable y) to one or more predictors (independent variables x_1, x_2, etc.). All variables are measured and the relationship is assumed to be linear. Simple linear regression assumes a function of the form (Clark and Hosking, 1986):

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

where,

Y_i = value of the dependent variable at the i^{th} observation,

β_0 = y-intercept value,

β_i = independent variable coefficient for variable X,

ε_i = error term for the i^{th} observation, which is assumed to be a random variable with mean of zero.

Application of linear regression to this research included analyzing the trends of biological measures (e.g., number of nesting pairs) through time.

A variation of ordinary regression is logistic regression, which is particularly useful for understanding observations that are restricted to two values. These values often represent the occurrence or non-occurrence of some outcome event (e.g., species presence or absence) and are usually coded as 1 or 0, respectively. The final form of the function takes on the shape of an "S" and is developed through an iterative approach. The resulting formula is used to predict the probability of the occurrence as a function of the independent variables (Hosmer and Lameshow, 1989).

Many categorical response variables are recorded as binary values. For instance, lake occupancy is described as presence (1) or absence (0) in the loon data. In this research, logistic regression was valuable to identify important variables for predicting loon occupancy of New Hampshire lakes.

4.4 Study Area

In wildlife applications, study areas are selected based on characteristics of an animal and the questions of concern. Consequently, the parameters to be measured and data collected for analysis are, in part, a function of the study area. In this project, the study area was limited to the summer range of loons within New Hampshire. It was selected because: 1) a substantial amount of biological data dating back to the mid 1970's had been collected for loons in New Hampshire, and 2) a geographic limitation had to be established to perform the geospatial analysis and develop a habitat occupancy model.

New Hampshire is located in the northeast portion of the United States with a climate moderated by the Atlantic Ocean. The elevation in New Hampshire ranges from sea level near the coast to 1916 m (6288 ft) on top of Mt. Washington, which is located in the White Mountain National Forest. The average elevation in the state is 342 m (1122 ft) with the highest areas concentrated in the northern region. Most of the upper elevations are gently rolling hills because they were smoothed over during the last glacial periods. The Monadnock region provides the highest topography in the southern portion of the state. Average total precipitation is approximately 106 cm, with approximately 152-203 cm of snowfall (Geraghty et al., 1973). Substantial rainfall during the nesting season can flood nests and result in high nest loss and chick mortality.

The distribution of freshwater lakes in the state is a result of previous glacial periods that created most lakes at lower elevations (Okrant and Clark, 2005). The median elevation of lakes is 824 meters and the average lake elevation is 945 meters. This study was confined to examining loon occupancy associated with summer range found on open water bodies within New Hampshire (Fig. 5).

At higher elevations of the state, it was noted that the density and size of fresh water bodies is reduced. Consequently, loons seeking optimal habitat are usually found at lower elevations. Figure 6 shows loon nest sites occupied in 2002 overlaid on elevation data for New Hampshire. Higher concentrations of nest sites were particularly apparent

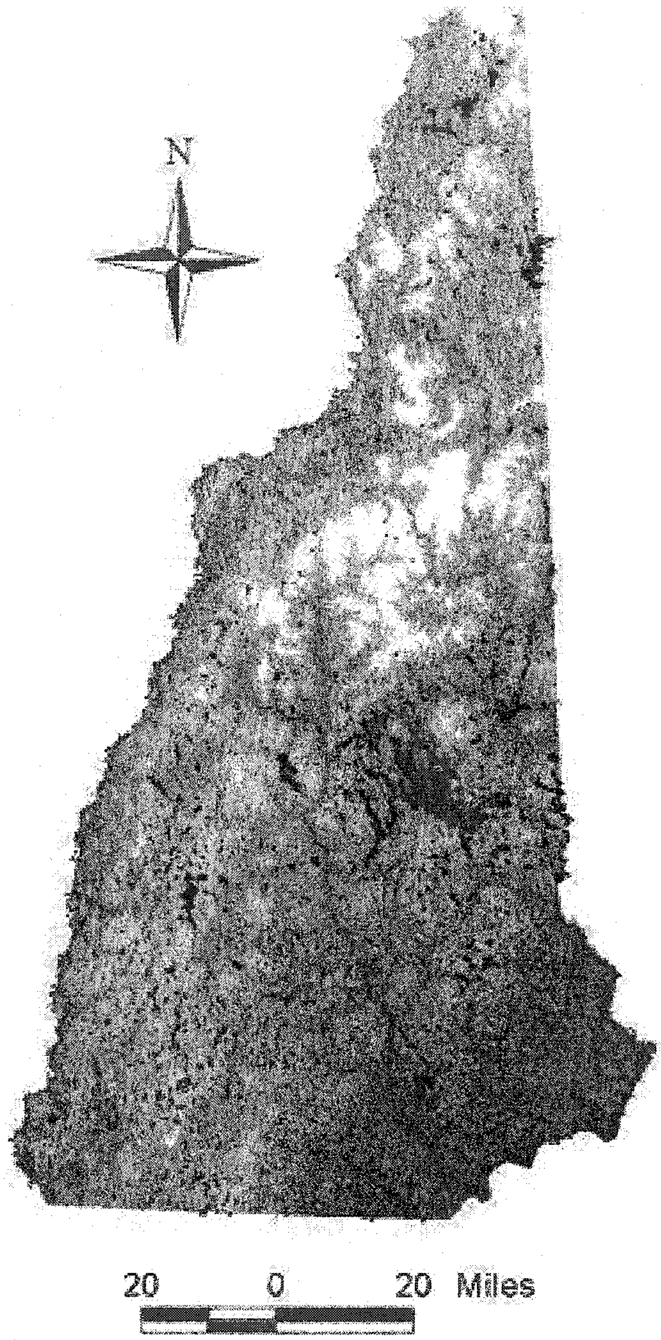


Figure 5. Digital Elevation Model (DEM) and fresh water body overlay for New Hampshire. Dark areas are lowest elevation, white areas are highest elevations and blue areas are water bodies.

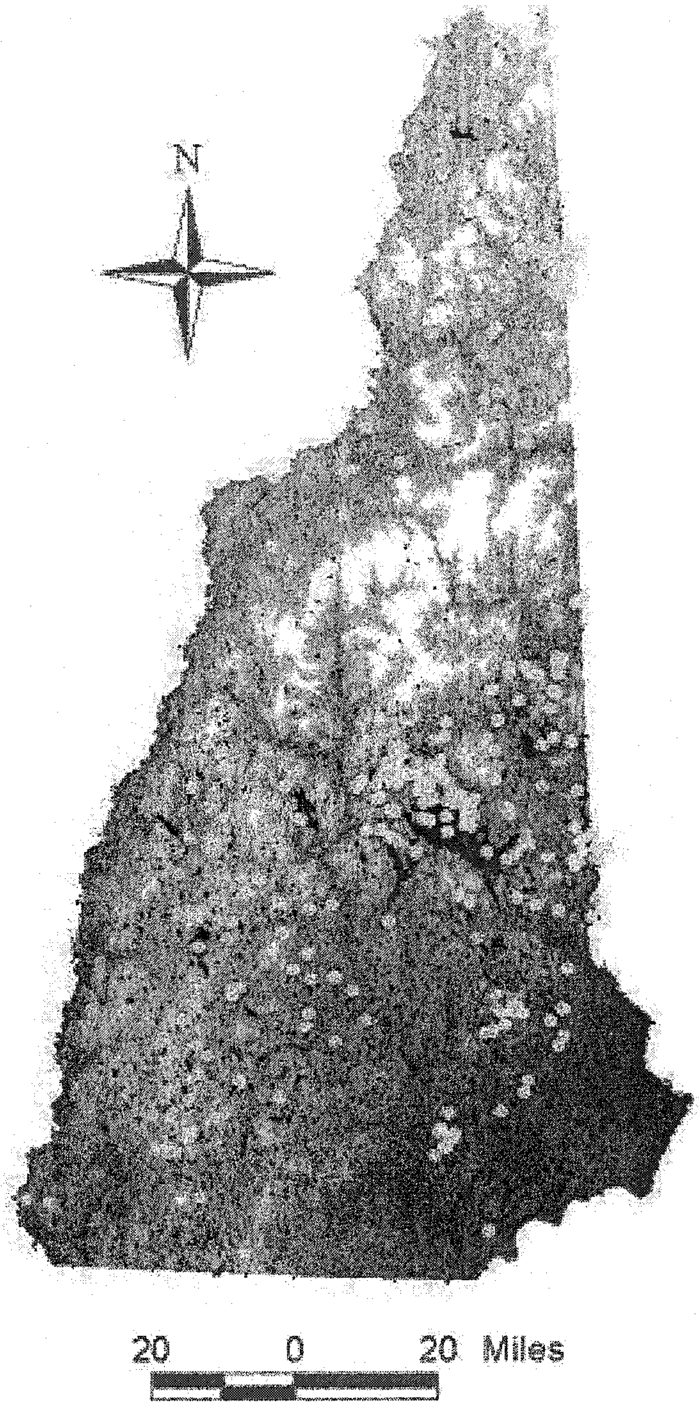


Figure 6. Digital Elevation Model (DEM), fresh water bodies and 2002 nest site locations for New Hampshire. Dark areas are lowest elevation, white areas are highest elevations, blue areas are water bodies and yellow dots are loon nest sites.

for two of the large water bodies in the south central portion of the state (Squam and Winnipesaukee) and for one lake in the north (Umbagog).

4.5 Analysis Methods

Visual and quantitative data analysis methods were used to identify general characteristics of the spatial and non-spatial related data referred to in Chapter 3. Results were used to identify habitat occupancy variables that would be most useful to include in a model for predicting the presence/absence of loons. Generating valid habitat occupancy models requires correct inputs; therefore, all parameters were carefully reviewed before analysis to identify and extract parameters related to New Hampshire loon habitat occupancy.

Tools provided within Mathsoft's S-PLUS4 and S-PLUS6.2 (MathSoft, 1997a, 1997b, Insightful, 2001), SAS (SAS Institute, 1996), SPSS (SPSS, 1997), and Microsoft Excel® analysis software were used for exploring non-spatial relationships. The S+SpatialStats module (Kaluzny, et. al., 1998) is an add-on to the S-PLUS4 application and was used to explore geospatial relationships. Results obtained using spatial data analysis techniques may be subject to individual interpretation. Therefore, careful examination of all data and methods was required to ensure complete and valid results.

4.5.1 Loon Data

The loon data used in the following analyses were developed in Chapter 3 and included: loon management, lake characteristics, lake-specific fish species composition, watershed characteristics and measures of human access to various lakes. Microsoft

Excel® and ESRI ArcView® were used to provide summary statistics of selected variables within the data tables: LOONDATA, FISH, and LAKES.

The initial list of variables used to evaluate the spatial distribution of loons included: nest location, nest type, number of eggs, chick survival, lake size, lake access, shoreline/lake area index, and fishery type. This list of parameters was examined to provide general information about loons and habitat use within New Hampshire.

4.5.2 Visual Data Analysis

4.5.2.1 Tracking Analyst

Loons frequently occupy the same territory for consecutive years. The locations of all territories within New Hampshire are well known and documented since 1976 by LPC biologists. Understanding the past, current, and future distribution of nest sites within New Hampshire was a primary focus for this study.

The ESRI Tracking Analyst was used to animate the location of nest sites occupied annually from 1980-1995. To do this, a NEST SITE LOCATION theme was loaded into the Tracking Analyst and linked with the LOONDATA table. The YEAR parameter within LOONDATA provided the information required by the Tracking Analyst to display all occupied nest sites in yearly increments.

4.5.2.2 Spatial Autocorrelation

Spatially related data are composed of measurements that are collected at known locations and it is important to know whether any geospatial interactions (autocorrelation) exist among the collection points and, if so, their influences on surrounding points.

Positive spatial autocorrelation means that nearby measurements have similar values or characteristics, and negative spatial autocorrelation means that nearby measurements have dissimilar values or characteristics. Lake size georeferenced to lake centers, productivity (number of chicks hatched/number of eggs produced) and survivorship (number of chicks surviving at the end of the season/number of chicks hatched) georeferenced to nest site locations composed the spatial dataset examined for spatial autocorrelation.

The first analysis was a test of complete spatial randomness (CSR). Diggle (1983) defined CSR by two criteria: *intensity* (number of points per unit area), and *interactions.* For a spatial point pattern to exhibit complete spatial randomness (lack of clustering), its intensity does not vary across a bounded region (New Hampshire in this study) and no interactions may exist between or among each other.

Nearest neighbor distances provide an objective method for understanding relationships among point locations at various scales. The distances can be calculated and compared to characteristics of random patterns. Point-to-point neighbor analysis compares the relationship of one point location to its nearest neighbor. An empirical distribution function (EDF) of the point-to-point nearest neighbor distances was computed and plotted to evaluate CSR. The EDF is defined as:

$$\hat{G}(y) = n^{-1} \sum_{d_i \leq y} 1$$

where,

$\hat{G}(y)$= proportion of points in a spatial point pattern within a distance y of their nearest neighbor,

y = distance to nearest neighbor,

n = number of observations in the region of interest,

d_i = distance from the i^{th} point to the nearest other point in the region of interest.

Point-to-point EDFs were compiled using lake centers and nest site locations. An EDF plot that shows an excess of short distance neighbors indicates that the points exhibit clustering. If there is regularity in the data, then the plot will show a larger number of long distance neighbors. The outcome of CSR analysis was used to support spatial autocorrelation analysis.

A second method for evaluating CSR is to compute an origin-to-point neighbor statistic ($\hat{F}$). This statistic is related to the $\hat{G}$ statistic because it is defined by overlaying a grid on top of the entire spatial region, and then comparing the origins of each grid intersection to their nearest neighbors. The EDF for this statistic is defined as:

$$\hat{F}(x) = m^{-1} \sum_{ei \leq x} 1$$

where,

$\hat{F}(x)$ = proportion of points on a grid within distance y of the nearest point in the original pattern,

x = nearest neighbor distance from a grid origin to the nearest other point in the region of interest,

m = number of origins in the region of interest,

e_i = distance from the i^{th} grid origin to the nearest other point in the region of interest.

The interpretation of the $\hat{F}$ plot is opposite of that for the $\hat{G}$ plot. An EDF plot that shows an excess of longer distance neighbors indicates that the points exhibit clustering.

Environmental condition changes such as higher than normal annual precipitation or major storm events may have short-term impacts on productivity or survivorship (Rossi, et al., 1992). Therefore, non-directional and directional variograms and correlograms were generated to visually detect any directional spatial autocorrelation associated with loon productivity and survivorship.

The variogram provides a description of how data are related, or correlated, with distance. The semivariogram is defined as half the average squared differences between points separated by a distance h (Matheron, 1963). It is calculated as:

$$\gamma(h) = \frac{1}{2\,|N(h)|} \sum_{N(h)} (z_i - z_j)$$

where,

$N(h)$ = is the set of all pair wise Euclidean distances $i - j = h$,

$|N(h)|$ = is the number of distinct pairs in $N(h)$,

z_i, z_j = are data values at spatial locations i and j, respectively.

The correlogram function is defined as (Kaluzny, et al., 1998):

$$\rho(h) = \frac{C(h)}{C(0)} = 1 - \frac{\gamma(h)}{C(0)}$$

where,

$C(h)$ = covariance of pairs of points separated by Euclidean distance h (the covariogram),

$C(0)$ = is the variance of the random field,

$\gamma(h)$ = is the corresponding variogram.

Directional variograms and correlograms were computed at 0, 45, 90, and 135 degrees to see if trends existed along a specific path. A relatively flat correlogram indicates that data are not spatially correlated.

4.5.3 Quantitative Analyses

4.5.3.1 Spatial Autocorrelation

Spatial autocorrelation exists where points in a dataset influence each other. Spatial modeling may be warranted if a data set exhibits autocorrelation. A common formal measure of spatial autocorrelation is the Moran statistic (*I*) defined as (Cliff and Ord, 1973):

$$I = \frac{n}{A} \frac{\sum_{i,j} w_{i,j} z_i z_j}{\sum_i z_i^2}$$

where,

n = number of spatial regions,

$w_{i,j}$ = the weight for the relationship between observations i and j (zero means no relationship),

$A = \sum w_{i,j}$,

$z_i = x_i - \bar{x}$ is the centered variate obtained from x_i, and

$z_j = x_j - \bar{x}$ is the centered variate obtained from x_j.

The Moran statistic was evaluated for lake centers and nest site locations (referenced to the New Hampshire State Plane NAD 83). The weight (w_i) Lake size, productivity and survivorship for each nest composed the spatial dataset evaluated for spatial autocorrelation. Lake size was used because it was a familiar and reliable physical parameter to describe lakes. Productivity and survivorship were used because they are common metrics used to monitor the loon population in New Hampshire.

4.5.3.2 Linear Regression

Biological data contained within the LOONDATA table developed in Chapter 3 were examined using linear regression to determine relationships in total loon populations, territorial pairs and nest success. From 1976-1979, the total population and the number of paired loons increased rapidly. One explanation for this increase was that the number of LPC staff collecting data during this same period also increased. Due to the uncertainty associated with the data collection methods during 1976-1979, the data analyzed using linear regression was limited to 1980 - 2002.

The formal regression model is (Myers and Well, 1995):

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

where,

Y_i = value of the dependent variable on the i^{th} trail,

β_0, β_1 = Y intercept and slope of the regression line, respectively,

X_i = constant that is the value taken on by the predictor variable on the i^{th} trial,

ε_i = random error component.

It is assumed that the error component ε is independently and normally distributed with mean 0 and variance σ_e^2. Therefore,

$E(\varepsilon_i) = 0$,

$\text{Var}(\varepsilon_i) = \sigma_e^2$,

$\text{Cov}(\varepsilon_i, \varepsilon_i) = 0$.

The loon data in this study were collected annually. Certain measures were dependent on measurements from a previous year, which could lead to a violation of the assumption that the residuals are independent. The Durbin-Watson test statistic (D) formed the basis for a test of serial correlation as follows (Neter and Wasserman, 1990):

$$D = \frac{\sum_{t=2}^{n} (e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2}$$

where,

n = number of samples,

e = residual for time t.

Serial correlated data were adjusted using the least squares based Cochrane-Orcutt procedure to transform the original variable, re-evaluate the Durbin Watson statistic and transform the variable back to its original form (Neter Wasserman, 1990). Tools found within Microsoft Excel® and S-PLUS were used for regression analysis.

4.5.3.3 Logistic Regression

Logistic regression is useful for predicting the presence or absence of a characteristic, or outcome based on values of a set of predictor variables. It is similar to a linear regression model but is suited to models where the dependent variable is dichotomous. Logistic regression was used to identify variables for predicting the presence/absence of loons in New Hampshire, which in turn, were used to develop a statewide habitat occupancy model (see Chapter 5). The data used in this analysis were collected from 1980-1996 and represented loon biology, lake morphology, fish species composition, watershed characteristics, and measures of human access to monitored lakes. Data collected from 1976-1979 were not used because of inconsistency of data collection. Data collected from 1997-2002 were set aside and used to verify the model results (see Chapter 5).

A Microsoft Excel® spreadsheet titled "PRESABS" was created using data contained within the LOONDATA, LAKES and FISH tables described in Chapter 3. The LAKEID parameter was common to all tables and used to link the data from the separate tables. Forty data variables were retained for 654 samples (LAKEIDs). These data were imported into SAS (SAS Institute, 1996) and Mathsoft's S-PLUS4 (MathSoft, 1997a, 1997b) to perform logistic regression analyses. A complete list of variables used in this analysis is provided in Table 2. The dependent variable (Number of Territories) was re-coded into a binary presence or absence value with presence (any number of territories greater than 0) = 1 and absence = 0. This resulted in 106 cases of presence and 548 cases of absence.

Table 2. Potential explanatory variables contained within the loon occupancy (PRESABS) data set.

Lake ID	Watershed Area
Lake Name, Lake town, Lake County	Shore Configuration
Lake Size (acres)	Flushing Rate (Watershed)
Lake Size (sq. miles)	Lake Access
Lake Elevation (meters)	17 Fish Species Categories
Maximum Lake Depth (meters)	Total Fish Species
Mean Lake Depth (meters)	Cold Division (Fish)
Lake Area (feet and meters)	Warm Division (Fish)
Lake Perimeter/Lake Area	Minimum distance to loon-lake (meters)
Shore Length (Perimeter)	Minimum distance to a no-loon-lake (meters)

The "17 Fish Species" category listed in Table 2 represented presence/absence data (t = true for presence) for 17 species of fish that were available for some of the lakes. Fish species definitions are presented in Appendix I. The fish species data were divided into COLD and WARM water divisions and further summarized into the variable coded TOTAL SPECIES. A variable related to accessibility to each lake, LAKE ACCESS, was also re-coded to numeric values and given a new name HUMDIST (human disturbance). The variable values were re-coded as follows: AF, AHA, HA, AR, and AU were all re-coded to A; RF to R; and IF to I. These three nominal values were then re-coded to: A= 1; I = 2; R = 3 to reflect increasing numeric value with decreasing access or human disturbance to the lake (higher value given to more remote access). Human disturbance definitions are presented in Appendix J.

A stepwise binary (presence=1, absence=0) logistic regression model was developed using presence and absence of loons as the dependent variable. The stepwise method is used when correlations among independent variables are present, as in this case. The stepwise method begins by entering into the regression model the variable that has the strongest positive or negative correlation with the dependent variable. At each subsequent step, variables with the next strongest partial correlation are added or removed based on the relationship with the dependent variable. Over-fitting the model and redundancy is avoided by excluding variables that exhibit high correlation with another variable. For example, PERIMETER/AREA RATIO was excluded due to its high correlation with PERIMETER.

Explanatory variables that should be included in the final model are based on the maximum likelihood principle: the best values for the parameters of a model are those for which the likelihood is a maximum. The procedure is iterative as it searches for parameter estimates that maximize the likelihood function predicting loon absence/presence.

4.6 Results

4.6.1 Visual Results

4.6.1.1 Nest Site Location Analysis

The NESTED variable within LOONDATA was segmented into three categories: occupied in current year of analysis, unoccupied for the previous year, or unoccupied for up to three years. Each category was assigned a different color and used to determine changing nest occupancy. An annual increase in the total number of nest sites and their expanding distribution was clearly evident by using the ESRI Tracking Analyst to animate the nest locations through time. Four sequences showing the changes in spatial distributions of occupied nests, each separated by five years, are presented in Figures 7-10. The total number of nests occupied in 1980, 1985, 1990, and 1995 were: 61, 83, 105 and 122, respectively. Green represents current occupancy for the given year, yellow is vacant for one year and red is vacant for up to three years. Visual interpretation showed that most nests remained occupied through time, or unoccupied for only one year. These results supported the need for additional spatial autocorrelation analyses.

4.6.1.2 Spatial Autocorrelation

Figure 6 (section 4.4) shows the locations of nest sites with respect to the lakes and ponds within New Hampshire during the 1996 field season. Review of this figure and the results from the Tracking Analyst suggested that the distribution of nest sites were clustered in areas of higher concentrations of lakes and ponds. This is logical because loons require open water to survive and reproduce. Higher concentrations of nest sites were particularly apparent for two of the large water bodies (Squam and Winnipesaukee)

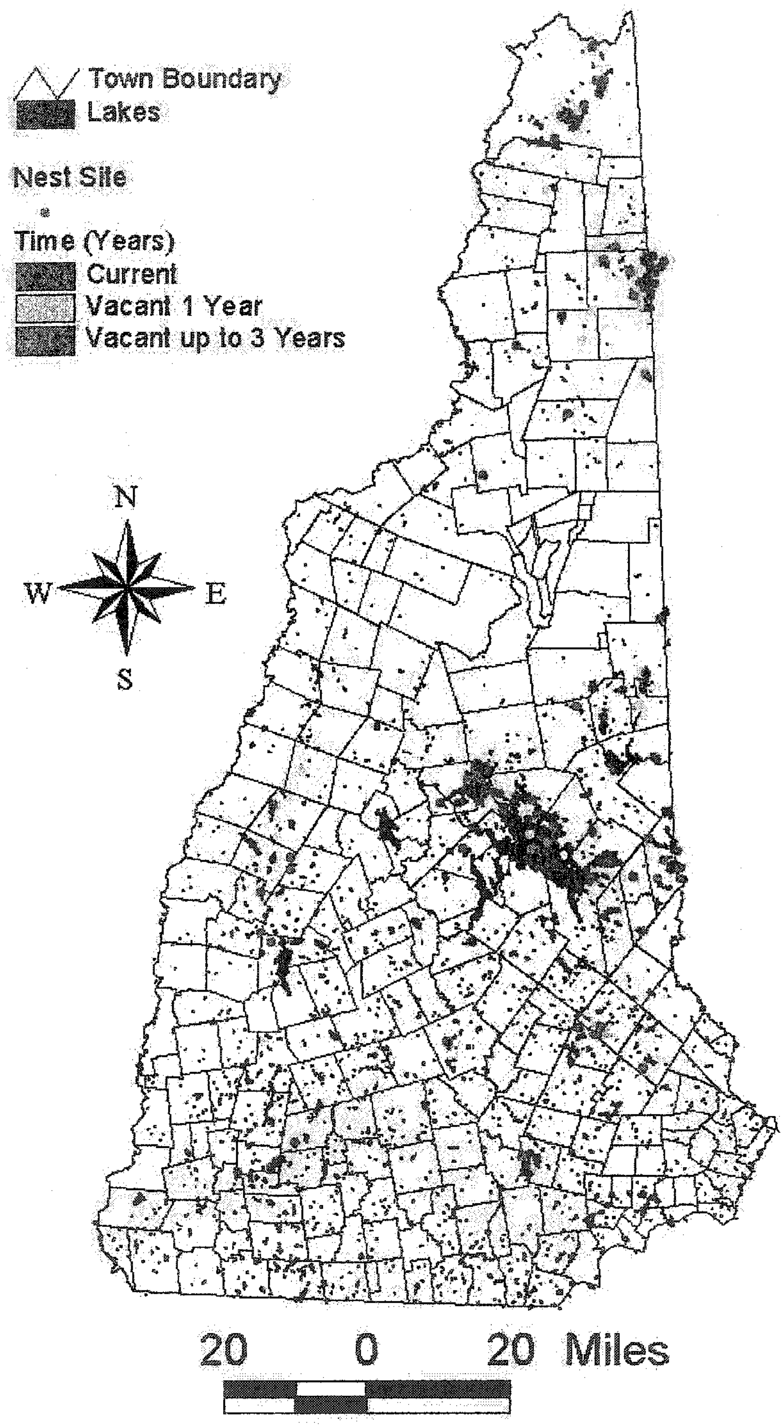


Figure 7. Occupied loon nest sites in New Hampshire during 1980.

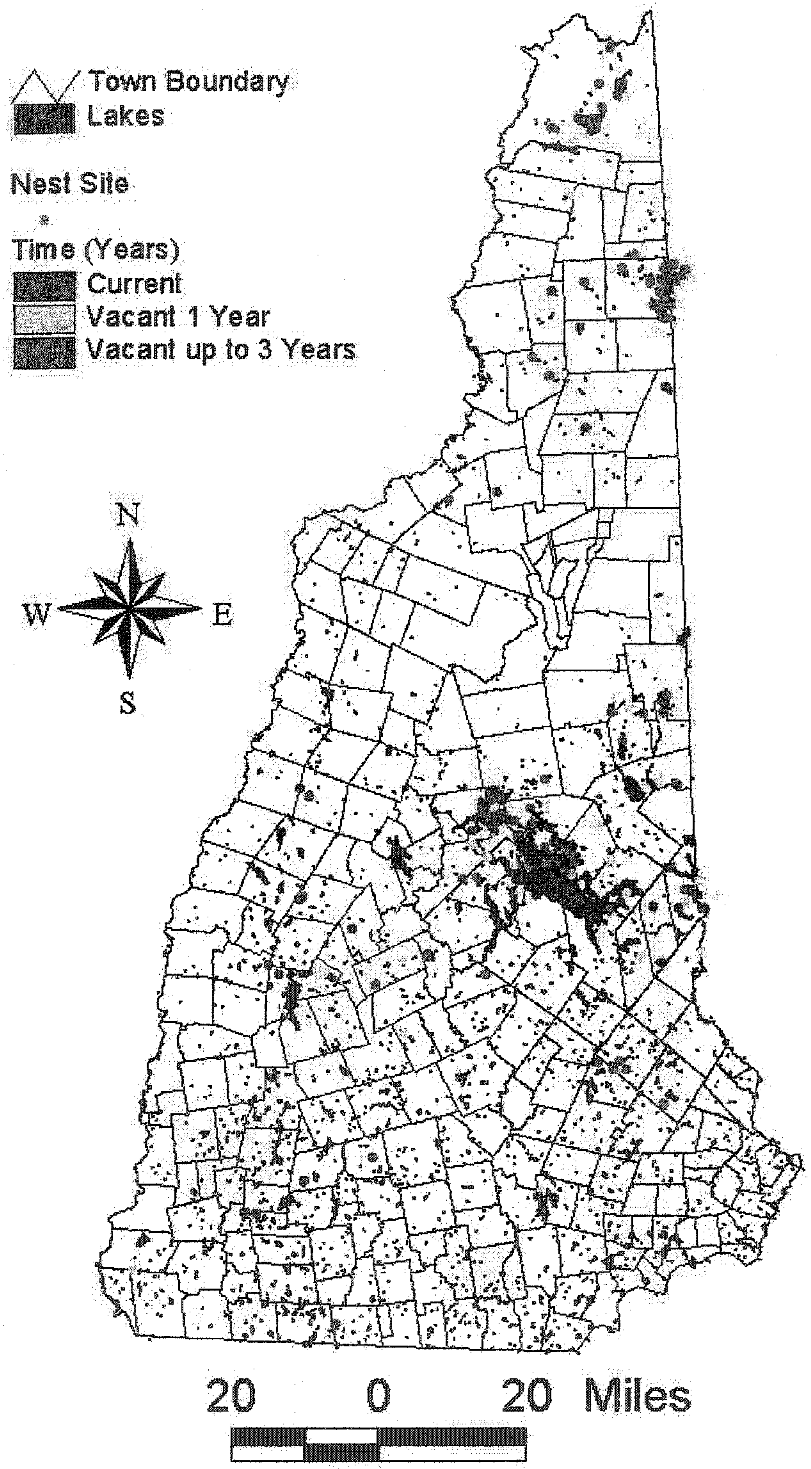


Figure 8. Occupied loon nest sites in New Hampshire during 1985.

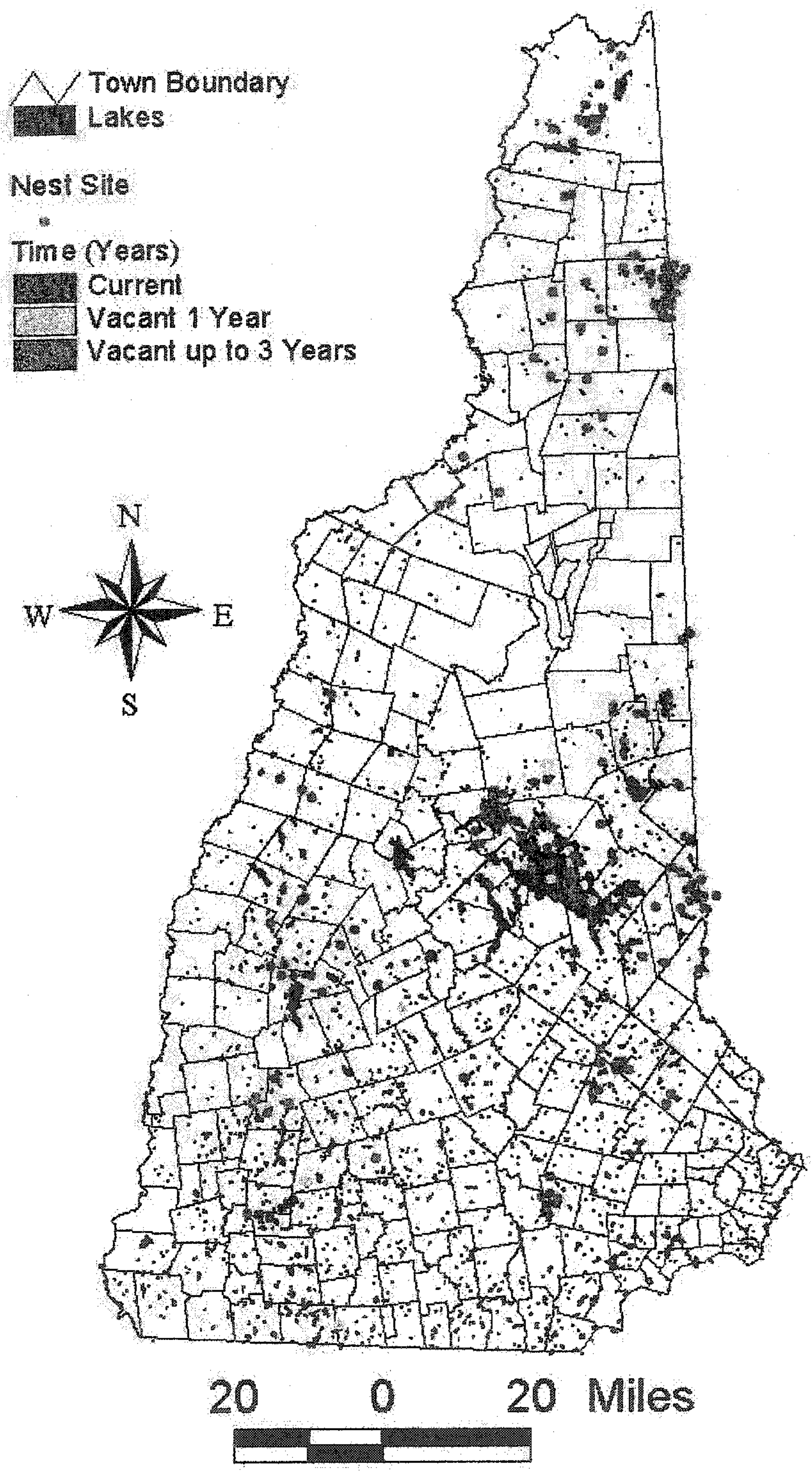


Figure 9. Occupied loon nest sites in New Hampshire during 1990.

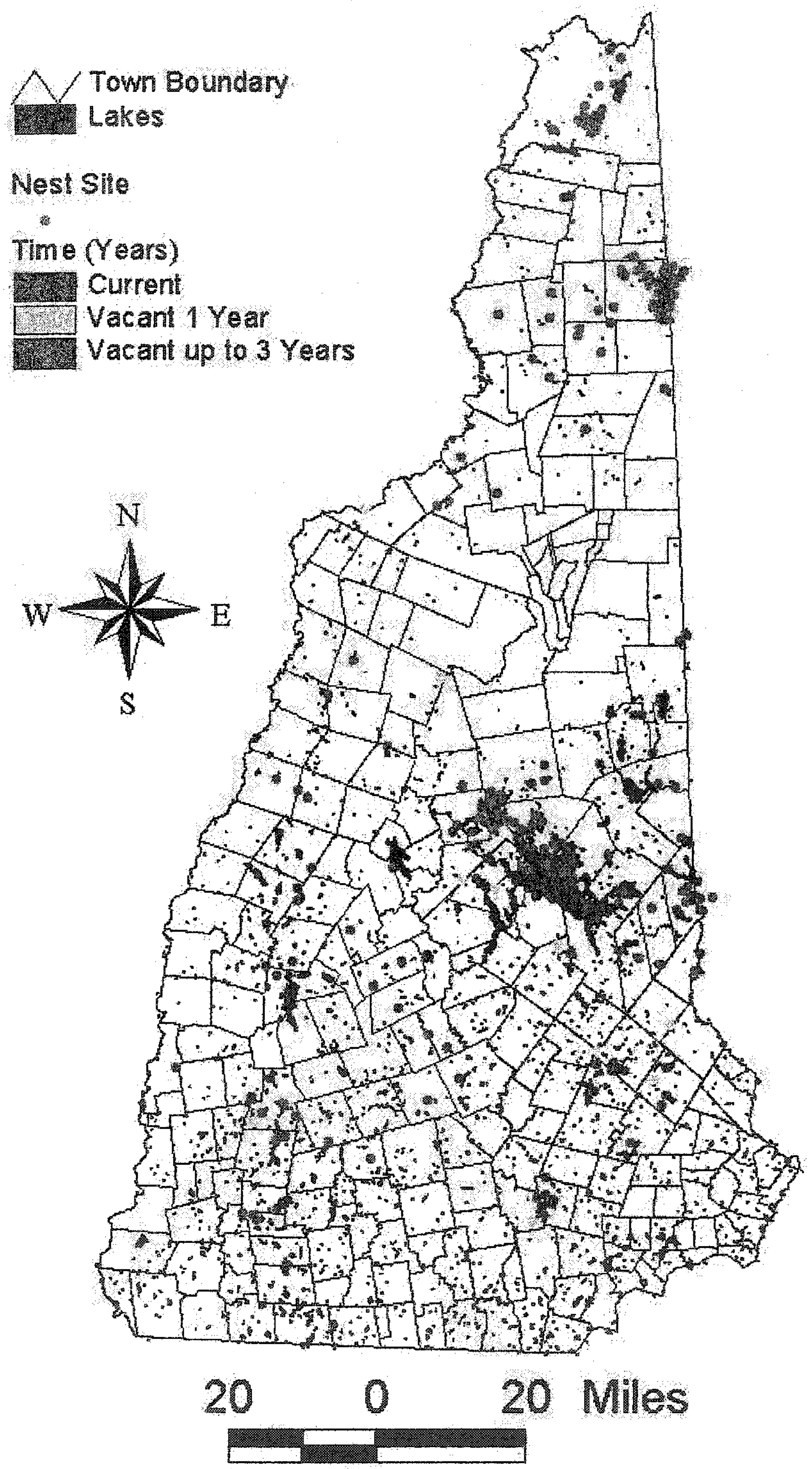


Figure 10. Occupied loon nest sites in New Hampshire during 1995.

in the south central portion of the state and for one lake in the north (Umbagog). Empirical Density Functions (EDF) showing point-to-point nearest neighbor distances $\hat{G}\ (y)$ for all New Hampshire lakes is presented in Figure 11. The majority of distances were concentrated at less than 8 km; however the gradual slope of the curve indicated that lakes were not clustered at the statewide scale. Alternatively, the lakes may be clustered at a larger (regional) scale but that effect was masked in the statewide analysis. Consequently, New Hampshire was segmented into three sub-regions and the analysis repeated to evaluate regional clustering.

Rossi et al. (1992), Store & Kangas (2001), and Isaaks and Srivastava (1989) suggested that multiple techniques are useful for analyzing and interpreting spatial information. Therefore, a statewide nest site survival contour map (Figure 12) was produced and demonstrated spatial variability. Pockets of high survival were found in all three regions with a declining trend that extended from the southwest to the northeast. The contour map, Figure 13 (spatial distribution of all lake centers), and the annual Tracking Analyst animations were used as references to determine the three state sub-regions. The commonly known "lakes region" area was selected as the core of the central sub-region because it appeared to be the location from where the remaining population expansion occurred during the previous 28 years and included pockets of high survival. Two latitudinal lines (43.4 N and 44.3 N in Figure 13) were visually selected to separate north, central and south sub-regions containing 60, 312 and 313, lakes, respectively. The EDFs for each of the sub-regions (Figures 14-16) showed that most lake neighbor distances were again less than 8 km and the gentle cumulative curves suggested that lakes were not clustered.

The loon nest site point-to-point nearest neighbor distances EDF is shown in Figure 17. The longest distance was approximately 30 km, and as expected, this EDF showed that there was a higher concentration of short distance neighbors (less than 7.5 km) suggesting that nest sites were clustered.

The origin-to-point EDF $\hat{F}(x)$ for the loon nest site data is presented in Figure 18, and as expected, it showed a larger number of high distance values indicating that the nest sites were clustered; the longest distance was approximately 96 km. The origin-to-point EDF was not generated for lake centers because the statewide and sub-region point-to-point EDFs suggested that lakes were not clustered. Additionally, nest site locations are dependent on the distribution of lakes and therefore, lake influences would be detected through the nest site analysis.

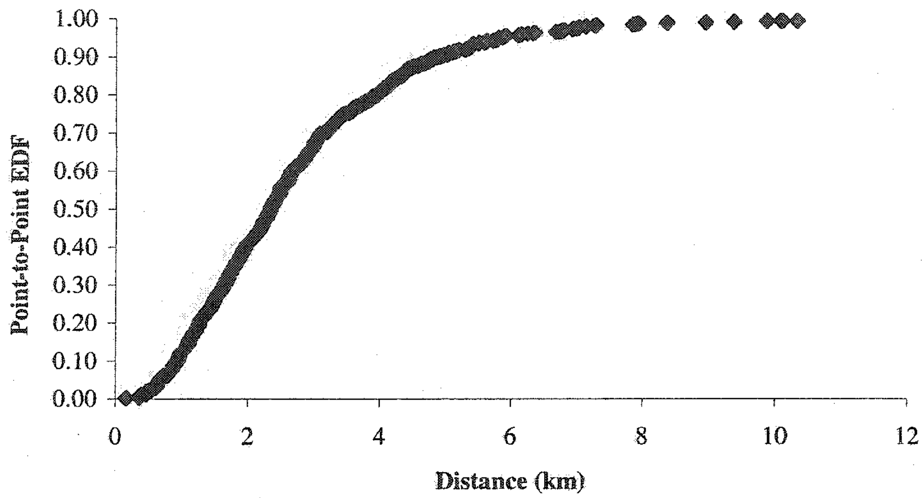


Figure 11. Point-to-point nearest neighbor EDF $\hat{G}(y)$ for all New Hampshire lake centers. Majority of distances concentrated below 8 km; however the gradual slope of the curve indicates that lakes are not clustered at a statewide scale.

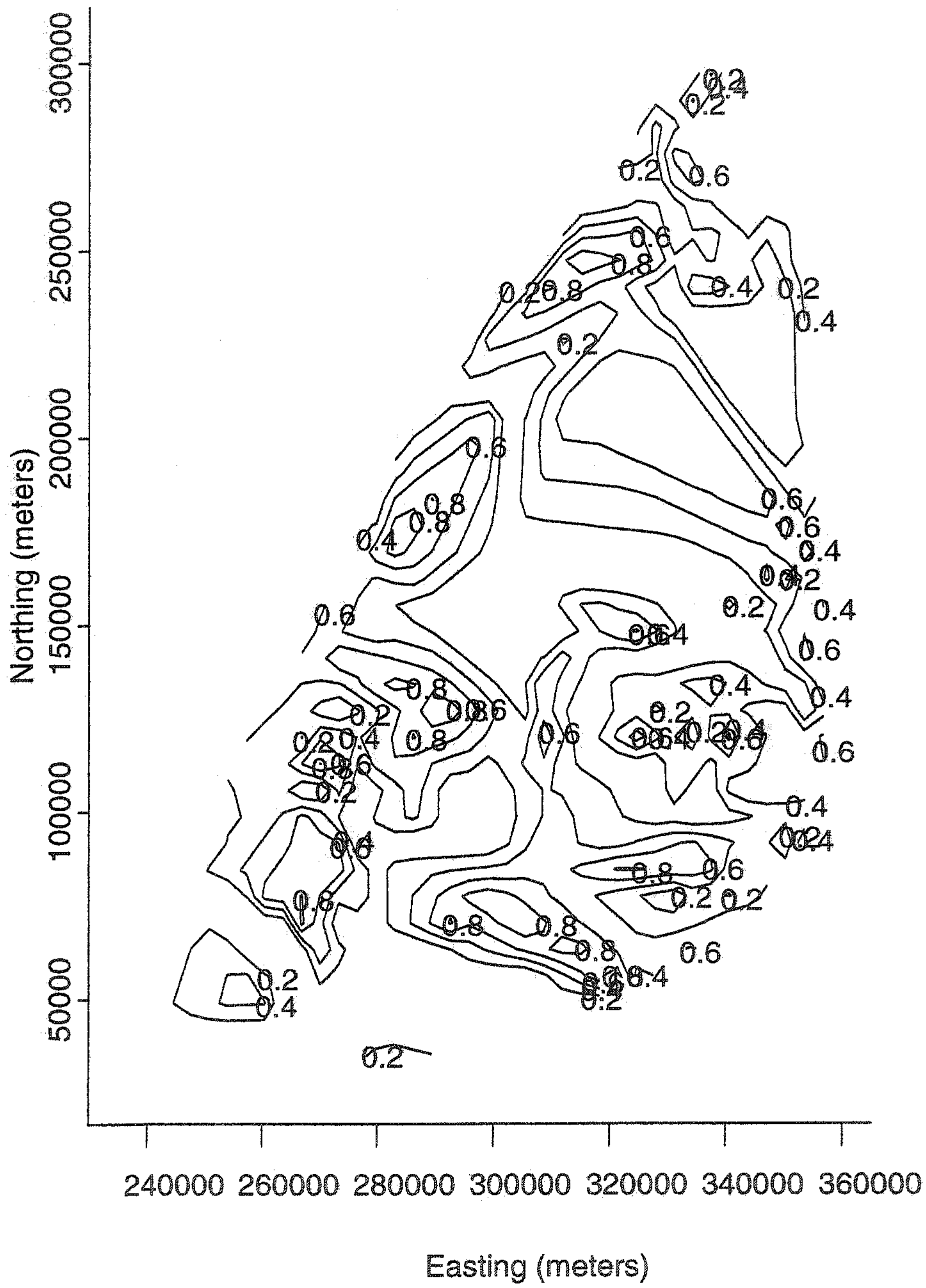


Figure 12. Loon survival contour map. High survival areas are located in all sub-regions: north, central and south.

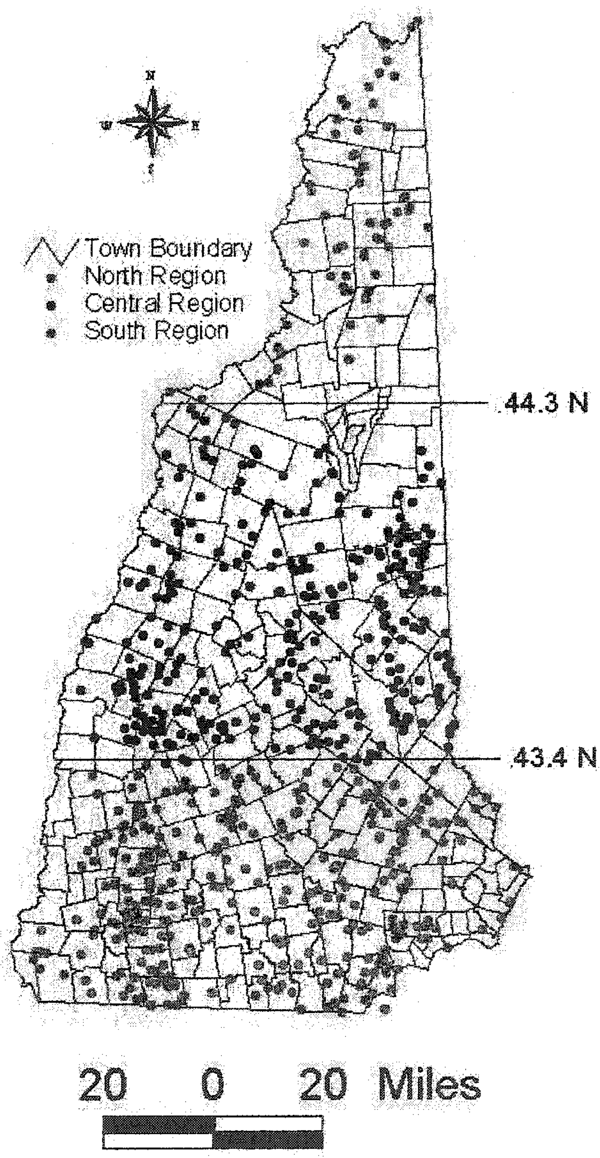


Figure 13. North (60 lakes), central (312 lakes) and south (313 lakes) New Hampshire lakes regions separated by 43.4 N and 44.3 N latitude.

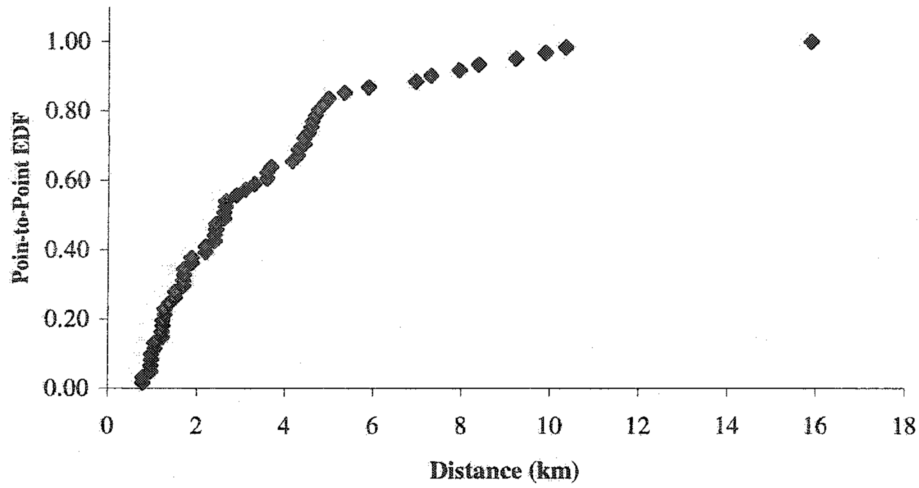


Figure 14. Point-to-point nearest neighbor EDF $\hat{G}(y)$ for northern region lake centers. Majority of distances concentrated below 8 km; however the gradual slope of the curve indicates that lakes are not clustered at a regional scale.

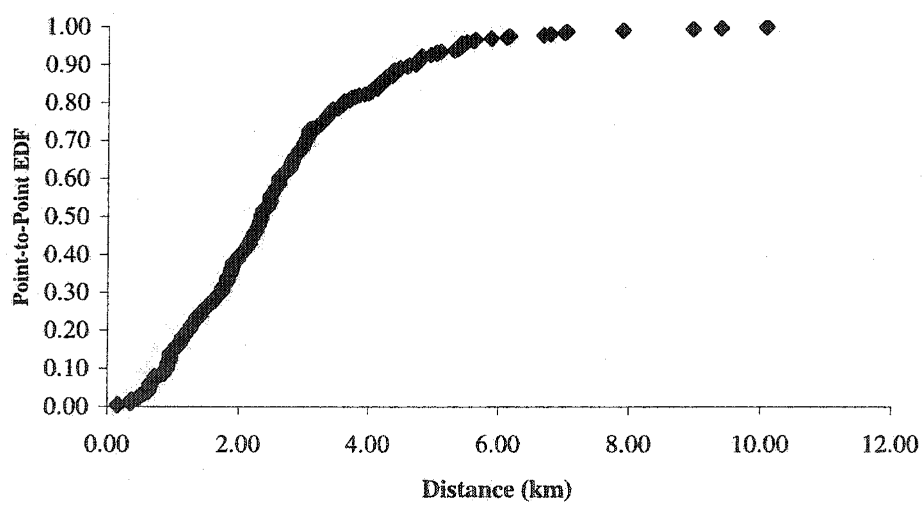


Figure 15. Point-to-point nearest neighbor EDF $\hat{G}(y)$ for central region lake centers. Majority of distances concentrated below 6.5 km; however the gradual slope of the curve indicates that lakes are not clustered at a regional scale.

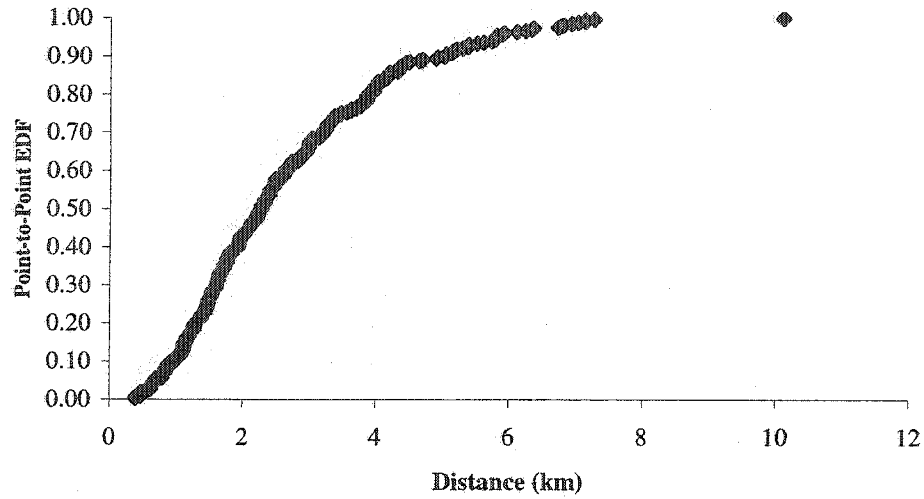


Figure 16. Point-to-point nearest neighbor EDF $\hat{G}(y)$ for southern region lake centers. Majority of distances concentrated below 8 km; however the gradual slope of the curve indicates that lakes are not clustered at a regional scale.

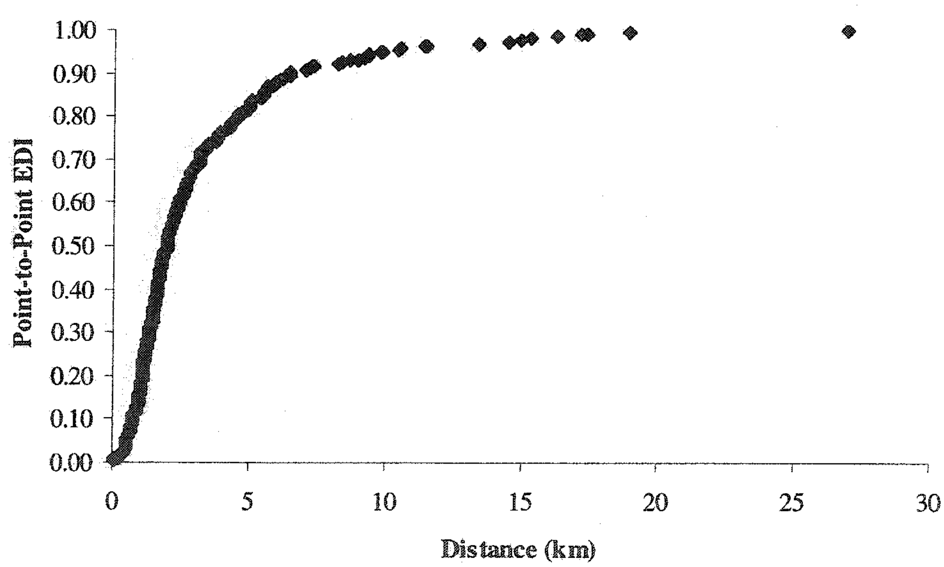


Figure 17. Point-to-point nearest neighbor EDF $\hat{G}(y)$ for 1996 loon nest site locations. Excess of shorter distances (less than 7.6 km) suggests that nest sites may be clustered.

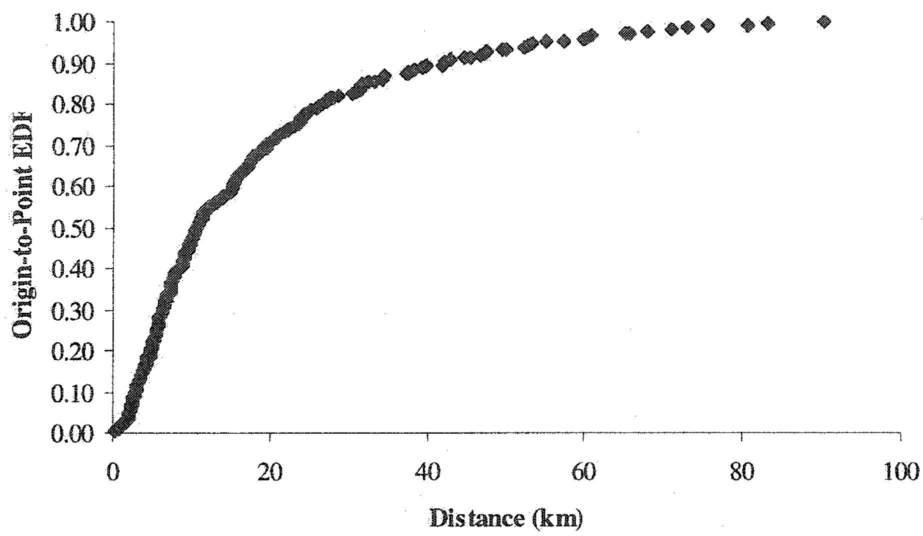


Figure 18. Empirical distribution function for origin-to-point nearest neighbors ($\hat{F}$) computed from 1996 loon nest site locations. Excess of longer distances suggests that nest sites are clustered.

Figure 19 shows a non-directional variogram generated using all lake centers and its structure (shape) was defined by a nugget = 4,000, sill = 15,000, and range = 12 km. The interpretation of this variogram indicates that lake centers separated by less than 12 km are more similar to each other than lakes separated by more than 12 km. To refine the structure of similarity of lakes at shorter distances, variogram analysis was repeated using multiple (shorter) lag distances for all lakes together and each of the three subregions. Additional structure was not evident through the statewide or regional scale analyses which suggested that the initial similarity noted for distances less than 12 km was a result of naturally occurring spatial variation such as short inter-lake distances (also determined through the previous point-to-point EDFs). Covariograms and correlograms were created to verify variogram analysis and not included in this document.

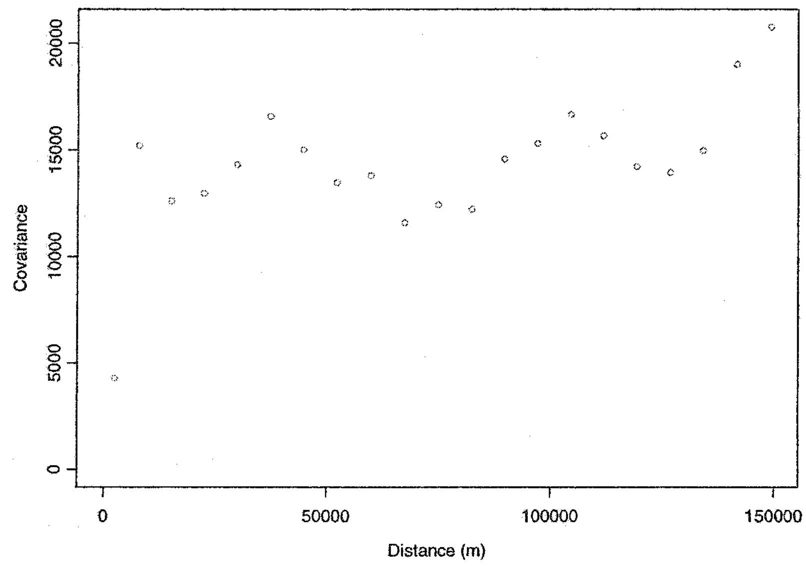


Figure 19. Non-directional variogram using all lake centers defined by a nugget = 4,000, sill = 15,000 and range = 12 km.

Variograms, covariograms and correlograms were constructed using nest site productivity and survivorship. Figure 20 presents the variogram for chicks surviving to the end of the summer. This variogram exhibits some structure defined by a nugget = 0.05, sill = 0.09 and range = 25 km. Directional variograms were produced to determine if trends existed along specific paths and the results for 0, 45, 90, and 135 degrees from North are shown in Figure 21. Minor structure was also noted for each of the directional variograms below 25 km, and little structure for higher distances. The 135°and 0° variograms show the most structure which is also consistent with perceptible declining loon survival trends in the NW-SE and S-N directions in Figure 12.

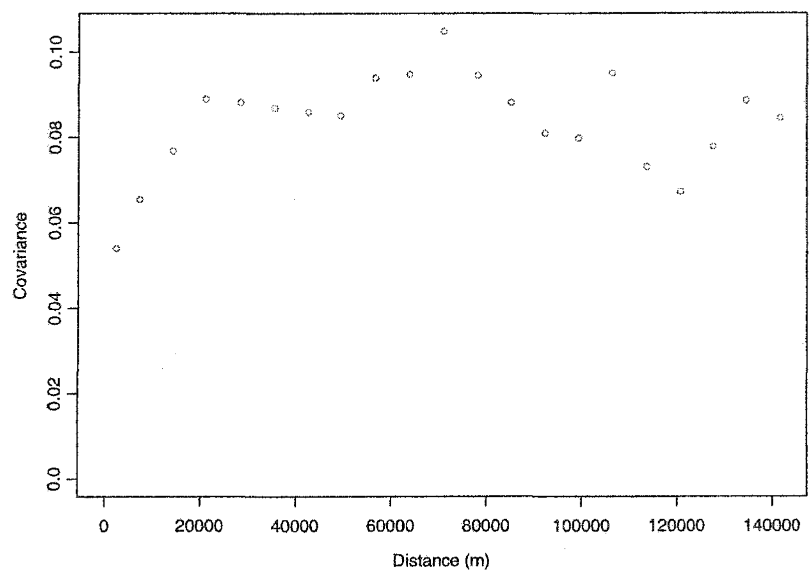


Figure 20. Non-directional variogram defined by a nugget = 0.05, sill = 0.09 and range = 25 km, using nest site survivorship data from 1980-1996.

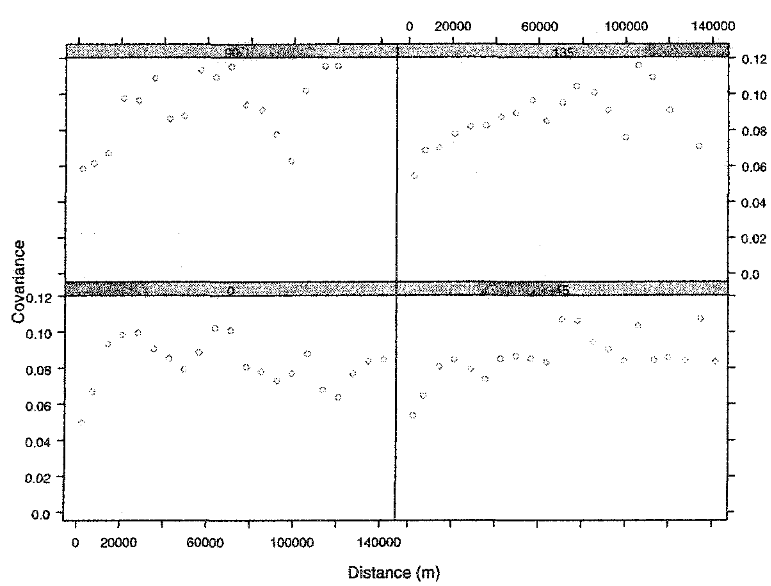


Figure 21. Directional variograms (0, 45, 90 and 135 degrees from North) generated using nest site survivorship data from 1980-1996.

Non-directional and directional correlograms were computed using 1980-1996 survivorship data and are shown in Figures 22 and 23. All plots are close to zero indicating that the survivorship data were not spatially related. Similar results were obtained with the productivity data suggesting that spatial autocorrelation does not exist. Variograms are more susceptible to error due to non-stationary variability and may contradict correlogram results as seen in this study (Rossi et al., 1992). Therefore, the correlogram and formal autocorrelation results (Moran statistic) were used to determine final autocorrelation conclusions.

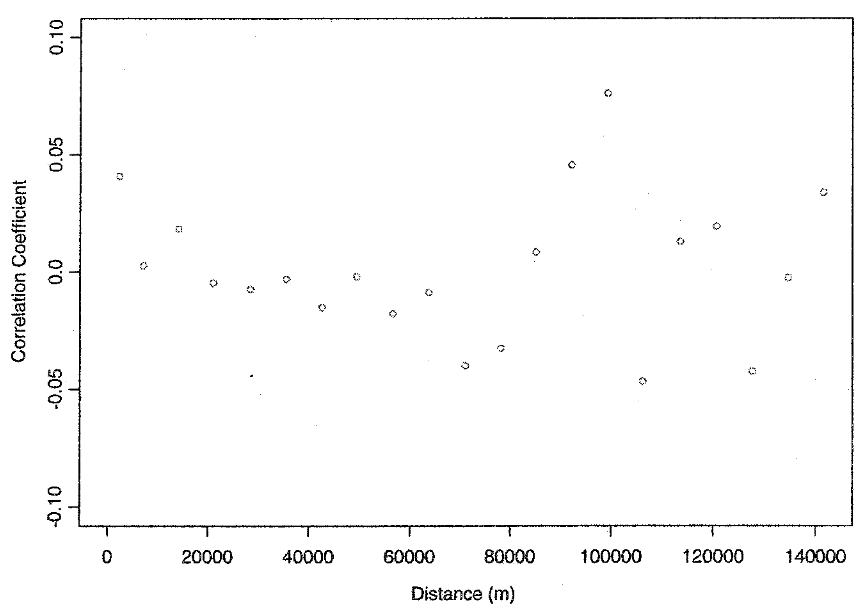


Figure 22. Non-directional correlogram produced using 1980-1996 survivorship data indicated no spatial autocorrelation (distance units are meters).

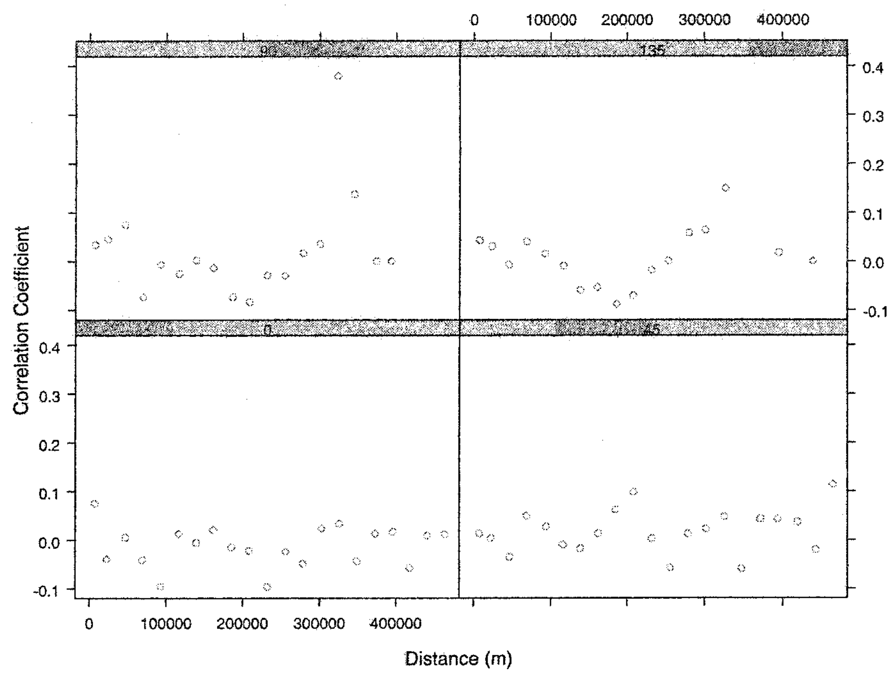


Figure 23. Directional correlograms (0, 45, 90 and 135 degrees from North) produced using 1980-1996 survivorship data.

Previous analyses (point-to-point EDFs and variograms) showed that spatial variation might exist for lakes less than 8 km and nest sites less than 25 km from each other. In searching for new habitat to occupy, the distance to occupied and unoccupied lakes may influence the future establishment of nest sites. Therefore, two new variables, LOONDIST (minimum distance to a lake with a loon) and NOLOONDIST (minimum distance to a lake with no loons), were computed using ESRI ArcInfo® software and were included in the list of potential explanatory variables (Table 2). A tool written in ArcInfo Macro Language (AML) was used to iteratively cycle through the lake polygon layer and create a grid showing all lakes, and a grid showing the current lake and the distance to the next closest lake. The program then combined the lake grid and the distance grid to contain distance values for cells in every lake. The cell with the minimum value (closest lake) provides the minimum distance metric and was used as an input to the logistic regression analysis.

4.6.2 Quantitative Results

4.6.2.1 Spatial Autocorrelation

The location of loon nest sites was dependent on the location of water bodies. Qualitative results were valuable for making initial spatial autocorrelation interpretations and formal quantitative methods were required to validate initial findings. The range for the Moran statistic value is from –1 indicating negative spatial autocorrelation to +1 for positive spatial autocorrelation. If no spatial autocorrelation exists, then the expected Moran statistic value is $E[I]=-1/(n-1)$. The Moran results for all lakes in New Hampshire and three sub-regions are presented in Table 3. The Moran statistics were slightly higher than the expected value for all the lake cases in Table 3 which indicates slight positive spatial autocorrelation existed for each set of lakes. However, each statistic was close to zero and the associated normal statistics were all non-significant leading to the conclusion that lake size at statewide and regional scales was not spatially autocorrelated. Spatial autocorrelation was recalculated for the central region lakes using three varying neighbor distances, corresponding to typical dispersion distances, and were not significant (22.8 km, $I = 0.007293$, $z = 1.081$; 7.6 km, $I = -0.01576$, $z = -0.4711$; and 4.5 km, $I = 1.29\text{e-}4$, $z = 0.08154$).

Productivity and survivorship spatial autocorrelation results at all nest sites are shown in Table 4. Neither productivity ($I = 0.01171$; $z = 1.186$) nor survivorship ($I =$

0.004212; z = 0.6038) was spatially autocorrelated at a statewide scale. Survivorship for nests located on Lake Umbagog was examined to determine if larger lakes supporting multiple nest sites exhibited spatial autocorrelation. Two maximum neighborhood distances (7.6 km and 4.5 km), representing typical dispersion distances, were used to determine if spatial autocorrelation was affected by the distance that loons flew to establish new territories. Positive spatial autocorrelation was not significant for the 7.6 km neighborhood distance (I = 0.010512, z = 1.91). Positive spatial autocorrelation was significant for the 4.5 km neighborhood distance (I = 0.1263, z = 3.669). The significance of the shorter distances may be due to a larger number of territories on Umbagog with shorter inter-nest distances and increased competition among resident loons caused by over crowding. Other large New Hampshire lakes were not evaluated because of limited nest site sample sizes (e.g., Lake Winnipesaukee, 24; Squam Lake, 16).

Table 3. Spatial autocorrelation results for all New Hampshire lakes and 3 sub-regions of lakes in New Hampshire.

Region of New Hampshire Lakes	Sample Size	Neighbor Distance (km)	Moran Statistic	Normal Statistic	Expected Moran Statistic (-1/n-1)
All Lakes	685	22.8	0.008916	1.519	-0.0014
North	60	22.8	0.01459	1.884	-0.0169
Central	312	22.8	0.007293	1.081	-0.0032
Central	312	7.6	-0.01576	-0.4711	-0.0032
Central	312	4.5	1.29e-4	0.08154	-0.0032
South	313	22.8	-0.01903	-1.733	-0.0032

Table 4. Spatial autocorrelation results for all nest sites in New Hampshire and Lake Umbagog separately. Lake Umbagog survivorship at 4.5 km is significant.

Nest Site Locations	Sample Size	Neighbor Distance (km)	Moran Statistic	Normal Statistic	Expected Moran Statistic (-1/*n*-1)
All Nest Sites (Productivity)	240	22.8	0.01171	1.186	-0.0041
All Nest Sites (Survivorship)	240	22.8	0.004212	0.6038	-0.0041
Umbagog (Survivorship)	31	7.6	0.01051	1.91	0.05611
Umbagog (Survivorship)	31	4.5	0.1263	3.669	2.434e-4

4.6.2.2 Linear Regression

Individual linear regression results are presented in Figures 24-28 and a summary of all regression analyses (including Durbin-Watson statistics) is presented in Table 5. The null hypothesis tested was $Ho: \beta_1=0$; the parameter being tested exhibited no trend. In all cases: $\alpha=0.05$, $n=23$, $k=1$, yielded the following serial correlation ranges for D:

- $0 < D <= 1.26$ = Serial Correlation,
- $1.26 < D <= 1.44$ = Inconclusive,
- $1.44 < D$ = No serial correlation.

The total loon population (defined as: total loons = paired loons + unpaired loons + immature loons) from 1980-2002 is shown in Figure 24. Since 1980, the total number of loons in New Hampshire has experienced positive growth ($F=370.81$; $p=0.000$). In 2002 there were approximately 200 nesting loon pairs within the state, versus 62 pairs in 1977. Total population did not exhibit serial correlation ($D=1.449$).

The number of paired adults and unpaired adults (Fig. 24) were initially serially correlated, D=0.783 and D=0.904, respectively. After adjusting for serial correlation, paired adults were found to increase through time (F=84.256; p=0.000, D=1.517); the number of unpaired adults did not increase through time (F=1.047; p=0.318, D=1.932).

Figure 25 shows the number of nesting pairs (a pair of loons that nest) and successful nesting pairs (nesting pairs that produce eggs) from 1980 to 2002. Analysis of both relationships indicates that they increased significantly through time and serial correlation was not evident in either case (F=271.35; p=0.000, D=2.050; F=74.882, p=0.000, D=2.114; respectively). The total adult population, paired adults (Fig. 24), and nesting pairs (Fig. 25) declined since 1999.

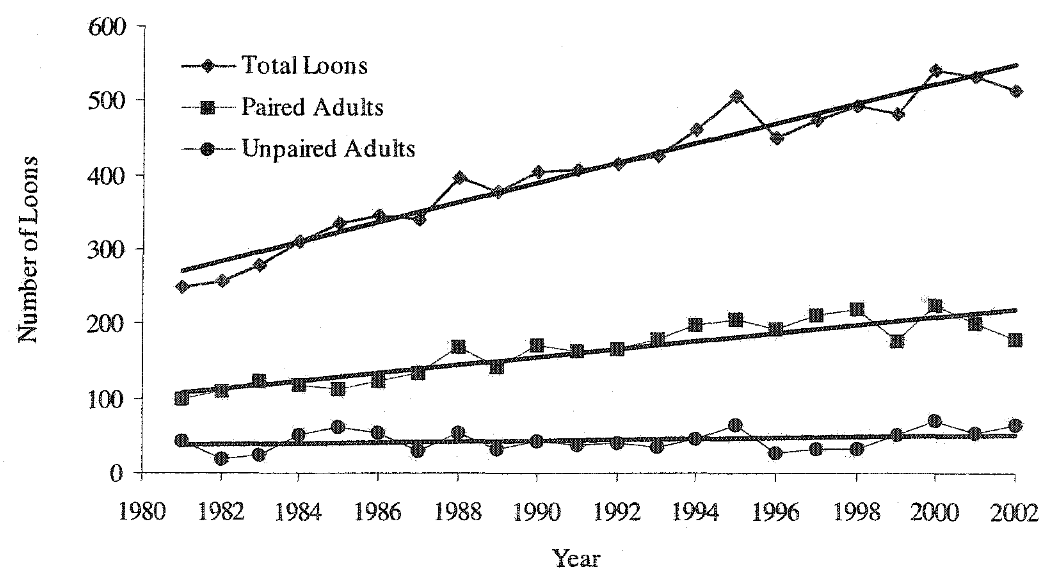


Figure 24. The total number of loons (defined as: total loons = paired loons + unpaired loons + immature loons) in New Hampshire experienced positive growth (*F*=370.81; *p*=0.000, *D*=1.449) during 1980-2002. The number of paired adults was adjusted for serial correlation and also found to increase through time (*F*=84.25; *p*=0.000, *D*=1.517). The number of unpaired adults was also initially serial correlated, however, it did not increase through time (*F*=1.047; *p*=0.318, *D*=1.932).

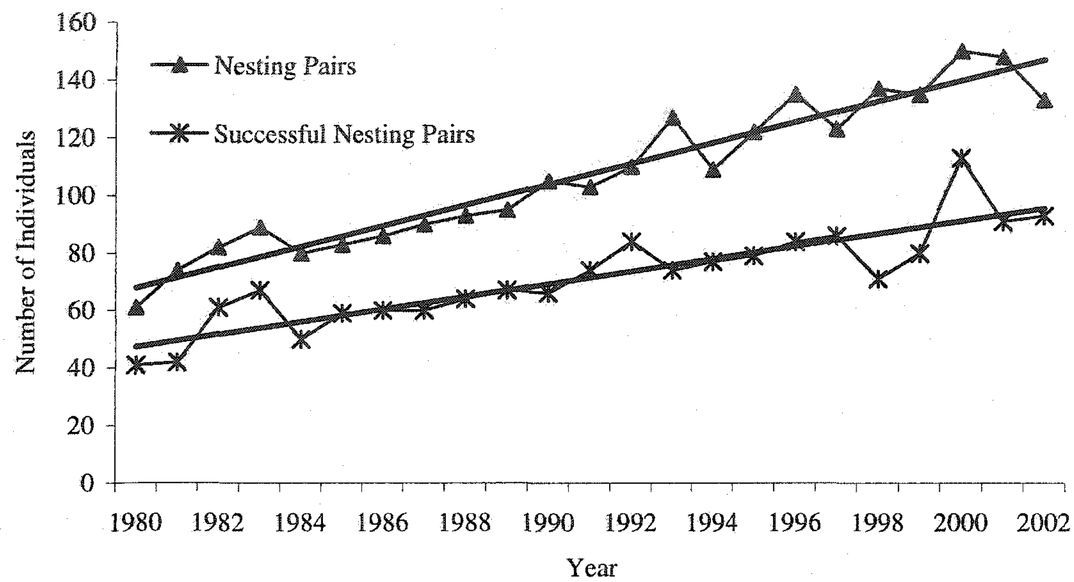


Figure 25. Nesting pairs (a pair of loons that nest) and successful nesting pairs (nesting pairs that produce eggs) show significant increase during 1980-2002 (F=271.35; p=0.000, D=2.050; F=74.882, p=0.000, D=2.114; respectively).

The number of chicks hatched (F=59.388, p=0.000, D=2.003) and chicks surviving (F=39.460, p=0.000, D=1.771) increased steadily from 1980-2002 (Fig. 26). Figures 27 and 28 show nesting frequency (nesting pairs/territorial pairs), hatch rate (chicks hatched/nesting pairs), productivity (chicks surviving/territorial pairs) and survivorship (chicks surviving/chicks hatched) during the 1980-2002 field seasons. Nesting frequency (F=7.505, p=0.012, D=1.361) decreased significantly through time with an inconclusive serial correlation result. Productivity (F=6.454, p=0.019, D=1.449) decreased significantly and was not serially correlated. Neither hatch rate (F=0.971, p=0.336, D=2.382) nor survivorship (F= 1.870, p=0.186, D=1.687) decreased through time.

Figure 29 presents the number of lakes occupied through time by territorial pairs (F=652.265, p=0.000, D=2.276), nesting pairs (F=271.35, p=0.000, D=1.699), and successful nesting pairs (F=74.882, p=0.000, D=2.006). All of these trend lines increased and none were serially correlated.

Paired and unpaired adults were the only serially correlated parameters (Table 5). Although the other parameters are dependent on the adult population, local spatial variability in environmental factors might have decreased the year-to-year correlation detected by the Durbin Watson test.

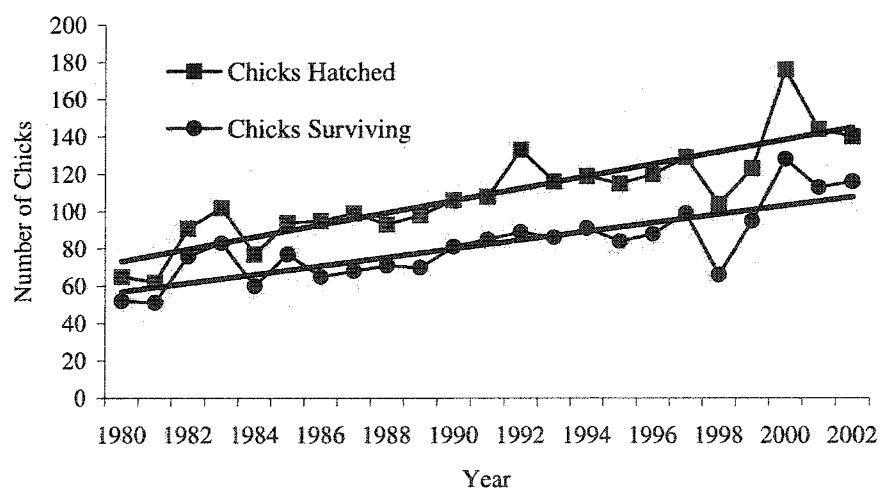


Figure 26. Chicks hatched (F=59.388, p=0.000, D=2.003) and chicks surviving (F=39.460, p=0.000, D=1.771) increased steadily from 1980-2002.

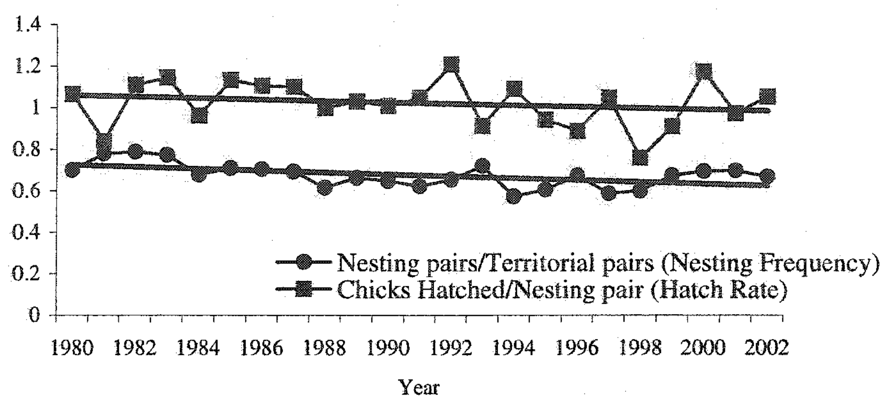


Figure 27. Nesting frequency (*F*=7.505, *p*=0.012, *D*=1.361) decreased significantly through time with an inconclusive serial correlation result. Hatch rate (*F*=0.971, *p*=0.336, *D*=2.382) did not decrease through time.

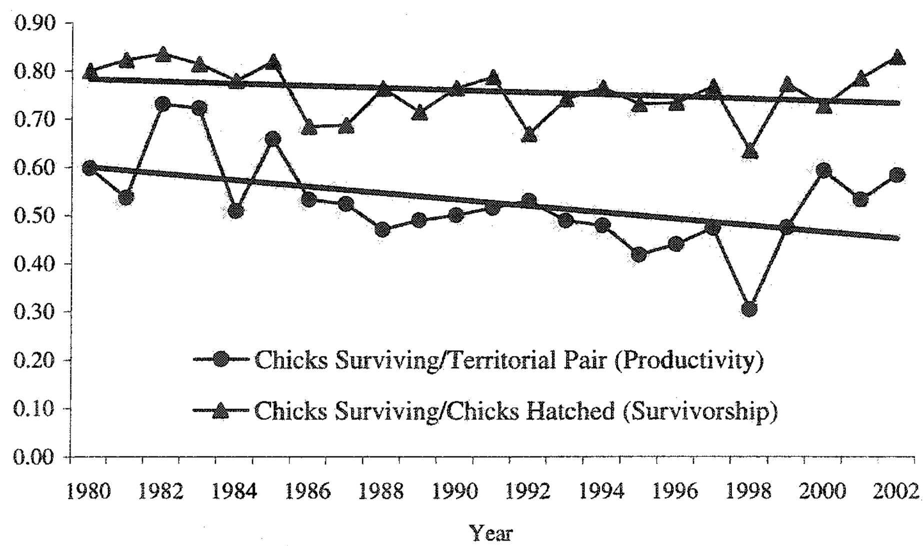


Figure 28. Productivity (*F*=6.454, *p*=0.019, *D*=1.449) decreased significantly and was not serially correlated. Survivorship (*F*= 1.870, *p*=0.186, *D*=1.687) did not decrease significantly through time.

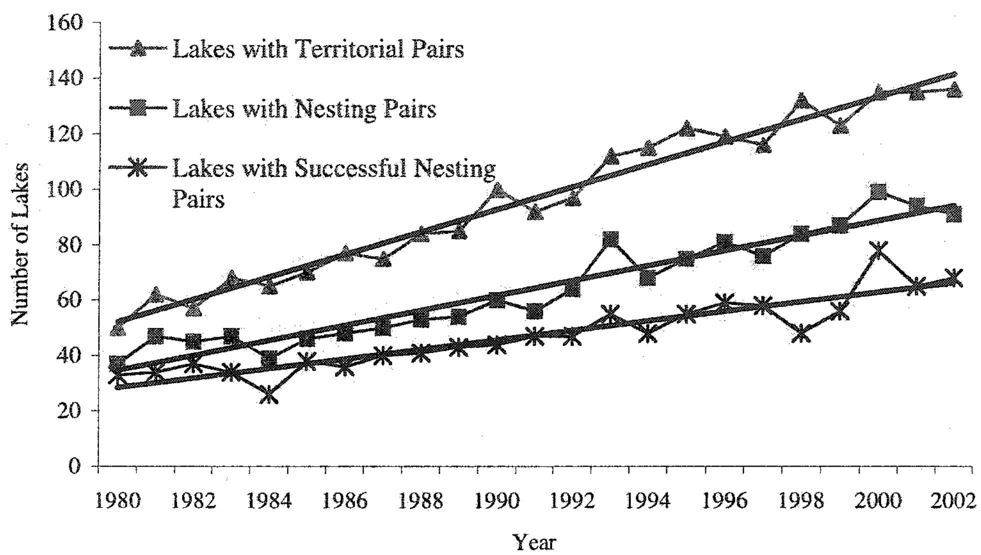


Figure 29. Number of occupied lakes through time by territorial pairs (F= 652.265, p=0.000, D=2.276), nesting pairs (F=238.725, p=0.000, D=1.699), and successful nesting pairs (F=103.643, p=0.000, D=2.006) during 1980-2002. All of these relationships were increasing and none were serially correlated.

Table 5. Regression models, significance tests and Durbin-Watson test statistics for multiple tests against null hypotheses using LOONDATA. Durbin-Watson test cutoff ranges based on α=0.05, N=23, k=1: D_{Lower}=1.26, D_{Upper}=1.44. Serial correlation status is determined as follows: Exists if D<1.26; Inconclusive if 1.26<D<1.44, and None if 1.45<D.

Null Hypothesis Test Conclusion (*Ho: β_1=0*)	Regression Equation (Standard Error)	R^2	F Statistic	p	Durbin Watson Statistic
Total loon population increased through time.	$y = -26067 + 13.29x$ (22.86)	0.946	370.81	0.000	1.449
Paired adult loons increased through time.	$y = -21689 + 11.05x$ (17.37)	0.808	84.256	0.000	1.517 0.783[a]
Unpaired adult loons showed no trend increase through time.	$y = -2203 + 1.14x$ (16.87)	0.049	1.047[b]	0.318	1.932 0.904[a]
Nesting pairs increased through time.	$y = -7055 + 3.59x$ (6.95)	0.928	271.35	0.000	2.050
Successful nesting pairs increased through time.	$y = -4276 + 2.18x$ (8.03)	0.781	74.882	0.000	2.114
Chicks hatched increased through time.	$y = -6397 + 3.26x$ (13.49)	0.738	59.388	0.000	2.003
Chicks surviving increased through time.	$y = -4523 + 2.31x$ (11.72)	0.653	39.460	0.000	1.771
Nesting pairs/territorial pairs decreased through time.	$y = 9.24 - 0.0043x$ (0.05)	0.263	7.505	0.012	1.361
Chicks hatched/nesting pairs showed no trend through time.	$y = 7.89 – 0.0034x$ (0.11)	0.044	0.971[b]	0.336	2.382
Chicks surviving/ territorial pairs decreased through time.	$y = 13.87 – 0.0067x$ (0.08)	0.235	6.454	0.019	1.449
Chicks surviving/ chicks hatched showed no trend through time.	$y = 5.29 – 0.0023x$ (0.05)	0.082	1.870[b]	0.186	1.687
Lakes with territorial pairs increased through time.	$y = -7979 + 4.05x$ (5.05)	0.967	652.265	0.000	2.276
Lakes with nesting pairs increased through time.	$y = -5316 + 2.70x$ (5.56)	0.919	238.725	0.000	1.699
Lakes with successful nesting pairs increased through time.	$y = -3369 + 1.716x$ (5.36)	0.832	103.643	0.000	2.006

Note: a - Denotes Durbin Watson statistic prior to adjustment.
b - Denotes non-significant result.

4.6.2.3 Logistic Regression

Some of the original variables were eliminated from analysis because they were missing a high number of values or measurements. Their elimination maximized the strength of the logistic regression model by including as many lakes or cases (both presence and absence) that had values for most of the explanatory variables. The variables that were excluded included TOTAL FISH SPECIES (the presence/absence values for 17 fish species) COLD DIVISION and WARM DIVISION (categorization of the fish species) and the human disturbance metric: ACCESS. These excluded variables were only measured at 328 of the total 654 lakes.

Correlation analysis was performed on the remaining variables and used to evaluate how the explanatory variables might be correlated with each other. High correlation existed among a few of the lake morphology variables as would be expected (e.g., LAKE ACRE, PERIMETER, AREA, PERIM/AREA RATIO). The correlation analyses also indicated significant positive correlation ($p<0.01$) between a few of the variables (e.g., LAKE ACRE, LAKEDEPTH, AREA, PERIMETER, PERIM/AREA RATIO) and the dependent variable (loon presence/absence). Significant negative correlation ($p<0.01$) with loon presence/absence was observed for two variables: LOONDIST and FLUSHRATE. This indicated that as these variables decreased, the probability of loon presence increased. The cross correlation matrix is presented in Appendix K.

Another way to evaluate the relationship of explanatory variables with the dependent variable (presence/absence of loons) is to test each variable individually with the dependent variable. Cumulative frequency or percent distributions provided information about thresholds of individual variables (e.g., what percent of the lakes with loons have mean depths greater than 12 m?). Cumulative frequency distributions for both presence and absence were plotted for each significant explanatory variable and are included in Appendix K. Table 6 provides the mean and median of each significant variable as it related to lakes where loons were present or absent. The physical lake parameters for lakes with loons (occupied lakes) were all higher than lakes without loons which suggested that loons occupied lakes that were larger and deeper. Additionally, occupied lakes were usually closer to lakes without loons than other lakes with loons.

Table 6. Mean and median values for selected lake parameters of lakes with (presence) and without (absence) loons.

Significant Explanatory Variables	Occupied Lakes (Presence)		Unoccupied Lakes (Absence)	
	Mean	Median	Mean	Median
Lake Size (ha)	223	79	37	14
Perimeter (m) including islands	111,528	62,185	32,903	21,019
Area (m) excluding islands	2,169,370	772,086	379,783	134,613
Ratio (Perimeter/sqrt(Area))	79	70	61	54
Lake Depth (m)	5.5	4.6	3.4	2.4
Lake Elevation (m)	288	251	251	232
Minimum dist to no loon lake (m)	2395	1963	2811	2135
Minimum dist to loon lake (m)	4432	2370	8889	6847
Flushing rate (watershed)	6.8	1.0	33.8	4.0

The stepwise logistic regression results using the significant explanatory variables are presented in Table 7. These results indicated that the top 4 independent variables for predicting loon presence or absence on New Hampshire lakes were: PERIMETER, LAKEDEPTH, LOONDIST and ELEV with high significance ($p<0.01$). PERIMETER and LAKEDEPTH contribute the most in the final model.

Table 7. Most important variables for determining loon habitat occupancy in New Hampshire based on logistic regression.

Variable	Coefficient	Standard Error	t	p
Intercept	-3.468348	0.045324	-7.652	0.000
PERIMETER	0.000063	0.0000005	5.901	0.000
LAKEDEPTH	0.045810	0.001168	3.919	0.001
LOONDIST	-0.000096	0.000026	-3.617	0.000
ELEV	0.000936	0.000283	3.303	0.000

The logistic model representing the probability of loon presence based on these parameters was:

$$p(\textit{loon presence}) = -3.4683 + 0.000063\,(\text{PERIMETER}) + 0.045810\,(\text{DEPTH}) - 0.000096\,(\text{LOONDIST}) + 0.000936\,(\text{ELEV})$$

Table 8 provides a summary of the four explanatory variables for occupied and unoccupied lakes. The six largest lakes in the dataset (lakes that were 2-5 times larger than the remaining lakes) were removed from the logistic regression analysis because their excessive size increased the variability and reduced model performance. Mean and median values for lake size (perimeter), lake depth and elevation were all higher for occupied lakes which represent better quality habitat. The mean and median distances between lakes with loons is higher for unoccupied lakes because these lakes reflected lower quality habitat and a greater distance must be traveled to find lakes occupied by loons.

Table 8. Mean and median values for the four most important variables used to determine loon habitat occupancy in New Hampshire.

Significant Explanatory Variables	Occupied Lakes (Presence)		Unoccupied Lakes (Absence)	
	Mean	Median	Mean	Median
PERIMETER (m)	79,221	56,718	30,765	20,900
LAKEDEPTH (m)	5.4	4.5	3.3	2.4
LOONDIST (m)	4544	2428	8919	6885
ELEV (m)	289	251	251	232

4.7 DISCUSSION

Maps are an effective mechanism for visually understanding relationships between and among geographically related information. The animation capability found within ESRI's Tracking Analyst® was critical for interpreting digital maps that showed seasonal change in nest site occupancy on water bodies in New Hampshire from 1976-2002 (Figures 7 - 10). It was apparent that the loon population expanded in number, and occupied new habitat (water bodies).

These findings led to additional qualitative and quantitative analyses to determine if lake centers and any LOONDATA measurements were spatially correlated, and if so, their influences on the expansion of the loon population. Qualitative autocorrelation analysis methods were used to evaluate lake center and nest site location spatial relationships, and the effects on two annual population metrics, productivity and survivorship. The Moran statistic was used to formally evaluate spatial autocorrelation and neither lakes centers, productivity (I=6.419; p=1.369e-10) nor survivorship (I=6.393; p=1.629e-10) were correlated at a statewide scale.

The present distribution of nest sites is most likely related to the locations of available habitat (water bodies), and the location of the surviving loon population in the early 1970's. Hammond and Wood (1976) noted that 91 territorial pairs occupied 55 lakes in 1976, and that many of these lakes were located regionally in the Lakes Region, southeast, and northeast portions of the state. The loons resident on these lakes were the foundation for subsequent population recovery, and therefore, the annual expansion in number and geographic spread of the population expansion seems predictable. As seen in Figure 29, the number of lakes with territorial pairs increased significantly from 55 in 1976 to 136 in 2002 (F=652.265, p=0.000, D=2.276).

The total loon population (F=370.81; p=0.000, D=1.449), number of paired adults (F=84.25; p=0.000, D=1.517), and nesting pairs (F=271.35; p=0.000, D=2.050) also increased through time. This positive growth was probably due, in part, to effective loon management and protection, public education, and research efforts conducted by LPC as envisioned by Hammond and Rawson in 1976. Management techniques that were implemented to protect or expand nest sites included signs alerting boat traffic to nearby loon sanctuaries and rafts deployed in selected water bodies. LPC has promoted a widespread and consistent message leading to increased public awareness and a suspected positive impact on the loon population in New Hampshire.

There are no records documenting the highest historical loon populations in New Hampshire, however, natural history descriptions indicate that loons were common and abundant throughout the state (Hammond and Rawson, 1976). The decline in total population measured from 1999-2002 may represent a population that has expanded to, or surpassed, a biological threshold which caused instability in local areas (local spatial variability). Alternatively, the lower populations measured in 2000-2002 may reflect the poor weather conditions in 1998. During May and June of 1998, 2.5 times the normal rainfall was received in prime breeding areas. By the third week of June, 53% of nesting pairs had abandoned their nests due to flooding. Forty-one percent of those abandoned re-nested, which is slightly less than the re-nesting rate of 50% under normal nesting conditions (McIntyre, 1977). The survival rate for that year was approximately 66% compared to normal rates of up to 85% (Hammond and Rawson, 1976; Taylor and Vogel, 2002), and this reduced recruitment may relate to the subsequent decline in total population.

Overall, from 1980-2002 the number of successful nesting pairs (F=74.882; p=0.000, D=2.114), chicks hatched (F=59.388; p=0.000, D=2.003) and chicks surviving (F=39.460; p=0.000, D=1.771) all increased. Further, the number of lakes with successful nesting pairs (F=103.643; p=0.000, D=2.006) continued to increase implying that the population continued to occupy new habitat. However, nesting frequency (nesting pairs/territorial pairs) and productivity (chicks surviving/territorial pair) decreased through time. One explanation for these results is that older loon pairs remained in established territories while young adults are forced to disperse and occupy new habitat. Loons usually return to natal lakes within 3-5 years of hatching (McIntyre, 1983; Evers, 2000) where they either compete for territories or disperse to new habitat if the water body is crowded or defended. The increased number of lakes with territorial pairs and number of lakes with successful nesting pairs most likely indicates that dispersed loons established breeding territories on unoccupied lakes and encountered less stress leading to increased hatch rate and survivorship.

The above discussion prompted the question: is the loon population experiencing density dependent or regional variations? Evers (2004) found that high quality territories were actively defended in breeding populations. Competition for breeding territories occurred when non-breeding loons intruded on an established territory and usually ended with the territory holder chasing off the intruder. As loon densities increased, divorce rates and reproductive success declined. Lake Umbagog may represent just such a density-dependent example as its breeding population increased 10% annually while experiencing an associated decline in reproductive success (Evers, 2002).

To explore the regional variation question, regression analyses and t-tests were used to examine and compare trends in lakes with nesting pairs, hatch rate and chick survival within and among the north, central and south sub-regions. In 1980 the southern sub-region had 11 active nest sites on 8 lakes (8/313= 2%), the central sub-region had 39 nest sites on 21 lakes (21/312=6%) and the northern sub-region had 28 nest sites on 13 lakes (13/60=21%). By 1996 lake occupancy had increased in all three sub-regions. The southern sub-region had 34 nest sites on 28 lakes (28/313=9%), the central sub-region had 105 on 63 lakes (63/312=20%) and the northern sub-region had 61 nest sites on 27 lakes (27/60=45%).

The number of lakes with nesting pairs increased in southern and northern sub-region through time (Table 9). The original high availability of unoccupied habitat in both regions likely explains this trend. The number of lakes with nesting pairs in the central region did not increase and probably reflects a mature population that stemmed from a higher original loon population, higher lake occupancy and local territorial competition.

Mean hatch rates and pairwise comparison summary statistics were computed for each region (Table 10). The critical t value=2.24 and was calculated based on the Bonferroni adjustment (α=0.016, df=32, comparisons=3) to account for a possible increase in type I error due to multiple comparisons using the same data (Myers and Well, 1995). The hatch rate in the southern region was greater than the hatch rates in the central (t=4.28; p=0.000) and northern (t=3.64; p=0.000) regions. This may be explained by a greater number of unoccupied, or low-density occupied, water bodies that existed in this region and provided non-competitive habitat, subsequently yielding higher hatch rates. The central and northern hatch rates were not significantly different. This may have been caused by poor weather or by a smaller, more limited number of lakes in the northern region that dampen the overall hatch rate.

Regression analysis indicated that the number of chicks surviving to the end of the summer increased in all regions through time (Table 11). The strongest relationship existed in the southern region and was possibly the result of available optimal habitat.

Table 9. Regression models, significance tests and Durbin-Watson test statistics for regional scale tests of lakes with nesting pairs against null hypotheses using LOONDATA. Durbin-Watson test cutoff ranges based on α=0.05, N=23, k=1: D_{Lower}=1.26, D_{Upper}=1.44. Serial correlation status determined as follows: Exists if D<1.26; Inconclusive if 1.26<D<1.44, and None if 1.45<D.

Null Hypothesis Test Conclusion ($Ho: \beta_1=0$)	Regression Equation (standard error)	R^2	F Statistic	p	Durbin Watson Statistic
Southern region lakes with nesting pairs increased through time	y = -1463.20 + 0.742x (2.596)	0.787	82.678	0.000	2.124
Central region lakes with nesting pairs did not increase through time	y = -524.05 + 0.635x (6.186)	0.079	1.720[b]	0.204	2.074
Northern region lakes with nesting pairs increased through time	y = -1591.49 + 0.807x (2.950)	0.786	75.67	0.000	2.126

b - Denotes non-significant result.

Table 10. Pairwise comparison of regional mean hatch rates. Southern hatch rate was significantly greater than both the central (t=4.28, p=0.000) and northern regions (t=3.64, p=0.000). Critical t=2.24 based on Bonferroni adjustment (α=0.016, df=32, comparisons=3).

Null Hypothesis Test Conclusion ($Ho: \mu_1=\mu_2$)	t	p
Southern region hatch rate was greater than central region hatch rate	4.28	0.000
Southern region hatch rate was greater than northern region hatch rate	3.64	0.000
Central region hatch rate was not significantly different than the northern region hatch rate	0.47[b]	0.074

b - Denotes non-significant result.

Table 11. Regression models, significance tests and Durbin-Watson test statistics for regional scale tests of chicks surviving against null hypotheses using LOONDATA. Durbin-Watson test cutoff ranges based on α=0.05, *N*=23, *k*=1: D_{Lower}=1.26, D_{Upper}=1.44. Serial correlation status determined as follows: Exists if *D*<1.26; Inconclusive if 1.26<*D*<1.44, and None if 1.45<*D*.

Null Hypothesis Test Conclusion (*Ho:* β_1=0)	Regression Equation (standard error)	R^2	*F* Statistic	*p*	Durbin Watson Statistic
Chicks surviving in southern region increased through time.	$y = -1225.76 + 0.887x$ (4.431)	0.591	17.407	0.00	1.935
Chicks surviving in central region increased through time.	$y = -2123.27 + 1.087x$ (8.340)	0.449	17.141	0.00	1.691
Chicks surviving in northern region increased through time.	$y = -925.37 + 0.476x$ (5.370)	0.275	7.952	0.01	1.717

The statewide trends for lakes with nesting pairs and chicks surviving increased through time while the statewide hatch rate did not increase significantly. One benefit of conducting the same analyses at larger (finer) scales is that regional variations were uncovered. The three regional analyses supported the concept that the southern region had more available unoccupied loon habitat than the other regions. This region may represent the best potential for loon population growth and expansion and require refined management techniques and strategies.

Loons occupy new habitat often because of predation, human disturbance and flooding (Christenson, 1981; McIntyre, 1988; Fair 1993). New territory establishment, as demonstrated by an increased number of lakes with nesting pairs, has occurred naturally and is critical to sustain the loon population in New Hampshire. A key result of this study is the development of a 4-parameter logistic regression model that can be used to assess and predict loon occupancy and identify habitat for monitoring and protection. The next chapter focuses on applying this model to predict loon occupancy, associated accuracy assessment, and development of a potential occupancy map as a management tool for loon biologists.

4.8 Conclusions

Variability associated with lake and loon biology parameters can not always be determined because minor changes in local environmental conditions may change spatially, or temporally, and go undetected for years. Therefore, multiple techniques were used to identify the best parameters for describing previous loon occupancy and forecasting future occupancy.

The loon database and management system developed in Chapter 3 was used to describe and evaluate the loon population and colonization patterns associated with its summer range within New Hampshire. Data exploration revealed that the total loon population and chick survival in New Hampshire increased substantially from 1980-2002. Qualitative trend analysis showed the changing distribution of annual nest site locations within New Hampshire and enabled additional regional (south, central, and north) quantitative analysis.

Qualitative and quantitative analyses were both useful methods for understanding the spatially related loon datasets. Qualitative analyses (e.g., empirical density functions, variograms, covariograms and correlograms) were useful for creating initial interpretations, and quantitative methods (e.g., Moran statistic) were required to validate these interpretations. As demonstrated, formal techniques confirmed that lakes and nest site locations were not spatially correlated.

Linear regression analyses confirmed that the statewide loon population expanded during 1980-2002. Similar regional analyses, time series analyses, hatch rate and survivorship comparisons illustrated that the southern region of the state had the best potential for future growth. This was a geographical shift away from the central and northern regions which were historically viewed as the optimal loon habitat. This conclusion is supported by a combination of the following results: 1) hatch rate in the southern region was higher than the central or northern regions, 2) the number of nesting pairs increased in the southern region, 3) chick survivorship increased in the southern region, and 4) the southern region has the highest number of unoccupied lakes (91%).

Multiple factors contributed to the spatially varying loon population results previously mentioned. Visual review of annual loon nest site maps verified the shift in habitat occupancy to the southern region, although the exact explanation for the shift was unclear. An elevated loon population density is one, and possibly the driving factor, which caused the dispersion from the central and northern regions to the southern region. Several years of high density populations would have increased competition and created a more stressful environment. Consequently, paired loons would have searched for less stressful unoccupied habitat such as that found in the southern region to establish new territories.

The unpaired adult loon population did not change during the study period (1980 – 2002). However, this portion of the population could have been a significant threat to the established territorial pairs because they cause nest failure through repeated territory intrusion and killing of chicks. This problem would have been accentuated due to high population densities and may have resulted in increased dispersion and population expansion in the southern region.

Additional factors that may have contributed to New Hampshire's changing loon population distribution include: shoreline development, recreational activities, lead poisoning, availability of methylmercury (MeHg) in aquatic environments, water level fluctuations from dam releases in the northern region, and avian and mammalian predators. The significance of these factors is unknown and interagency initiatives have been proposed to study the potential impacts of shoreline development and methylmercury on loon populations in New Hampshire and Maine.

Logistic regression proved to be a valuable tool to identify four critical parameters (lake perimeter, lake depth, distance to a lake with a loon, and lake elevation) related to the presence and absence of loons on New Hampshire lakes. The next step in this project (Chapter 5) was to evaluate how well the logistic regression model predicted presence and absence of loons using two approaches. First, the model was used to predict presence and absence using all data and comparing predicted vs. observed loon presence and absence. The second method required implementing the logistic regression model within a GIS framework and comparing predicted vs. observed loon presence/absence for the 1996-2002 data that were not used to build the model.

This study showed that there was available habitat within the state for loons to establish and maintain new territories from 1980-2002. It also supported undocumented historical reports that there were loons on most lakes and hundreds of nesting pairs statewide. Future monitoring of all three sub-regions is warranted to verify: 1) expansion, contraction, or re-distribution of loons within New Hampshire, and 2) habitat that requires protection or management intervention (e.g., raft deployment).

The results presented (not always conclusive) support the notion that the loon population in New Hampshire is doing well. Much of its success is attributed to the endless effort by the Loon Preservation Committee. Public awareness, loon monitoring, educational and research efforts were some of the activities sponsored by LPC and should be continued. One near term goal to accomplish in 3-5 years should be to remove the loon as a threatened species in New Hampshire. Future research areas to support this goal include: 1) examining the changes in productivity (if any) for multiple years within the state, and 2) examining the impact of human disturbance for the most productive, larger, and multiple occupancy lakes such as Winnipesaukee, Squam and Umbagog, and 3) using advanced modeling techniques such as local indicator of spatial autocorrelation - LISA – (Zhang & Gove, 2003) to see if the spatial variability associated with nest site parameters can be determined at larger scales.

CHAPTER 5

LOON HABITAT OCCUPANCY MODEL DEVELOPMENT

5.1 INTRODUCTION

Wildlife is one of many renewable natural resources that requires proper management to ensure sustainability through time. Prior to civilization as we know it today, natural checks and balances were in place and wildlife populations existed without human intervention. However, increasing population and urban sprawl requires wildlife populations to find other, and, sometimes less optimal habitat.

By the early 1970's the Common Loon *(Gavia immer)* population in New Hampshire had experienced a dramatic decline. In 1975, the Audubon Society of New Hampshire recognized this problem and established the Loon Preservation Committee (LPC) to: 1) collect information regarding the presence or absence of loons and loon productivity and, 2) to educate the public regarding loon ecology and preservation. Through the New Hampshire Endangered Species Act, the loon was listed as threatened in 1979 and additional emphasis and importance was placed on managing this species to stimulate population growth and sustainability.

Three major threats to the loon in this state have been identified: reduced breeding habitat due to shoreline development, fluctuating water levels caused by hydro-electric dams on controlled lakes, and contaminant loading from mercury and lead poisoning. In part, because of these issues, the LPC is currently assessing its management and data collection priorities to best address future loon management efforts. During the last 24 years, the LPC has monitored known nesting pairs of loons in New Hampshire and compiled a large database that includes: productivity, occurrence, and location of reproductive loons. Although little analysis of these data has occurred, either statistical or geographical, LPC recognizes that analysis of this database is essential to best guide their future management and data gathering activities. Through this study, the results of analyzing LPC's database are implemented using GIS technology to determine the loon habitat occupancy in New Hampshire. The results of this work will be used for future loon management and decision-making.

5.2 BACKGROUND

Loons are poor colonizers and population growth is further hindered for territories located on lakes with amplified shoreline development, high recreational use, and predation (Piper et al., 1997). Much of the hands-on work to foster sustainability has been conducted only in recent years and is undocumented. Three types of loon territories are occupied, unoccupied, and new territories, and are monitored through time to assess the loon population health and prioritize management decisions.

Forecasting species-specific habitat occupancy is critical for sustaining wildlife populations. Geographic Information Systems (GIS) technology is available and used to manage and manipulate geographically referenced data for decision making in a variety of disciplines (Burrough, 1986; Maguire, Goodchild and Rhind, 1991; Congalton and Green, 1992). For example, habitat models are developed within a GIS to identify preferred habitat for individual species (Agee, et al., 1989; Gagliuso, 1991; Perira and

Iami, 1991; Congalton et al., 1993) including waterfowl (Ringelman, 1992; Cohen, 1998). Through the use of a GIS, local, state and federal organizations are able to manage the large geospatial databases that are required for sustainable wildlife management and decision-making (Stoms, et al., 1992).

The United States Fish and Wildlife Service (USFWL) has developed habitat suitability indices to determine habitat use by waterfowl (USFWL, 1979). Many of these models rely on extensive field data that are difficult to obtain for species with large summer ranges. The use of geospatial data collection and processing technology to model migratory bird habitat allows for more efficient data gathering (e.g., through remote sensing) and analysis over large geographic areas (Herr and Queen, 1993).

The application of a GIS for loon management is novel (Brennan, et al., 1998). Through this effort, however, the results of analyzing loon biology, water body physical characteristics, and nest site proximity parameters are prioritized and captured as a model to establish habitat occupancy for loons in New Hampshire. Model parameters may be adjusted by wildlife managers to conduct “what if scenarios” for identifying habitat with particular management requirements. For example, identifying habitat that may benefit from deploying rafts, a successful technique to enhance nesting results (McIntyre, 1977; Kelly, 1992), may be isolated by dissecting lake size into multiple narrow intervals.

Geographic Information Systems (GISs) presently incorporate a diverse suite of analytical tools for processing large data sets of differing types. One drawback with the proliferation of this technology, however, is that data are sometimes being collected, processed, provided to users, and used in applications without regard to "how good they are." Interpretations that are made using a GIS rely heavily on the results that are obtained from statistical models developed for specific applications. For example, determining correct habitat potential for a particular animal relies on many spatially referenced data layers that may also be independently subject to error. Three of these errors may include: inaccuracy of input source data (digital or hardcopy), analyst judgment, invalid field check results, and final user interpretation (Congalton, 1991; Lunetta, et. al., 1991; Stoms et al., 1992; Congalton and Green, 1999). Operational error sources contribute to total uncertainty and may include: calibration of instrumentation, constant values that are used in spatial data processing models, and algorithms or models used for processing (Walsh, 1989; Collins, 1994). To mitigate error, it is imperative that the quality of input data and the models used to process the data and their underlying assumptions be understood prior to generating and distributing derivative data.

An example of a systematic error is the calibration associated with field instrumentation. If the calibration is off then that bias is passed through to data collected and may affect future processes. Thematic errors are often associated with feature specific layers (e.g., maps, database tables, results from processing steps) that are imported by a GIS. Position information governs the three dimensional location (X, Y, Z) of data stored within a GIS. These coordinates may be associated with a formal coordinate system and are also subject to error.

The propagation of error associated with processing steps is often overlooked. For example, when computing a habitat suitability index, it may be inappropriately assumed that the model being used is correctly adjusted for the species being studied. The data used as input to the model may have varying unknown accuracy that becomes compounded through the modeling process. Also, algorithms used to perform standard operations during model development, such as registration and layer transformation, may exist and be unknown.

Human errors are often difficult to find and quantify. Blunders are the easiest to determine, but small biases or random errors may not surface for quite a while, if at all (Dangermond, 1989). Interpretation and presentation of final results may also be sources of error in the decision-making processes. These errors, however, are external to the GIS framework and the impacts are not known until decisions have been made.

Some accuracy assessment techniques have been developed for use in the remote sensing community. Young and Stoeckeler (1956) used a contingency table to compare photo interpretations with field information. They suggested that these procedures be adopted for quantitatively assessing the results of future aerial photography based mapping studies.

Techniques developed in the remote sensing community are often used to create informational layers that in many cases fall within a GIS framework. Therefore, selected techniques can be applied to GIS applications. Congalton (1991) presents "A review of assessing the accuracy of classifications of remotely sensed data". This method uses an error matrix (contingency table) to present errors associated with classification layers and is based on work by Congalton (1983). An error matrix is an array of numbers organized in rows and columns. These numbers express the number of pixels assigned to a particular category relative to the category that exists on the ground, respectively (Story and Congalton, 1986; Congalton et al, 1993). Categories are listed down the left side (Y axis) and obtained from classes observed in a GIS layer. Those categories listed across the top of the matrix (X axis) are identical, but obtained from collecting reference data. Each value in the matrix represents the frequency with which the observed category and reference category intersect. Matrix values may represent evaluations performed for point, line or polygon features.

The use of the error matrix is an effective means for determining overall map accuracy, which is computed by summing the major diagonal and dividing by either the row or column total. Errors of exclusion (omission) and errors of inclusion or, commission may also be calculated. The total number of correct samples in a category is divided by the total number of samples of that category as derived from the reference data (column total). This measure indicates the probability of a reference sample being correctly identified and is the measure of omission, or producer's error. Commission error, or user's accuracy, is defined by dividing the total number of correct samples in a category by the total number of samples assigned to that category. This measure, also called reliability, is indicative of the probability that a sample identified on a map or layer actually represents the category that is found on the ground.

As described above, analysis of error sources, propagation, and assessment techniques have been studied since the 1950's. There have been far fewer reported investigations into methods for displaying or presented error metrics to end-users (Spear et al., 1996). Some mapping organizations, for example the United States Geological Survey, have provided accuracy metrics with their products for many years (Fitzpatrick-Lins, 1980). These metrics provide users with an estimate of the horizontal and vertical accuracy associated with products at various scales. Some of these products include:

digital elevation matrices (DEM), digital line graph (DLG) and orthomosaics. As an example, error reported for USGS DEM data is in the form of root-mean-square (RMS). This value may seem primitive to some; however, it is better than nothing at all.

Accuracy assessments involving GIS applications are usually performed after all processing is complete and the results may vary depending on the data processing approaches that are used to solve a management question. For example, increased accuracy results may be obtained when locating habitat potential using only three input layers versus five. For this study, initial habitat prediction performance may be reported using a contingency table. A simple 2x2 table can be used to show predicted versus observed loon presence and absence results.

5.3 STUDY AREA

For wildlife applications, study areas are selected based on characteristics of an animal, and the questions being asked about it. Consequently, the parameters to be collected and used for analysis are in part a function of the chosen study area. Therefore, the study area used in this research is limited to the summer range of loons found within New Hampshire. This geographic area was selected because: 1) a substantial amount of biological data dating back to the mid 1970's had been collected for loons in New Hampshire, and 2) a geographic limitation had to be established to perform the geospatial analysis and develop a habitat occupancy model.

New Hampshire is located in the northeast portion of the United States and the climate in this area is moderated by the Atlantic Ocean. Average total precipitation is approximately 106 cm, with approximately 152-203 cm of snowfall (Geraghty, et al., 1973). Significant increases in rainfall during the breeding season can flood nests and result in higher chick mortality.

The elevation in this state ranges from sea level near the coast to 1916 m (6288 ft) on top of Mt. Washington, which is located in the White Mountains National Forest. The average elevation in the state is 342 m (1122 ft) with the highest areas concentrated in the northern portion of the state. Most of the upper elevations are gently rolling hills because they were smoothed over during the last glacial periods.

New Hampshire water bodies are principally fresh water and used by loons during the summer for territory establishment and breeding. This study is confined to examining the loon habitat occupancy associated with summer range found on open water bodies within New Hampshire (Figure 30).

In the higher elevations of the state, it is noted that the density and size of fresh water bodies is reduced. Consequently, loons seeking optimal habitat are usually found in lower elevations. Figure 31 shows the loon nest sites recorded in 2002 overlaid on top of the elevation data for New Hampshire.

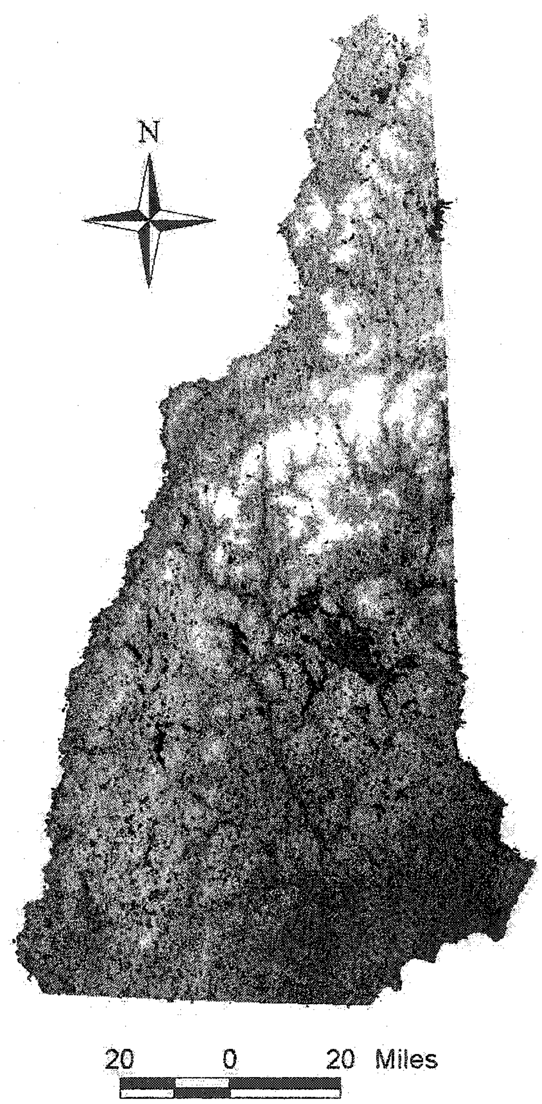


Figure 30. New Hampshire topography with fresh water body overlay (dark areas are lowest elevations and white areas are highest elevations).

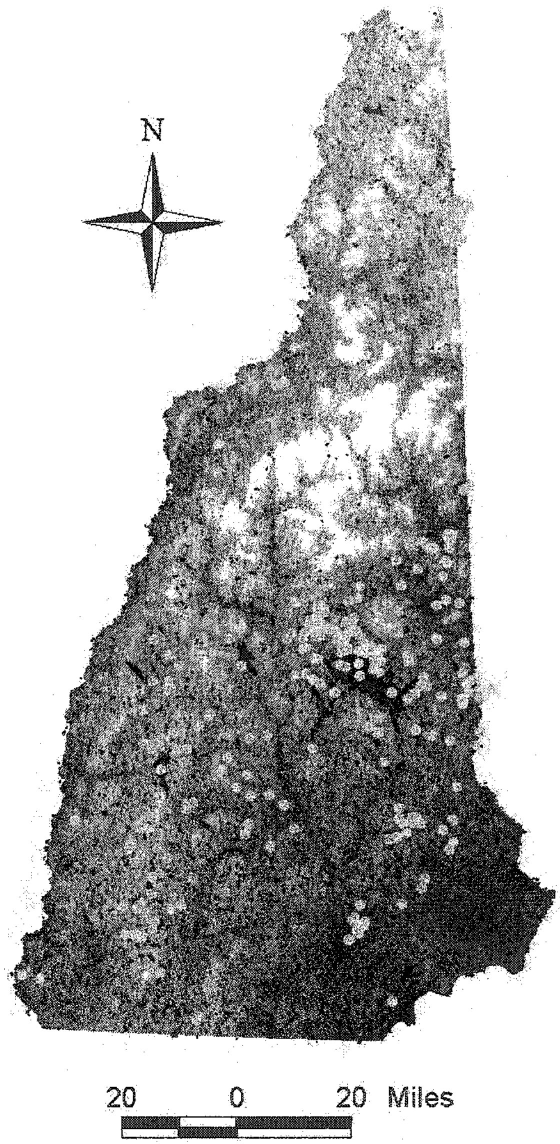


Figure 31. New Hampshire topography with 2002 loon nest sites.

5.4 HABITAT MODEL DEVELOPMENT METHODS

This section describes the procedures used to build a habitat occupancy model within ArcView® and apply the model to the entire state.

5.4.1 Habitat Occupancy Model

A habitat occupancy model is a mathematical function that expresses species-specific occupancy for a particular habitat based on a limited set of parameters. This measure is designed to incorporate the spatial, temporal, and biological variability associated with the species for which it is developed. It is also desired to develop a model using the fewest parameters as possible that explain the maximum amount of variance.

The function developed in Chapter 4 to represent the probability of loon presence based on four habitat occupancy parameters is as follows:

$$p(\textit{loon presence}) = -3.4683 + 0.000021\,(\text{PERIMETER}) + 0.045810\,(\text{DEPTH}) \\ -0.000096\,(\text{LOONDIST}) + 0.000936\,(\text{ELEV}) + \epsilon$$

LPC biological data and GIS layers are the primary input parameters for this study. A shapefile (NESTSITES) containing all known nest site locations was created in Chapter 3 by digitizing the locations of nesting sites identified on 1:24,000 USGS topographic maps and importing locations captured using a handheld GPS unit. This shapefile and the LAKES shapefile were loaded into ArcView® as individual themes. The LAKES, LOONDATA, and FISH tables were each linked to the LAKES theme. Occupancy ranges were established for the PERIMETER and LAKEDEPTH habitat parameters identified in Chapter 4. Using the ArcView® query builder, a map (theme) showing habitat occupancy within the state was created. Lakes identified according to these ranges were compared to actual data collected during the 1997-2002 field seasons.

The probability of a lake being occupied by a loon was calculated for each lake using the four-parameter habitat occupancy function provided above. Results were stored as a separate variable, LOONPROB, and added to the LAKES table. A map (theme) showing loon occupancy potential (high, medium and low) was produced using these probabilities.

5.4.2 Habitat Occupancy Model Testing

Various sources of data are used for natural resource management studies. A common procedure to reduce error is to use data sources that can be acquired from reputable organizations that employ high quality data collection methods, report some form of data accuracy (i.e., metadata), and reference all layers to a common reference system. For the loon study, all field data were collected according to standard operating procedures and GIS layers were georeferenced to New Hampshire state plane coordinate system, NAD83 horizontal datum.

Range and probability based model results identifying habitat occupancy were displayed within ArcView® over the lakes and geopolitical boundary themes. Presence and absence field data collected by LPC from 1980-1996 were used to develop the model. A reference list of newly occupied lakes was compiled from field data collected during the 1997-2002 field seasons. Three performance assessments were computed through this effort: 1) a contingency matrix (2x2) was computed to compare predicted loon presence and absence obtained from the loon habitat occupancy function to observed loon presence and absence during 1980-1996, 2) a contingency matrix (2x2) was computed to compare predicted loon presence and absence obtained from the loon habitat occupancy function to observed loon presence and absence during 1997-2002 field seasons, and, 3) predicted loon presence and absence based on model results implemented within ArcView® were compared to observed loon presence and absence during 1997-2002.

5.5 RESULTS

A total of 78 water bodies within New Hampshire experienced new occupancy during a portion of 1997-2002. Thirty-one lakes (40%; 31/78) had new occupancy with no prior occupancy history during this period and represented newly occupied loon habitat. Thirty-one lakes (40%; 31/78) were newly occupied during the same period and with minor prior occupancy history, defined as less than two years occupancy since 1980. The remaining sixteen lakes (20%; 16/78) appeared as new occupancy, however, they also had multiple years of previous occupancy dating back to 1980. Elimination of these 16 lakes leaves 62 lakes that were considered to be the best candidates for newly occupied loon habitat during 1997-2002. The distribution of the 78 lakes is shown in Figure 32.

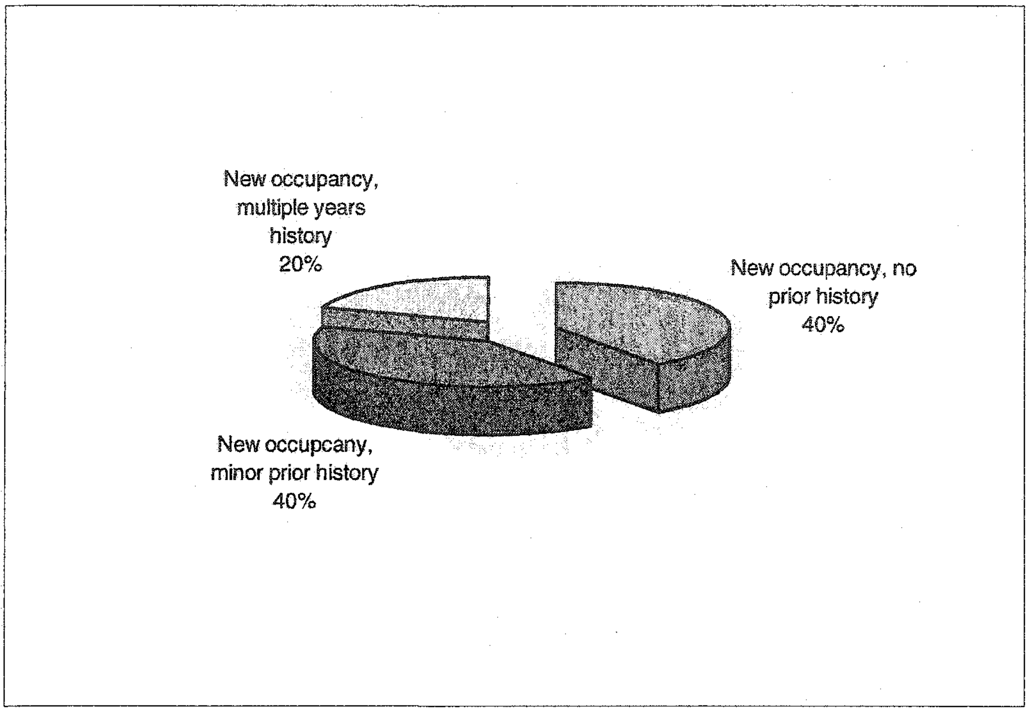


Figure 32. Distribution of 78 newly occupied lakes during 1997 to 2002.

A summary of the four habitat occupancy parameter mean and median values for the 62 newly occupied lakes during 1997-2002 is presented in Table 12. Results are separated to show the differences between new lakes with no prior occupancy (31) and lakes with minor previous history (31). The mean and median values for both sets of PERIMETER and LAKEDEPTH values were less than the values for the same loon presence parameters for all lakes identified in Chapter 4. This suggests that loons occupied new habitat that was smaller and shallower than in previous years. Additionally, the LOONDIST parameter (distance to a lake with loons) increased indicating that loons traveled further to find new suitable habitat.

Table 12. Mean and median values for the four habitat occupancy parameters for the 62 newly occupied lakes.

Parameter	New Occupancy Lake – No Prior History (31)		New Occupancy Lake – Minor Prior History (31)	
	Mean	**Median**	**Mean**	**Median**
PERIMETER (meters)	45765	41716	53536	42631
LAKEDEPTH (meters)	13	12	18	20
LOONDIST (meters)	7061	3896	6258	4999
ELEV (meters)	822	878	925	823

The logistic regression coefficients generated using the 1980-1996 data were applied to the 1980-1996 dataset to verify its initial performance. A contingency table showing the comparison of predicted loon presence/absence versus observed loon presence/absence using the model development data collected during 1980-1996 is presented in Table 13. Overall accuracy was 81% and was expected be high because the same data that were used to develop the model coefficients were reapplied to the model development dataset. Producer's and User's accuracies were higher for both of the Loon Absence categories possibly because there is a naturally occurring higher number of lakes categorized as loon absences versus loon presences.

Table 13. Contingency matrix showing comparison of correct and incorrect predicted loon presence and absence to observed loon presence and absence based on the habitat occupancy function developed for the 1980 to 1996 dataset.

	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	58	72	130
Observed Loon Absence (0)	29	372	401
Totals	87	444	531
		Overall Accuracy	**81%**

Producer's Accuracy			**User's Accuracy**		
Loon Presence	58/87	67%	Loon Presence	58/130	47%
Loon Absence	372/444	84%	Loon Absence	372/401	93%

The next analysis compared loon presence and absence during 1997-2002 field seasons to loon presence and absence as predicted by applying the loon habitat occupancy function to all lakes. The prior probability of a loon being present on a lake in New Hampshire (based on observed data collected 1980-1996) is approximately 19%. Therefore, a cutoff value of p=0.2 was selected to isolate the lakes with the highest probability of predicted loon presence ($p(presence)$>0.2) and considered to be prime candidates for new occupancy. A random sample of 100 lakes was selected using 60 lakes that were expected to support loon occupancy and 40 lakes that were not expected to support loon occupancy. A contingency table showing the observed loon presence/absence versus predicted loon presence/absence is presented in Table 14. Overall accuracy for the model predictions was 78%. Of the 41 correctly predicted presences found in Table 14, 23 were paired adults and 18 were single adult loons. Nine of the 19 incorrect predicted presences have probabilities <0.24 and were considered marginal. If these 9 lakes were included as correctly classified absences, then the overall accuracy was 87%. Producer's accuracy indicates that the model is best at predicting presence. User's accuracy indicated that biologists would have confidence in verifying lakes with no loon occupancy (absence). The overall producer's and user's accuracies suggest that this model is useful to predict potential loon habitat in New Hampshire.

Table 14. Contingency matrix showing comparison of correct and incorrect predicted newly occupied lakes based on the habitat occupancy function developed for the 1997 to 2002 dataset.

	Observed Presence	Observed Absence	Totals
Predicted Presence P > 0.2	41	19	60
Predicted Absence P < 0.2	3	37	40
Totals	44	56	100
		Overall Accuracy	**78%**

	Producer's Accuracy		User's Accuracy	
Presence	41/44	93%	41/60	68%
Absence	37/56	66%	37/40	93%

The Query Builder available within ArcView® was used to implement a model that would identify loon habitat occupancy in New Hampshire. The two most significant habitat occupancy parameters previously identified through logistic regression

(PERIMETER and LAKEDEPTH) were used to build the model and compare to the 1997 to 2002 reference data.

This analysis indicated that loons were occupying smaller lakes usually larger than 12 hectares. Therefore, a PERIMETER range of 20,000 (approximately 12 hectares) to 93,405 (maximum of α =0.05 confidence interval) was used to capture the smaller to midsize lakes. A LAKEDEPTH range of 15m (minimum of α =0.05 confidence interval) to 18m (average LAKEDEPTH) was used to capture shallow lakes that still support a good food source (Table 15).

Table 15. Habitat occupancy parameter ranges.

Parameter	Range	Description
PERIMETER	20000 - 93405	Lake perimeter (m)
LAKEDEPTH	15 - 18	Lake depth (m)

Using these ranges, 34 new lakes during 1997-2002 were identified. Twelve of the 34 lakes (36%) were new lakes, of which 8 had no previous occupancy and 4 had minor previous occupancy. Increasing the ranges for both PERIMETER and LAKEDEPTH yielded more candidate lakes, but reduced the performance of actually finding new lakes. Twelve (36%) of the remaining 22 lakes have multiple years of prior occupancy during 1980-1996, and the other 10 (28%) lakes have no previous record of occupancy. The distribution of these newly occupied lakes is shown in Figure 33.

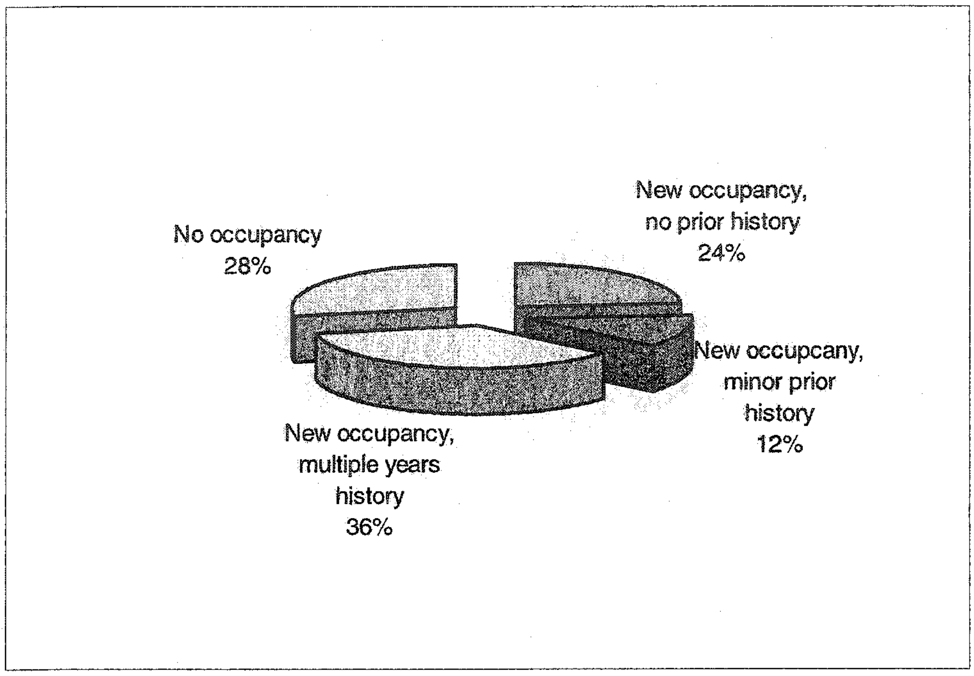


Figure 33. Distribution of 34 newly occupied lakes during 1997 to 2002 determined by using the habitat occupancy ranges.

Figures 34-36 show loon nest sites displayed over three ranges of loon habitat occupancy for southern, central, and northern New Hampshire. These results are based on segmenting the habitat occupancy probabilities, calculated using the 4-parameter habitat occupancy model into high ($p \geq 0.5$), medium ($0.20 \leq p < 0.5$), and low ($p < 0.2$) habitat occupancy ranges. Using this approach, 36 water bodies were classified as high loon habitat occupancy, 102 as medium occupancy, and 395 as low habitat occupancy.

The average values for each of the 4 parameters according to habitat occupancy are presented in Table 16. As habitat occupancy changes from high to low, mean values for PERIMETER and LAKEDEPTH decrease, mean values for LOONDIST increase, and ELEV increases and then decreases. This is expected because loons appear to be occupying less optimal habitat.

Table 16. Average values for habitat occupancy parameters.

	PERIMETER (meters)	LAKEDEPTH (meters)	LOONDIST (meters)	ELEV (meters)
HIGH Loon Habitat Occupancy Potential	48,418	26	2498	894
MEDIUM Loon Habitat Occupancy Potential	17,120	18	4156	1029
LOW Loon Habitat Occupancy Potential	8089	9	9697	795

Figure 37 shows an enlarged area south and west of Alton Bay (part of Lake Winnipesaukee) to illustrate the use of the habitat occupancy model for determining and monitoring habitat occupancy. In the southern portion of the figure (near #1), Upper Suncook Lake (with a nest site) is classified as a medium potential habitat occupancy lake. This lake is also one of the new lakes with minor prior history found during 1997-2002. This lake was occupied in 1989 only, and then not again until 2002. This lake should be monitored for loon activity very closely during the coming field seasons.

Manning Lake is a low habitat occupancy lake and shown with a nest site near # 2 in Figure 37. This lake was occupied 3 times from 1977-1996 and abandoned since that time. This is an example of a low quality lake, which may only be occupied sporadically. The two medium occupancy lakes to the east and south should be monitored closely for loon activity.

Near #1 in Figure 37 is Paugus Bay, which according to the loon habitat model is suggested to be high habitat occupancy. This water body is identified as a new lake during 1997-2002 with no previous history and should be monitored very closely along with Opecheee Bay immediately to the south of Paugus.

Lakes classified as high loon habitat occupancy and selected medium loon habitat occupancy should be monitored regularly during the next few field seasons. This will provide additional detail about loon activity on these lakes and also further validate the habitat occupancy model developed through this study. A map showing habitat occupancy for the entire state is provided on CD and may be used for prioritizing the monitoring of lakes for new occupancy.

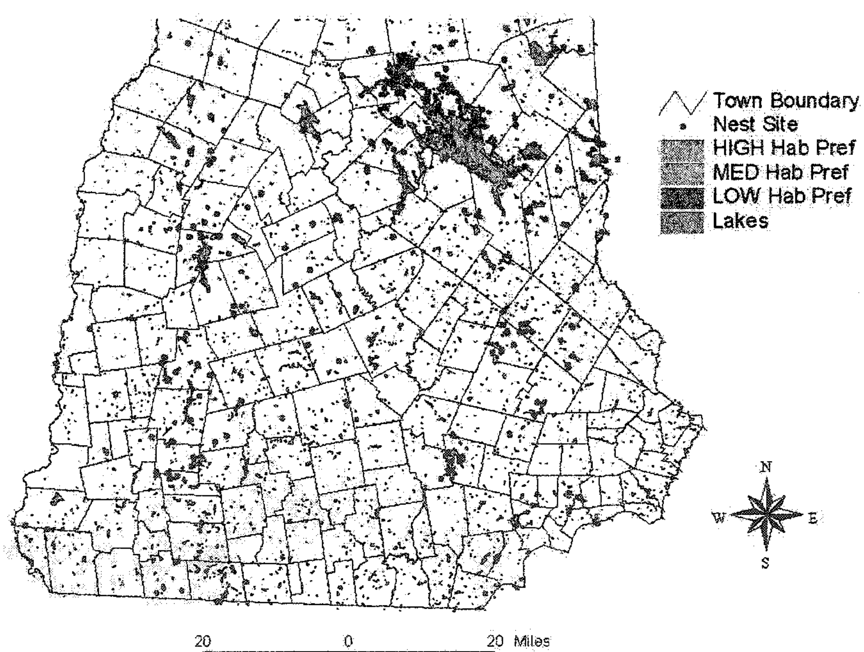


Figure 34. Predicted loon habitat occupancy for southern New Hampshire. Green indicates high habitat occupancy; orange is medium habitat occupancy, and, red is low habitat occupancy.

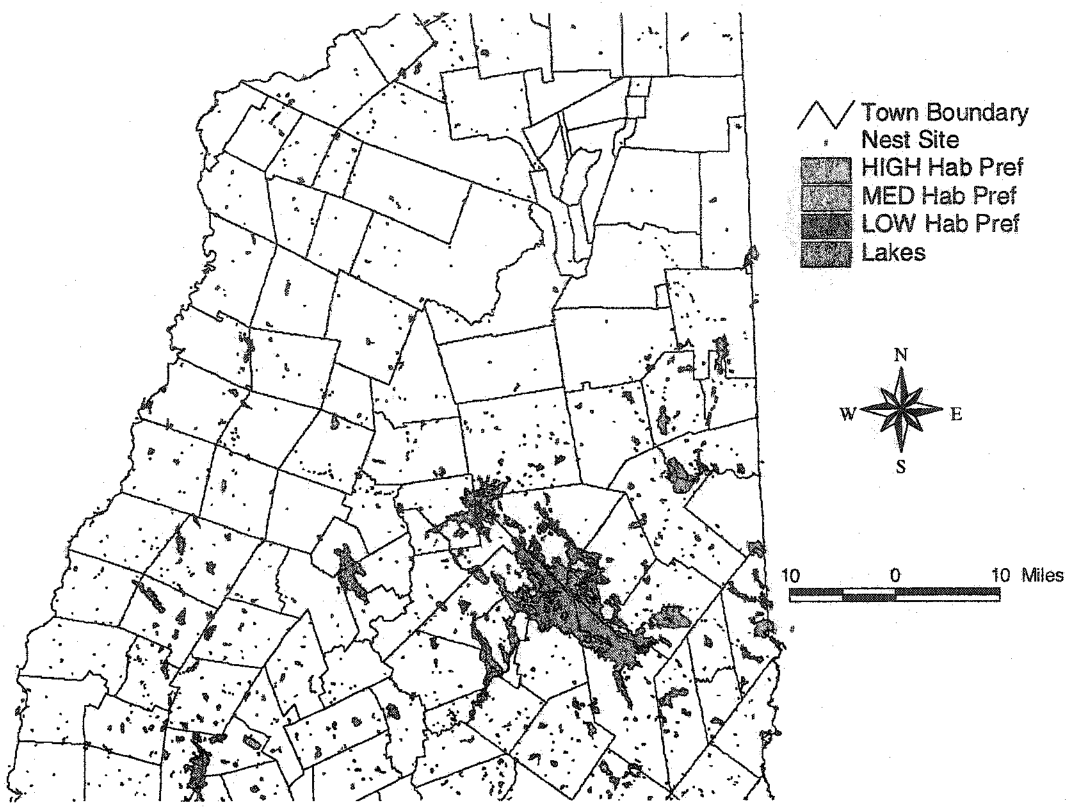


Figure 35. Predicted loon habitat occupancy for central New Hampshire. Green indicates high habitat occupancy; orange is medium habitat occupancy, and, red is low habitat occupancy.

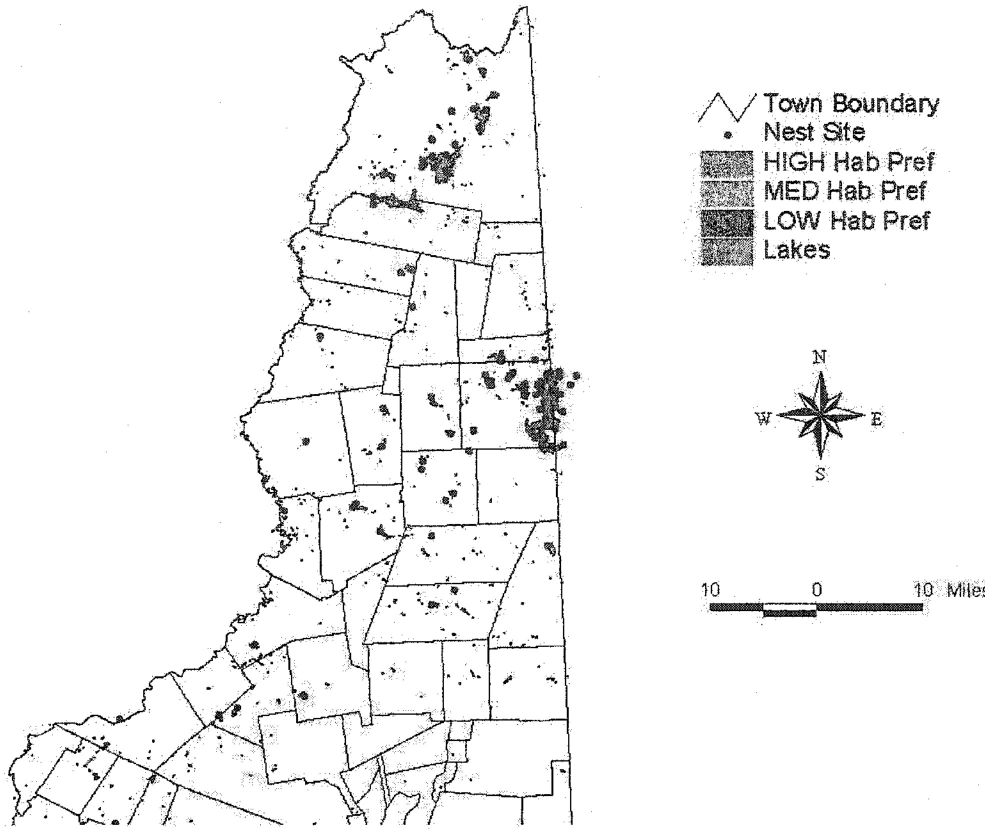


Figure 36. Predicted loon habitat occupancy for northern New Hampshire. Green indicates high habitat occupancy; orange is medium habitat occupancy, and, red is low habitat occupancy.

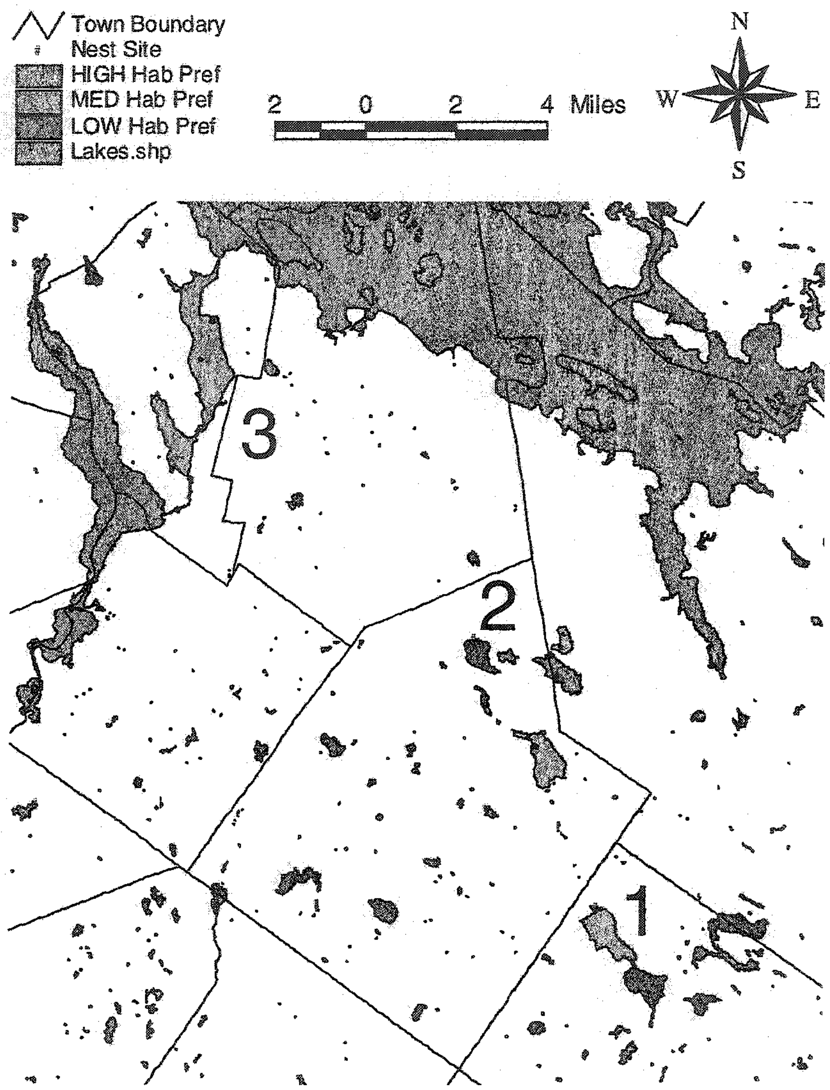


Figure 37. Enlarged view of the area south and west of Alton Bay showing loon habitat occupancy. Green indicates high habitat occupancy; orange is medium habitat occupancy, and, red is low habitat occupancy.

5.6 Discussion

The results obtained in this effort were very encouraging. Although the source of error associated with the results is not completely understood, it was minimized primarily by: 1) using consistent field and ancillary data collection methods, 2) the availability of a large dataset for statistical analysis, 3) quality control reviews for all data used in the study, and, 4) developing a rigorous model to represent habitat occupancy. LPC biologists will continue to verify the habitat occupancy lake list during future field seasons and information gathered during that time can be used to refine the habitat model results.

The next operational step is to have loon biologists use the model results to direct monitoring efforts during the next field season(s) and provide feedback regarding model performance. This can be accomplished by recording predicted occupancy and observed occupancy for each lake visited during the field season. Lakes experiencing new loon occupancy represent very good candidates for long term occupancy and must be monitored closely in future field seasons.

5.7 Conclusions

The overall (78%), producer's and user's accuracies suggest that the habitat occupancy model developed through this research is very useful for predicting potential loon habitat in New Hampshire. The next operational step is for loon biologists to use the model results to direct their monitoring efforts during future field seasons which will provide further model verification and refinement.

The habitat occupancy model was implemented using ESRI ArcView® to identify loon habitat in New Hampshire. The results reveal that new lakes occupied during 1997 – 2002 are smaller and shallower when compared to lakes occupied during 1980 to 1996. One reason for this is that larger lakes supporting multiple territories have reached, or are reaching their limit and forcing loons to disperse to less optimal habitat. The resulting list of new and unoccupied lakes will be used by LPC biologists to guide their monitoring strategy during future field seasons. Further, complete assessment of model performance will be accomplished during the next few field seasons by gathering additional lake occupancy data and then checking end of season reports against forecasted results.

It is anticipated that: 1) the model developed in this study will be revised based on findings during future field seasons, and 2) that the model, and GIS, will be an essential tool for future loon management in New Hampshire, and, potentially surrounding states. The parameters used in this model may be updated by changing the queries developed within the ArcView® framework. Eventually, it will be desirable to migrate the database and model implementation to the ESRI ArcGIS® framework.

The loon management system, developed in Chapter 3 and enabled by a GIS engine was critical for performing the logistic regression and parameter determination presented in Chapter 4. This tool allowed for data import, management, processing and displaying results in one environment, consequently allowing for easy wildlife management decision making. The system was integrated using software components that provide diverse functionality, flexibility, ease of use, portability to new hardware platforms, and relatively low cost. The GIS engine, ESRI ArcView®, is a critical component in this system and provided the querying capability to determine potential loon habitat occupancy in New Hampshire. This system, along with the loon database, ArcView® GIS and the project files reside at the LPC in Moultonborough, New Hampshire. Further research may be warranted to investigate habitat occupancy confined to the largest lakes that currently have loon territories or the potential to support territories to see if any intra-lake habitat occupancy arises.

Additional research also needs to be performed to better understand the uncertainty associated with the results obtained in this study. For example, developing accuracy metrics associated with individual data sources or using new attributes that are collected by the summer biologists may be warranted. Examples of new attributes include: water quality measurements, fishery type and quality, human disturbance, and recreational use patterns. A combined error function may be developed to monitor the error terms during different stages of the analyses and may aid in identifying data types or processes that contribute the greatest amount.

No other studies like this have been performed before. The impacts of the potential errors associated with original data and GIS layers become evident once a habitat occupancy model is developed, tested, and demonstrated. The practical application demonstrated in this work has provided usable results in identifying potential loon habitat as compared to reference data collected over 7 field seasons. This is attributed to consistency in data collection methods used by LPC staff, selection of appropriate field data collected from multiple organizations, incorporation of high quality georeferenced data produced by GRANIT, and proper use of spatial and non-spatial analysis methods.

CHAPTER 6

CONCLUSIONS, BENEFITS & FUTURE WORK

6.1 CONCLUSIONS

Loon biological data originally captured in hardcopy from 1975 to 1996 were converted to digital files. This was a laborious task and highlighted the need for developing and implementing new semi-automated methods to collect and store in digital form any loon specific data. This requirement resulted in the development of the loon data management system and its successful implementation is demonstrated through its use by wildlife managers both internal and external to LPC. Recent policy development and data analysis would have experienced lengthy delays without the use of the tools in this system. The extensive digital database can accommodate: loon territory locations, territorial pair characteristics, banding information, water body parameters, and GIS layers, and will be important for use in future statewide loon management.

Analysis of the loon database showed an increasing loon population in New Hampshire from 1980-2002, and during the same period new habitat (water bodies) was occupied. Regional analysis (north, central and south) revealed that the southern portion of the state may represent the best potential for loon population expansion. One explanation is that historical habitat is filling up in the central and northern regions and younger loons returning to natal lakes are forced to establish territories on new lakes with lower occupancy and reproductive pressure.

A habitat occupancy model was developed using historic loon presence and absence data on water bodies during 1980-1996. Four parameters – lake perimeter, lake depth, distance to a lake occupied by loons and lake elevation – were found to be significant (p=0.001) in determining loon occupancy. This model was tested using loon occupancy data collected during the 1997-2002 field seasons, yielding 78% accuracy. LPC biologists will benefit from this analysis by using a habitat occupancy map derived from the 4-paqramaeter model to guide monitoring efforts during subsequent field seasons. Continued validation is important for model refinement and will be achieved through feedback from LPC biologists after each field season.

Qualitative GIS-enabled trend analysis using 17 years of loon presence and absence data initially revealed the spatial expansion for loon territories throughout New Hampshire. Quantitative regression analyses showing increasing total loon population and number of lakes with successful nesting pairs confirmed the perceived expanded spatial distribution. Additionally, spatial analysis was conducted using lake centroids and nest site locations and showed that loon territories are not clustered. The combination of qualitative and quantitative, spatial and non-spatial analyses were important for investigating initial hypotheses recommended for future habitat occupancy efforts.

An increase in the total population and spatial distribution across the state from very low population levels noted in the early 1970's is documented through this research. The southern portion of the state represents the best potential for future growth because of lower loon densities coupled with higher hatch rates as compared to the central and north regions. Plans need to be developed to manage and possibly protect habitat that is likely to be occupied by loons in the future to sustain a healthy loon population.

6.2 Benefits

The benefits of this work have, and will continue to impact many organizations as summarized below.

6.2.1 University of New Hampshire

A key benefit of this research to the University of New Hampshire is that the wildlife management research role conducted within the department of Natural Resources is expanded to a new species. Through this effort mapping and database technologies were used and exposed in new ways to broaden the experience of department staff. It is envisioned that future projects will stem from this effort and that the department may continue its presence in future loon management activities. Additionally, this work was conducted with no financial impact to the university because graduate student funding was acquired through partnerships with private companies.

6.2.2 Loon Preservation Committee (LPC)

The LPC is tasked with monitoring and promoting the New Hampshire loon population. This function requires staff and financing to support data collection and education activities. Efforts between the LPC and cooperating external organizations are necessary to help achieve its goals. Some of the benefits to LPC realized through this study are:

- Streamlined data collection standard operating procedures that yield annual cost savings.
- Worldwide recognition and accessibility through the development of an

Internet website (http://www.loon.org). This site has proven useful in directing the public to LPC, general awareness of loons and initializing emergency response activities for injured loons.

- Development of a New Hampshire loon habitat occupancy map used to determine future field season monitoring schedules.
- Development of a digital database containing 29 years of loon specific data which is used for current loon management.
- Development of habitat protection plans in conjunction with other loon management organizations (e.g., NHDES Wetlands Bureau) for loons in New Hampshire are enabled using the loon database.
- GIS enabled software tools were delivered to LPC and are used for loon management.
- The work conducted in this study was performed at no cost to the LPC.

6.2.3 New Hampshire State Agencies

New Hampshire state agencies benefit from this work in the following way:

- Nest site locations corresponding to territorial pairs have been transferred to the NHDES Wetlands Bureau. This information is directly compatible with their ESRI based GIS system and provides the office with approximately 80 new nest locations. These data are critical to their wetland management functions as they monitor loon nest sites and use them in part to deny or approve shoreline building permits.

- The Department of Environmental Services can use the loon database management system to assist in identifying new lakes to sample and monitor water quality.
- The work performed in this study is consistent with Hew Hampshire Fish and Game long range management plans. Two particular goals are: 1) delist the loon as a threatened species, and 2) extend relevant loon research methods to other listed threatened or endangered species.
- Integrating the loon database for use within multiple organizations (e.g., LPC, NHF&G, NHDES) promotes better cooperation and enhanced species protection.
- Positive relationships were created among corporations such as: BAE Systems, Space Imaging, Pacific Meridian Resources, TASC, WSI, ESRI and selected state agencies. Additional corporate/state relationships will develop through the continuation of this research.

6.2.4 Federal Agencies

The U. S. Fish and Wildlife Service supported this project since its inception. A benefit to the staff located in the Concord office (New England Field Office) was the transfer of database and GIS technology that is applicable to other wildlife management applications within New Hampshire and surrounding region. An example of this technology transfer is that portions of the loon database concept are being applied to manage loon in other parts of the United States.

The Environmental Protection Agency is responsible for watersheds in their respective regions. EPA Region I located in Narragansett, Rhode Island is using the loon database concept as a model to organize information related to mercury and lead poisoning. They are also designing field data collection methods that will be compatible for future loon research.

6.2.5 Local Organizations

Local organizations including conservation committees and lake associations will benefit from this research by:

- Having access to a central loon management database specific to water bodies in their area for a variety of local monitoring purposes;
- Educating and interacting with the public through the use of proven, easy and inexpensive GIS tools; and
- Increased public awareness of loons.

6.2.6 LPC Web Site

Internet usage continues to rise and allows for increased general public awareness for any organization that develops and maintains its own website. The cost of developing and maintaining a website is minimal and serves as a low cost advertising tool.

A designated LPC website was developed for communicating activities and general information concerning loons in New Hampshire. The homepage for this site may be visited at http://www.loon.org. It is envisioned that this web site may eventually be integrated into the current state of New Hampshire homepage. The web site is currently hosted by GRAN-NET, a small computer and Internet services company located in southern New Hampshire. The long-term maintenance of this web site has transferred from the author of this document to an internal LPC staff member.

A basic loon mapping website was developed for testing purposes. Plans are underway to provide permanent Internet loon-mapping services, which will enable the public to view maps of New Hampshire loons and potentially limited access to specific territory information.

6.3 FUTURE WORK

This research presents a current view of the New Hampshire loon population which is increasing and expanding into new habitat. Questions related to existing and new loon habitat planning, protection and management must be addressed to sustain healthy populations in this state as well as other geographic regions that support loons.

One long term extension to this research is to develop a habitat planning and management capability that will account for human disturbances and changes in surrounding landscape in addition to loon habitat requirements. This development effort will require increased coordination with resource management organizations at various levels of government. However, wildlife decision makers will be provided with an enhanced ability to develop wildlife management plans that are more closely aligned with local and state planning organizations.

Diffusion modeling is one habitat planning and management technique that allows for adjusting variable habitat requirements (patch size, shape and location) and is a viable approach when designing new habitat for a particular species (Bevers & Flather, 1999;

Flather & Bevers, 2002; Bevers et. al., 2003). For example, when developing a harvest plan, a forester can determine the amount of a particular type of timber to harvest and then adjust the harvest size, shape and location to accommodate habitat development or preservation to satisfy species specific wildlife management plans.

Open water bodies are the most critical habitat for loons because they spend the majority of their life on ponds, lakes and coastal areas to live, feed and reproduce. In New Hampshire, the size, shape and location of loon habitat is considered to be static. Minor annual changes usually occur only in the form of shoreline development and water level fluctuations.

A secondary parameter to open water, nest site location, does vary according to habitat availability. This could be adjusted through diffusion modeling techniques and implemented in the field by deploying floating rafts to create artificial habitat. Deploying rafts to attract paired loons is a management technique used by LPC in New Hampshire for establishing new loon territories. However, the policy is strict and allows for raft deployment only on water bodies that exhibit a characteristic that hinders new territory establishment, e.g., fluctuating water levels on impounded water bodies or continued nest predation. In this case, rafts are deployed in areas (often coves or near islands) that are accessible by boat and which provide protection from predators, food and area to raise young.

Development of a dynamic loon habitat planning and management modeling tool will be required in the future to manipulate the increasing complexity of loon habitat parameters. Diffusion modeling may be a candidate technology to include as a component within a future tool, but is not a viable option at this time because: 1) current loon management variables are fixed, and 2) current LPC policy prohibits wide scale raft deployment for increasing territory establishment.

Additional extensions of this research are as follows:

- LPC continue working collaboratively with BioDiversity to analyze banding data. This will provide information regarding: 1) return rates of adult loons to specific territories, 2) mate and territory switching rates, 3) chick survival, and 4) migration and wintering patterns.
- Development of Internet-based tools for remote data entry, download, mapping and alerting mechanisms. This will require an infusion of hardware and software technology such as field deployable GPS enabled data collection devices.
- LPC work with the Lay Lakes Monitoring Program at the University of New Hampshire to streamline lake monitoring procedures and provide consistent data for all high priority loon lakes.
- Install telemetry devices on loons for selected territories to monitor and analyze intra-lake, inter-lake and migratory patterns.
- Expand loon database to include human disturbance, land use and other evolving loon habitat parameters.
- Refine and re-validate loon habitat occupancy model based on subsequent field season feedback.

- Provide EPA Region I with territory data to support their mercury and lead poisoning research.
- Convert ArcView GIS loon management framework to the ArcGIS environment.
- Establish formal nest site and brooding protection zones for lakes with high recreational use. These zones will be marked to restrict recreation use and shoreline development for 2 - 3 weeks after hatching. Precise timing of restriction and location will depend on lake specifics (e.g., location and time on nest).
- Develop materials (posters, signs, flyers) that can be used to continue public awareness purposes. This information may be distributed via press releases, public hearings, mass mailings, radio (NPR) and television interviews (PBS/NOVA), displays, special events or discussion pieces at invited programs. These materials will address specific issues relating to loon preservation with the intent of increasing public awareness about loon conservation.

LITERATURE CITED

Agee, J. K., S. C. F. Stitt, M. Nyquist, and R. Root, 1989. A geographic analysis of the historical grizzly bear sightings in the North Cascades. Photogrammetric Engineering & Remote Sensing 55:1637-1642.

Allen, T. F. and T. W. Hoekstra, 1992. Toward a Unified Ecology. Columbia University Press, New York. 384 p.

Alvo, R. 1981. Marsh nesting of Common Loons (*Gavia immer*). Canadian Field-Naturalist 95:357.

Barklow, W. E., 1979. The function of vocalization of the Common Loon (*Gavia immer*). Ph. D. Thesis, Tufts University.

Blair, R. B., 1992. Lake features, water quality and the summer distribution of common loons in new Hampshire. Journal of Field Ornithology, Vol. 63, No. 1, pp 1-9.

Bevers, M., C. H. Flather, J. Hof and H. F. Kaiser, 2003. Sustaining wildlife populations in productively managed forests. In: G. J. Arthaud and T. M. Barrett (eds.), Systems Analysis in Forest Resources, 225-242. Netherlands.

Bevers, M. and C. H. Flather, 1999. The distribution and abundance of populations limited at multiple spatial scales. British Ecological Society, Journal of Animal Ecology, 68:976-987.

Brennan, M and R. Congalton. 1999. Analysis of spatially related data for Common Loon (*Gavia immer*) management in New Hampshire. In: Proceedings of the 65th Annual Meeting of the American Society for Photogrammetry and Remote Sensing, Portland, OR, pp. 203-206 CDROM.

Brennan, M. W., R. G. Congalton, P. J. Pekins, and K. Taylor, 1998. Use of remote sensing and GIS tools for Common Loon (*Gavia immer*) management in New Hampshire. In: Proceedings of the 64th Annual Meeting of the American Society for Photogrammetry and Remote Sensing, Tampa, FL, pp. 470-478 CDROM.

Burrough, P. A., 1986. Principles of Geographic Information Systems for Land Resource Assessment. Oxford University Press. New York, NY. 194 pp.

Caron, J. A., and W. L. Robinson, 1994. Response of breeding Common Loons to human activity in Upper Michigan. Hydrobiologia, 280: 431-438.

Carroll, D., 2002. Wood ducks. News and Views of Wildlife Management. New York State Department of Environmental Conservation, Region 8.

Christenson, 1981. Reproductive ecology of and response to disturbance by Common loons in Maine. M. S. Thesis, University of Maine, Orono. 43 pp.

Cliff, A. D., and J. K. Ord, 1973. Spatial autocorrelation. Pion, London.

Cohen, J. B. , 1998. Greater scaup as bioindicators of contaminants in Long Island Sound. M. S. Thesis, University of Connecticut, Storrs, CT.

Collins, F. C., and J. L. Smith, 1994. Taxonomy for error in GIS. The International Symposium on Spatial Accuracy of Natural Resource Data Bases, Williamsburg, VA.

Congalton, R. G., J. M. Stenback and R. H. Barrett, 1993. Mapping deer habitat suitability using remote sensing and geographic information systems. Geocarto International, Vol. 8, No. 3:23-33.

Congalton, R. and K. Green. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC/Lewis Press, Boca Raton, FL. 137 p.

Congalton, R. G., and K. Green, 1992. The abcs of GIS. Journal of Forestry, Vol. 90, No. 11:13-20.

Congalton, R. G., 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment, 37:35-46.

Cressie, N. A. C., 1993. Statistics for Spatial Data, Revised Edition. John Wiley & Sons, Inc., New York.

Dangermond, J., 1989. A review of digital data commonly available and some of the practical problems of entering them into a GIS. Fundamentals of Geographic Information Systems: a Compendium, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, pp 41-58.

Diggle, P. J., 1983. Statistical Analysis of Spatial Point Patterns. Academic Press, New York.

Dzubin, A., 1969. Assessing breeding populations of ducks by ground counts. Saskatoon Wetlands Seminar. Canadian Wildlife Service Report Series – Number 6. 178 – 237 pp.

Evers, D. C., 2004. Status assessment and conservation plan for the Common Loon (*Gavia immer*) in North America. U.S. Fish Wildlife Service, Hadley, Massachusetts.

Evers, D.C., 2001. Common Loon population studies: Continental mercury trends and breeding territory philopatry. Ph.D Dissertation, University of Minnesota, St. Paul.

Evers, D. C. 2000. An update of North America's Common Loon breeding population.

Pp. 91-94 in J.W. McIntyre and D.C. Evers (eds.). Loons: Old history and new findings. Proceedings of a symposium from the 1997 meeting, American Ornithologists' Union. North American Loon Fund, Holderness, NH.

Evers, D. C.,J. D. Kaplan, P. S. Reaman, J. D. Paruk and P. Phifer, 1997. A demographic characterization of the Common Loon in the Upper Great Lakes. American Ornithologist's Union Conference, 1997.

Fair, J. and B.M. Poirier, 1993. Managing for Common Loons on hydroelectric project reservoirs in northern New England. Pp. 221 *in* L. Morse, S. Stockwell, and M. Pokras (eds.). The loon and its ecosystem: Status, management, and environmental concerns. North American Loon Conference Proceedings, U.S. Fish Wildife Service, Concord, NH.

Fitzpatrick-Lins, K, 1980. The accuracy of selected landuse and land cover maps at scales of 1:250,000 and 1:100,000. United States Geological Survey, USGS Circular 829, 24 pp.

Flather, C. H. and M. Bevers, 2002. Patchy reaction-diffusion and population abundance: the relative importance of habitat amount and arrangement. The American Naturalist Vol. 159 No. 1, pp. 40-56.

Garmin International, 1998. Garmin 45XL GPS Owner's Manaual and Reference Guide. Garmin International, 9875 Widmer Road, Lenexa, KS, 66215.

Gagliuso, R. A., 1991. Remote sensing and GIS technologies; an example of integration in the analysis of cougar habitat utilization in southwest Oregon. GIS Applications in Natural Resources. GIS World, Inc. Fort Collins, CO. pp. 323-329.

Geraghty J. J., D. W. Miller, F. V. D. Leeden and F. L. Troise, 1973. Water Atlas of the United States. A Water Information Center Publication, 44 Sintsink Drive East, Port Washington, N. Y., 11050.

Giles, R. H., Jr., 1979. Modeling decisions on ecological systems. p 147-159 in J. Cairns, Jr., G. P. Patil, and W. E. Waters, (eds.). Environmental biomonitoring, assessment, prediction and management/certain case studies and related quantitative issues. Statistical Ecological Series. Vol. 11. Int. Coop. Publ. House, Fairland, MD 433 p.

Giles, R. H., Jr., 1969. A systems approach to refuge management. Transactions North American Wildlife Natural Resourource Conference 34:103-115.

Guisan, A. and N. E. Zimmermann, 2000. Predictive habitat distribution models in ecology. Ecological Modelling, 135:147-186.

Hammond, D. E. and R. L. Wood, 1976. New Hampshire and the disappearing loon.

Loon Preservation Committee, Lee Mills Rd, Moultonboro, NH. 27 p.

Herr, A. M., and L. P. Queen, 1993. Crane habitat evaluation using GIS and remote sensing. Photogrammetric Engineering & Remote Sensing 59:1531-1538.

Hosmer , D.W. and S. Lemeshow, 1989. Applied Logistic Regression. John Wiley & Sons, New York.

Isaaks, E. H. and R. M. Srivastava, 1989. An Introduction to Applied Geostatistics. Oxford University Press, New York.

Kaluzny, S. P., S. C. Vega, T. P. Cardoso, and A. A. Shelly, 1998. S+SpatialStats User's Manual for Windows® and UNIX®. Maple-Vail Book Manufacturing Group, York, PA.

Kelly, L.M. 1992. The effects of human disturbance on Common Loon productivity in northwestern Montana. M.S. Thesis, Montana State Univiversity, Bozeman, MT.

Kerekes, J., 1990. Possible correlation of summer Common Loon (Gavia immer) population with the trophic state of a water body. Verh. Int. Ver. Limnol. 24:349-353.

Kerlinger, P., 1982. The migration of Common Loons through eastern New York. Condor 84:97-100.

Klein, T., 1990. Loon Magic. Northwood Press, Wisconsin.

Leopold, A, 1933. Game Management. Charles Scribner's Sons, New York 481 p.

Longcore, J. R., R. K. Ross, and K. L. Fischer, 1990. Wildlife resources at risk through acidification of wetlands. Transactions 52nd North American Wildlife Natural Resourource Conference.

Loon Preservation Committee, 1999a. Loon Preservation Committee Field Program Field Collection Protocol. Internal Document. LPC, Meredith, N.H.

Lunetta, R. S., R. G. Congalton, L. K. Fenstermaker, J. R. Jensen, K. C. McGwire and L. R. Tinney, 1991. Remote sensing and Geographic Information System data integration: error sources and research issues. Photogrammetric Engineering & Remote Sensing, 57:677-687.

Matheron, G., 1963. Principles of geostatistics. Economic Geology, 58:1246-1266.

Maguire, D. J., M. F. Goodchild, and D. W. Rhind, 1991. Geographic Information Systems: Volume I. John Wiley & Sons, Inc., New York.

MathSoft, 1997a. S-Plus User's Guide Version 4.0. Data Analysis Products Division, Mathsoft, Inc, Seattle, WA. 620 pp.

MathSoft, 1997b. S-Plus Programmer's Guide. Data Analysis Products Division, Mathsoft, Inc, Seattle, WA.

McIntyre, J. W., 1988. The Minnesota Report: a 15-year survey comparison. In: P. Strong (ed.) Paper from 1987 Conference Loon Resource Management, North American Loon Fund, Meredith, NH. Pp. 118-130.

McIntyre, J. W., 1983. Nurseries: a consideration of habitat requirements during the early chick-rearing period in Common Loons. Journal of Field Ornithology, 54:247-253.

McIntyre, J. W., 1979. The Common Loon: spirit of the Northern lakes. University of Minnesota Press. 327 pp.

McIntyre, J. W., 1977. Artificial islands as nest sites for Common Loons. Journal of Wildlife Management, 41:317-319.

McIntyre, J. W., 1975. Biology and behavior of the Common Loon (*Gavia immer*) with reference to its adaptability in a man-altered environment. Ph. D. thesis, University of Minnesota, Minneapolis, MN.

McIntyre, J. W. and J. F. Barr. 1997. Common Loon: Birds of North America. Academy of Natural Sciences, Philadelphia, PA.

Miconi, R., M. Pokras, and K. Taylor, 2000. Mortality in breeding Common Loons: How significant is trauma? Pp. 19-24 in J. McIntyre and D.C. Evers (eds.). Loons: Old history and new findings. Proceedings of a Symposium from the 1997 meeting, American Ornithologists' Union. North America Loon Fund, Holderness, NH.

Murphy, D.D., 1988. Challenges to biological diversity in urban areas. Biodiversity (E.O. Wilson, editor), National Academy Press, Washington, D.C., pp. 71-76.

Myers, J. L. and A. D. Well, 1995 Research Design & Statistical Analysis. Lawrence Erlbaum Associates, Publishers, Hillsdale, New Jersey.

Neter, J. and W. Wasserman, 1990. Applied Linear Statistical Models. McGraw-Hill/Irwin.

New Hampshire Fish & Game Department, 1999. 1999 Freshwater Fishing Digest. New Hampshire Fish & Game Department, 2 Hazen Dr., Concord, NH 03301.

Okrant, M. J. and C. E. Clark, 2005. "New Hampshire", Microsoft® Encarta® Online Encyclopedia 2005. http://encarta.msn.com © 1997-2005 Microsoft Corporation, All Rights Reserved

Olson, S. and W. H. Marshall. The Common Loon in Minnesota, 1952. Minneapolis, Minnesota, Minnesota Museum Natural History, University of Minnesota.

Palmer, R. S., 1962. Handbook of North American Birds, Vol. 1, Yale Univ. Press, New Haven, Connecticut.

Perira, J. M. C. and R. M. Itami. 1991. GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel. Photogrammetric Engineering & Remote Sensing, 57:1475-1486.

Peterson, R. T., 1961. A Field Guide to Western Birds. Second Edition. Houghton Mifflin conpany, Boston, MA.

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

Pokras, M.A. and R. Chafel, 1992. Lead toxicosis from ingested fishing sinkers in adult Common Loons (*Gavia immer*) in New England. J. Zoo. Wildl. Med. 23:92-97.

Ream, C. H., 1976. Loon productivity, human disturbance, and pesticide residues in northern Minnesota. Wilson Bulletin, 88:427-432.

Ringelman, J. K., 1992. Identifying the factors that limit duck production. U. S. Department of Interior, Fish and Wildlife Service, Fish and Wildlife Leaflet 13, Washington, D. C.

Robinson, J.G. and K.H. Redford, 1994. Community-based approaches to wildlife conservation in the neotropics. In: Natural connections. Perspectives in community-based conservation, (Eds. D. Western, M. Wright, and S. Strum), pp. 300-320. Island Press, Washington D.C.

Rossi, R. E, D. J. Mulla, A. G. Journel and E. H. Franz, 1992. Geostatistical tools for modeling and interpreting ecological spatial dependence. Ecological Monographs, 62(2):277-314.

Salafsky, N., 1995. Ecological limits and opportunities for community-based conservation. Ecology: Chapter 20.

SAS Institute, 1996. SAS/C Debugger User's Guide and Reference. SAS Publishing, 446. pp.

Schemnitz, S. D., 1980. Wildlife Management Techniques Manual. Fourth Edition. The Wildlife Society, Washington, DC.

Spear, M, J. Hall and R. Wadsworth, 1996. Communication of uncertainty in spatial data to policy makers. Spatial Accuracy Assessment in Natural Resources and Environmental Sciences: Second International Symposium, May 21-23, 1996, Fort Collins. Co, pp 199-216.

Springs, G., 1999. The Critical Edge: Shoreland Protection Reference Guide. New Hampshire Department of Environmental Services, 6 Hazen Dr., Concord, NH 03301. 89 pp.

Stoms, D. M., F. W. Davis, and C. B. Cogan, 1992. Sensitivity of wildlife habitat models to uncertainties in GIS data. Photogrammetric Engineering & Remote Sensing 58:843-850.

Store, R. and J. Jokimaki, 2003. A GIS-based multi-scale approach to habitat suitability modeling. Ecological Modeling, 169:1-15.

Store, R. and J. Kangas, 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habiat suitability modeling. Landscape and Urban Planning, 55:79-93.

Story, M. and R. G. Congalton, 1986. Accuracy assessment: a user's perspective. Photogrammetric Engineering & Remote Sensing. 52(3)97-399.

Strong, P. I., and J. A. Bissonette, 1987. Effects of nest-site loss on Common Loons. Canadian Field-Naturalist, 101:581-583.

Sutcliffe, S. A., 1978. Changes in status and factors affecting Common Loon populations in New Hampshire, USA. Transactions of the Northeast Section of the Wildlife Society 35:219-224.

Sutcliffe, S. A., 1980. Aspects of nesting ecology of Common Loons in New Hampshire. M. S. Thesis, University of New Hampshire, Durham, NH. 95 pp.

Taylor, K., and H. Vogel. 2002. Summary of Loon Preservation Committee Research and Management Activities for the 1999 Field Season. Internal Report. LPC, Moultonboro, NH.

Taylor, K., and J. Lanier, 1998. Personal communication.

Taylor, K., 1997. Personal communication.

U. S. Fish and Wildlife Service, 1918. Migratory Bird treaty Act of 1918. http://laws.fws.gov/lawsdigest/migtrea.html.

U. S. Fish and Wildlife Service, 2002. Migratory Bird List.

http://migratorybirds.fws.gov/intrnltr/mbta/mbtintro.html.

U. S. Fish and Wildlife Service, 1979. Concept plan for waterfowl wintering habitat preservation: Washington and Oregon coasts: priority categories 14 and 15.

Varney, R. W., J. Dabuliewicz, and D. F. Delbert, 1994. Official List of Public Waters in New Hampshire. New Hampshire Department of Environmental Services, Concord, NH, NHDES-WRD-91-4.

Walsh, S. J., 1989. User considerations in landscape characterization, In M. F. Goodchild and S. Gopal, (Ed.) Accuracy of Spatial Databases, Taylor and Francis, New York, pp. 35-43.

Welty, J. C., 1975. The Life of Birds. 2nd edition, W. B. Saunders Company, Philadelphia.

Wood, R, J. Fair, C. Mauhs-Pugh, and K. Neilson, 1986. The calling continues: 1976 - 1985 Ten Year Report. Loon Preservation Committee, 16 pp.

Wood, R. J., 1997. Personal communication.

Young, H. E. and E. G. Stoeckeler. 1956. Quantitative evaluation of photo interpretation Mapping. Photogrammetric Engineering. 22(1)137-143.

APPENDIX A MEETINGS ATTENDED

Date	Meeting
June 6, 1996	Northeast Loon Study Working Group
April 10 & 11, 1997	Northeast Loon Study Working Group
December 1 & 2, 1997	Northeast Loon Study Working Group
May 22, 1998	Northeast Loon Study Working Group
February 11 & 12, 1999	Northeast Loon Study Working Group
December, 2000	Northeast Loon Study Working Group
January 13 & 14, 2001	Northeast Loon Study Working Group
October 23, 1997	Loon Preservation Committee Technical Committee
April 8, 1999	Loon Preservation Committee Technical Committee
December 2, 1999	Loon Preservation Committee Technical Committee
June 30, 2000	Loon Preservation Committee Technical Committee
September 22, 2000	Loon Preservation Committee Technical Committee
April 26, 2001	Loon Preservation Committee Technical Committee
August, 2002	Loon Preservation Committee Technical Committee
April 1998	64^{th} Annual Meeting of ASPRS
May, 1999	65^{th} Annual Meeting of ASPRS
July, 2000	ESRI User Group Meeting
February 15, 1999	North American Loon Fund Annual Meeting

APPENDIX B BIOLOGICAL DATA REPORT FORM

NHLOONS DATA SHEET

YEAR 1991

PAIR NUMBER 88 02

LAKE NAME UMBAGOG

PAIR NAME HARPERS MEADOW

LAKE NUMBER 88

NESTED? TRUE FALSE

NESTSITE 0) UK 1) SHORELINE 2) ISLAND 3) RAFT

LOCATION IN LAKE SWEATT'S MEADOW

NEST TYPE 0) UK 1) BOWL 2) SCRAPE 3) HUMMOCK

DESCRIPTION FLOATING VEGETATION MATS

NUMBER OF EGGS 2

DATE OTN 06 14 91

CALCULATED DATE? TRUE FALSE

NEST FAILURE? TRUE FALSE

DESCRIPTION NA

EGG 1 WHEN NA

Loon Preservation Committee
P.O. Box 604, Moultonborough, NH 03254 (603) 476-5666

1

CALCULATED DATE? TRUE FALSE

REASON FAILED NR

EGG 2 WHEN NR

CALCULATED DATE? TRUE FALSE

REASON FAILED NR

HATCH DATE 07-16-91

CALCULATED DATE? TRUE (FALSE)

NUMBER OF CHICKS HATCHED 2

NUMBER OF CHICKS SURVIVED 2

NUMBER OF CHICK MORTALITIES 0

REASON FOR CHICK MORTALITIES?

FIRST NR

SECOND NR

CHICK AGE AT TIME OF DEATH- weeks

FIRST NR

CALCULATED AGE? TRUE FALSE

SECOND NR

CALCULATED AGE? TRUE FALSE

Loon Preservation Committee

P.O. Box 604, Moultonborough, NH 03254 (603) 476-5666

NUMBER OF ADULT MORTALITIES: 0

REASON FOR ADULT MORTALITIES?

FIRST: NR

SECOND: NR

DISTANCE FROM NEST TO WATER AT TIME OF:

FINISHED NEST: UK

HATCHING: UK

FAILURE: NR

OTHER PERTINENT INFO:

Loon Preservation Committee
P.O. Box 604, Moultonborough, NH 03254 (603) 476-5666

LOON DATA SUMMARY REPORT FORM

1996
Final Report Form

Biological Survey Summary

Staff Name: Rebecca Robbins

Territory: Winnipesaukee

Date of this Report: August 1996

Lake (Town)	Pair Designation	# Territorial Adults	# Adults Summering	# Territorial Pairs	# Nesting Pairs	# Successful Pairs	# Nest Failures	Date of hatch	# Chicks Hatched	# Chicks Surviving	# Unpaired Immatures	Total Final Population	Comments: Include such bits of information as nest type (natural or raft), causes of nest failure, causes of chick or adult mortality, and anything else pertinent and helpful.
Moultonboro	Lincoln I.	1	1	0	0	0	0	0	0	0	0	1	
	Long Island Bridge	2	2	1	0	0	0	0	0	0	0	2	
	Poplar I.	2	2	1	0	0	0	0	0	0	0	2	
	Salmon Meadow Cove	2	2	1	1	1	0	9/17	2	0	0	2	raft, chicks killed by rogue males
	Spectacle I.	2	2	1	1	0	2	0	0	0	2	2	natural, predation on both original & renest = raccoon
	Whaleback	2	2	1	1	1	0	7/22	2	2	2	4	raft
Center Harbor	Little One Mile	0	0	0	0	0	0	0	0	0	0	0	
	Little Six Mile	2	2	1	1	0	1	0	0	0	0	2	natural, unknown reason for failure

Loon Preservation Committee P.O. Box 604, Moultonborough, NH 03254 603-476-LOON (5666)

APPENDIX C SITE SURVEY REPORT FORM

Site Survey Report - 2002 Field Season Loon Preservation Committee

Date____________________________ (circle one) weekend weekday
Lake/Territory____
Observer____
Nearest Town____
Region____

1. Visit and Weather Information

Observation number: (circle one): Visit 1 Visit 2 Visit 3 Visit ___
Observation times (e.g. 12:00 - 1:15):______________________
Weather (circle one): Sunny/Clear CloudyBeaufort Wind Scale:_________
Other:____
Water (circle one): Calm Swell (< 6") White Caps (Do not count as a valid check)

2. Loon Observations

☐ No individuals

☐ Single(s) Number: _______ ☐ Immature

☐ Territorial pair ☐ Bands Observed

Loon 1: Left Leg: _______/_______ Right Leg:_______/_______
Loon 2: Left Leg: _______/_______ Right Leg:_______/_______

☐ Nesting pair: Suspected hatch date:_______

☐Renest: Suspected hatch date:_______

☐ Pair with chicks

☐ Chick(s) Actual hatch date/range:_________________
#chicks hatched: ____
#chicks surviving: ____

3. Nest Site

Nest Site: ☐ Island ☐Marsh ☐ Raft ☐Shoreline

Nest type: ☐Bowl ☐Hummock ☐ Scrape

☐ Nest Failure: ☐ Original nest ☐ Renest

Describe condition of egg 1: ☐ Egg with hole ☐ Eggshell fragments ☐ Egg in water

☐ Egg gone

Suspect cause of failure as: ☐ Water level fluctuation
☐ Predation (circle one): Avian Mammalian
☐ Unknown ☐
Other:____________________________

Describe condition of egg 2: ☐ Egg with hole ☐ Eggshell fragments ☐ Egg in water
☐ Egg Gone

Suspect cause of failure as: ☐ Water level fluctuation
☐ Predation (circle one): Avian Mammalian
☐ Unknown ☐
Other:____________________________

☐ Egg (s) Collected: Number:_____ (***Submit a Biological Collection Report with egg(s)***)

4. Remarks: Detail information on loon activity, nest sites, failures, banding activity, nest/mate switches, and mortalities as necessary. Include an appended sketch of lake/territory if necessary.

Loon Preservation Committee, P.O. Box 604, Moultonboro, NH 03254, (603) 476-5666

APPENDIX D NEST SITE PARAMETERS

Parameters that are collected for all loon territories.

Field	Name	Type	Description
1	LAKEID	Character	ID number of lake
2	PAIRNUM	Character	Pair ID # for lake ID
3	TERRITORYID	Character	ID # of individual nesting territory
4	YEAR	Character	Data record year
5	ATTEMPT	Character	Nesting attempt number (1,2,3)
6	NESTED	Logical	Was nesting successful? Y/N
7	NESTSITE	Character	Nest site code (see NSITE code below)
8	NESTLOC	Character	Description of site location
9	NESTTYPE	Character	Nest type code (see NTYPE code below)
10	NESTDESC	Character	Description of nest
11	EGGKNOWN	Logical	Were number of eggs known? Y/N
12	NUMEGGS	Numeric	If known, how many?
13	OTNDATE	Date	Date on the nest
14*	OTNWEEK	Numeric	Week Nnumber on the nest
15	OTNCALC	Logical	Was date on the nest calculated? Y/N
16	NESTFAIL	Logical	Did the nest fail? Y/N
17	NESTFCDE	Character	If failed, nest fail code (see NFAIL code below)
18	NESTFDSC	Character	Description of failure
19	FAILEGG1	Logical	Did egg1 fail? Y/N
20	FAIL1DAT	Date	Date egg1 failed
21*	FAIL1WK	Numeric	Week egg1 failed
22	FAIL1CLC	Logical	Was date egg1 failed calculated? Y/N
23	FAIL1CDE	Character	Egg1 fail code
24	FAILEGG2	Logical	Egg2 fail? Y/N
25	FAIL2DAT	Date	Date egg2 failed
26*	FAIL2WK	Numeric	Week egg2 failed
27	FAIL2CLC	Logical	Was date egg2 failed calculated? Y/N
28	FAIL2CDE	Character	Egg2 fail code
29	HATCHEGG	Logical	Did eggs hatch?
30	HATCHDAT	Date	Date eggs hatched?
31	HATCHWK	Numeric	Week eggs hatched?
32	HATCHCLC	Logical	Was this hatch date calculated? Y/N
33	NUMHATCH	Numeric	Number hatched
34	NUMSURV	Numeric	Number survived
35	NUMMORT	Numeric	Number of mortalities
36	MORT1CDE	Character	Chick1 mortality code (see MORT code below)
37	MORT1DAY	Numeric	Days to mortality1
38	MORT1CLC	Logical	Was days1 calculated? Y/N

39	MORT2CDE	Character	Chick2 mortality code (see MORT code below)
40	MORT2DAY	Numeric	Days to mortality2
41	MORT2CLC	Logical	Was days2 calculated? Y/N
42	NMADLMRT	Numeric	Number of adult mortalities
43	AMRT1CDE	Character	Adult1 mortality code (see MORT code below)
44	AMRT2CDE	Character	Adult2 mortality code (see MORT code below)
45	CHICMORT	Character	Description of chick mortality
46	MORTDESC	Character	Description of adult mortality
47	ENTRDATE	Date	Date record was entered / updated

* Week is always numerical week number from Jan 1st of whatever year.

Code Type	Code ID	Code Description
MORT	0	Unknown
MORT	1	Disease / Infection
MORT	2	Sibling rivalry
MORT	3	Blunt trauma
MORT	4	Rogue loon
MORT	5	Monofilament
MORT	6	Lead poisoning
MORT	7	Severe weather
MORT	8	Human disturbance
MORT	9	Mammalian predation
MORT	10	Avian predation
MORT	11	Other predation
MORT	12	Starvation
MORT	13	Accidental
NFAIL0		Unknown abandonment
NFAIL1		Avian predation
NFAIL2		Mammalian predation
NFAIL3		Watr level fluctuation
NFAIL4		Human disturbance
NFAIL5		Loon disturbance
NFAIL6		Environmental
NFAIL7		Never hatched
NFAIL8		Egg(S) disappeared
NFAIL9		Unknown predation
NSITE	0	Unknown
NSITE	1	Shoreline
NSITE	2	Island
NSITE	3	Raft

NTYPE	0	Unknown
NTYPE	1	Bowl
NTYPE	2	Scrape
NTYPE	3	Hummock

APPENDIX E FIELD COLLECTION PROTOCOL

Loon Preservation Committee

Field Program

Field Collection Protocol

Updated 5/99

I. Introduction and Purpose of Methods

The Loon Preservation Committee (LPC) was created in 1975 in response to concerns about human impacts on loons and declines in the presence and breeding success of loons in New Hampshire. A self-funded project of the Audubon Society of New Hampshire, LPC's mission is the restoration and maintenance of a healthy loon population throughout the state as a component of a regional population and ecosystem. LPC has monitored every known nesting pair of loons in the state since 1976 and continues to assess population status and breeding success throughout the state on a yearly basis.

Large-scale monitoring coverage is accomplished by dividing the state into 4 geographical and 4 single lake territories. Data on numbers of adult loons, numbers of territorial pairs, nesting success and chick survival are collected by field biologists. Although the number of staff and number of waterbodies monitored have increased with the expansion of LPC's monitoring and management program, present territory delineation and coverage has been relatively stable since 1991.

An annual state-wide loon census provides a mid-season check on the productivity of loons on the breeding grounds. Volunteers are a critical element in this event, as well as all other data gathering. Field biologists supplement their activities with information and assistance provided by volunteers, and are encouraged to nurture that relationship as well as recruiting new volunteers.

Public outreach is LPC's strongest and most successful tool in preserving New Hampshire's loon population. Campaigns of education coupled with field management have resulted in a slow, but steady increase in loon numbers since LPC's first field season. It is the vision of LPC to continue its' work of loon conservation and provide a greater understanding of this bird. Excellence in conducting the collection methods outlined below is critical to this success.

I. Research

One of the most important and most involving responsibilities of the field biologist is the collecting of numbers. Field biologists determine loon numbers in their assigned monitoring regions, along with other pertinent information such as nest and brooding site locations, disturbances, intrusions, and return rates of banded birds. This data is collected in a field notebook. Information is transferred from this notebook to Site Survey Reports.

Site Survey Reports should be hand-delivered or submitted by mail on Thursday of each week to the Senior Biologist. Reviewed reports are returned to the biologist with comments and are then filed in the Lake Books located in the library.

*Requests for raw field data from interested parties should be referred to the Senior

Biologist.

A. Lakes Survey

1. Field biologists are responsible for surveying assigned lakes in their monitoring region for loon activity.

a. Tier I Lakes: these lakes have a current history of territorial pairs (minimum of 3 years occupancy or newly established territories) and should be considered highest priority. Three (3) visits are required for all Tier I lakes.

Tier I lakes should be visited in the following order of priority:

1. Tier I lakes with banded birds.

2. Tier I REMAP lakes (these lakes are highlighted on the lake lists). For all REMAP lakes, report any sightings of Belted Kingfishers or Common Merganser on the Site Survey Report.

3. All other Tier I lakes.

b. Tier II Lakes: Tier II lakes support loons on a irregular basis. Visit these lakes at least once.

c. Tier III Lakes: these lakes are considered marginal loon habitat and should be considered lowest priority. Visit as time allows.

2. Make note of weather conditions assigned on the Site Survey Report. See Appendix for Beaufort Wind Scale.

3. Each lake survey should last at least one (1) hour. Observations lasting less than 1 hour are considered invalid. Fill out Lake Characterization Form for the first visit only. Fill out a Site Survey Report with every visit.

B. Biological Survey

For each lake/pond determine the number of loons present:

1. Mated Loons (Territorial Pairs): a pair of loons establishing and defending a territory for at least 4 weeks and having the potential to breed. Nesting pairs are defined as those laying at least 1 egg, and successful pairs hatch at least 1 chick.

For each pair:

a. Identify territory by name. Use previous years' field reports as a guide for pair names.

b. Determine if a nest has been established. Is it an initial nest attempt or a renest? Define nest site as the mainland, marsh, island, or raft. Define nest type as bowl, scrape, or hummock (see Figures 1, 2, 3, in Appendix).

c. Report location of nest. Sketch a detailed map of nest site. If the pair produces young, identify brooding area and add to map.

d. Determine number of eggs. Report this number *only* if a determination can be made *without* disturbing the bird.

e. Field biologists should try to be at the nest at time of hatching. Estimated hatch date is 27 days from first incubation. Use this to calculate a range or window of possible hatch. Back date correct hatch date by plumage of chick.

f. Determine nest success. A successful nest produces at least one chick. A nest determined as "successful" includes information about the number of chicks, and any unhatched eggs. A nest categorized as a "fail" includes evidence as to the cause of the failure (predation - mammalian or avian, water-level fluctuation, disturbance, over-incubation, etc). Document cause only if it can be reported with certainty.

2. Unmated Loons: Also referred to as "residents", " wanderers", "loners" or "floaters", these are adult loons not establishing a pair bond, or are part of a pair bond lasting less than 4 weeks. Unmated loons are usually found on low quality territories and are most likely young birds (ages 3-6), or established adults that have been usurped from their former territory.

a. Determine if unmated loon is in alternate (breeding) plumage.

b. Determine if unmated loon is in immature plumage.

3. Social Interactions: Determine chronology, frequency and duration of intrusions by one or more loons into an established territory. Rate the intrusion (intra-or interspecific) using the intensity scale found on the Site Survey Report.

4. Human and Predator Disturbances: Determine and quantify type, distance and response to human or predatory disturbances using assigned codes on the Site Survey Reports.

5. Final Field Reports - Final field reports are due by the end of the field season. This report is a detailed data package compiled by the field biologist after conclusion of a twelve-week field survey. Final reports are due on the last day of the field season. Final pay checks are withheld until report is submitted. Included in this report are all the parameters noted in the weekly field reports in addition to the following:

a. Number, location and cause of any mortalities.

b. Identification of nest and brooding sites on *topographical* maps.

*Field notebooks will also be submitted along with the Final Site Survey Report.

C. Biological Collections

In the state of New Hampshire, the Common Loon is listed as a "threatened species". Under Chapter 212-A of the Endangered Species Conservation Act, a threatened species is defined as "...any species of wildlife which appears likely, within the foreseeable future, to become endangered." (See Appendix)

LPC holds permits from NH F&G, USF&WS, and the State of Maine, which grant authorization to "conduct loon surveys, to band loons, and to possess non-viable loon eggs and specimens of deceased loons for scientific study." These permits also allow LPC permittees to "salvage, possess, or transport debilitated wildlife..." Field Biologists are listed as "sub-permittees" at each of the above organizations. It is required that permittees and sub-permittees carry copies of permits while conducting any of activities listed above.

Field biologists are responsible for collecting the following:

1. Failed eggs: Whole eggs are collected only when it is certain they have failed.

a. If egg is cold or putrid-smelling, mark suspect egg with an "X" in pencil. Return the following day. If the "X" is still in the same position, indicating the egg has not been turned in 24 hours, collect the egg by using the following procedure:

- Seal wrapped egg in a small ziplock plastic bag. Enclose collection tag written in pencil. Double bag using a larger ziplock and label outside with date, lake, territory, and town. Use a black Sharpie when labeling.

- Freeze egg until it can be brought and stored at the Loon Center's sample freezer* for later processing in the lab. See "Protocol for Processing Eggs for Contaminant Analysis."

* When placing anything in the sample freezer, fill out log book and notify Senior Biologist.

b. Fill out a Biological Collection Report. Under "observations/remarks" on this form, use as much information as possible regarding history of nest, number of eggs, reason for failure, and any hatches. Submit weekly with Site Survey Reports.

2. Eggshells: Collect eggshells from hatch site after birds have left nest with young.

a. Collect eggshells and membranes and allow to dry. Seal in a plastic bag, along with a collection tag, and return to the Loon Center. A box labeled with this year's eggshells can be found in the wetlab.

b. No Biological Collection Report is necessary for eggshells/membranes.

3. Carcasses

a. Wrap sharp edges with cloth or paper. Use double plastic bags to hold recovered bird. Place a collection tag in bag with bird. Label outside of bag with date, collection site (waterbody), territory, and town.

b. Transport carcass to The Loon Center for immediate necropsy by Tufts Staff. If unable, freeze as soon as possible and bring to The Loon Center.

* When placing anything in the sample freezer, fill out log book and notify Senior Biologist.

c. Fill out a Biological Collection Report with as much detail as possible regarding history of bird, and behavior prior to death. Ask volunteer or reporter for his/her observations. Submit to Senior Biologist.

4. Sick or Injured Loons. Field biologists respond to and aid distressed loons. If a report is called in, ask reporter to describe behavior they are witnessing. Often normal maintenance behaviors can appear as if a bird is in distress. If this is suspected,

ask reporter to maintain observation for another half-hour and call back if behavior persists. Take care not to insult reporter. All calls should be taken seriously and individuals encouraged to call with any sightings or activities of concern.

a. Lead Poisoning. Lead poisoning in loons is the direct result of ingestion of lead fishing weights ("sinkers"). Loons swallow sinkers mistaken for food or grit. Ingested lead enters the gizzard where stomach acids and abrasion lead to the breakdown and absorption of the metal. Lead in the bloodstream is distributed to vital organs, such as the kidney and brain.

Field signs of lead poisoning include: gasping, gaping, slanted eyes, wing droop, listing - impaired balance, head tremors, green feces around vent, beaching.

- If field signs look suspicious, contact the Senior Biologist. Keep bird under close observation and wait for opportunity to capture. See "Protocol for Handling Sick/Injured Loons".

- Any loon that is determined to be beyond recovery, especially in cases of lead poisoning, will be euthanized.

b. Monofilament Entanglement. Loons become entangled, injured, or immobilized by discarded line which has not been disposed of properly.

- If the entanglement is such that the bird is still mobile, there is little that can be done. To pursue these loons risks injury. Solicit volunteers to keep bird under observation and wait for opportunity to capture. Contact the Senior Biologist. See "Protocol for Handling Sick/Injured Loons".

- If the loon is immobilized by the entanglement, react quickly. Carefully cut bird loose and release. Keep bird under observation. If line is going down throat, DO NOT pull out. Contact the Senior Biologist.

D. Census

1. This is annual state-wide simultaneous loon count. The loon census is a mid-season check on productivity set to coincide with peak of hatch.

2. Field biologists are responsible for soliciting and coordinating volunteers in their territory, distributing census forms, and tallying results. It is critical that census be conducted on the set day. Partial data cannot be used.

E. Banding

The banding project on Lake Umbagog began in 1993 with the banding of one adult and one juvenile. It continues to expand state-wide with each field season, including efforts on more waterbodies. In observing banded pairs, more can be learned about pair bonds and nest-site fidelity, as well as gaining knowledge about the chronology of arrival to and departure from the breeding grounds. In banding chicks, information can be gathered about age of first breeding, where young birds attempt to establish a territory, and lifespan.

In 1994, the Northeast Loon Study Working Group (NELSWG) was organized with representatives from state and federal agencies, non-profit and private organizations, and researchers in response to concerns for loons in the northeast region. The major focus of this group is mercury. Loons, being at a high trophic level, act as indicator species of the overall health of the environment. Currently, loons in the northeast region are carrying the highest levels of mercury in the country. During capture and banding, feathers and blood samples, as well as other measurements, are taken for further analysis. NELSWG hopes to use this information in understanding the physiological and behavioral effects of elevated mercury levels in loons for use by agencies determining national emission standards.

1. For all banded loons, field biologists will record: return chronology by sex and by habitat, adult return rates, mate fidelity and territory faithfulness/switching.

2. Record banded loon return rates on the Site Survey Report. See Appendix for the "New Hampshire Banding Summary, 1993-98".

3. Field biologists are responsible for assisting with any banding occurring in their monitoring region. This includes notifying key volunteers, identifying access points, surveying for location of pair pre-banding, and conducting follow-up observations post-banding.

On observing color-marked loons...

Obtaining band combinations on loons is not easy. It requires patience, luck, and in time, skill. The following suggestions should prove useful in making field observations on banded birds:

1. Use a spotting scope from shore. Do not chase the birds.

2. Keep the sun at your back, look from a height of land if possible, and make observations during flat water.

3. Focus on the lower hind end of the bird. First just look for flashes of color on the left side, or a flash of silver on the right side. At a minium this confirms that a banded individual has returned.

4. Getting the correct color band combinations is the next step. There are 2 color bands on the left leg, and the right leg has a silver U.S. Fish & Wildlife Service band and color band. Report returns according to leg and order of color band. For example, a loon with a red band on top of a blue band on the left leg would be reported as, "left leg, red over blue".

5. Seeing the color bands is easiest during preening when the birds are most likely to foot waggle or belly preen. Loons preen most during and just after rain or 4-6 minutes every hour except pre-nesting.

6. Report only what you see. Just confirming a banded bird has returned without the color combinations is extremely useful.

*Requests for raw field data from interested parties should be referred to the Senior Biologist

III. Management, Protection and Enforcement

Field biologists are responsible for the management and protection of nest sites, brooding areas, and chicks according to the instructions described below. The use of volunteers in this capacity is highly encouraged. LPC employs the following management tools and protection schemes 1.) signs and floatlines 2.) artificial nesting islands and 3.) chick watches.

A. Management Tools

1. Signs and Floatlines. Once a nest or brood site is established and determined to be in a high traffic or high visibility area, signs and/or floatlines can be utilized . Used as a tool to allow a measure of privacy, signs and floatlines may also serve to attract attention. Take this into consideration when decision-making, or follow recommendations from previous years. Discuss options with the Senior biologist.

*Take care not to flush incubating loon when floating signs and/or line. Follow recommendations from previous years, consult with volunteer or the Senior Biologist and observe anxiety level of birds.

**Fill out "Notification of Restriction - Loon Nesting/Brooding site" Form and submit with Site Survey Reports.

2. Artificial Nesting Islands. Artificial nesting islands, or rafts, can be used as nesting platforms for incubating pairs in those cases where natural nesting attempts have been unsuccessful. Specifically, when successive failure is due to water-level fluctuation or predation, this area may be considered for a raft. They do not serve to attract loons to a waterbody. LPC strictly monitors the construction, placement, and use of all rafts under the authority of the State of New Hampshire. Discuss recommendations with the Senior Biologist. See "Protocol for the Use of Artificial Nesting Islands".

B. Protection Schemes

1. Chick Watches. Shortly after hatching, adults rear young chicks at a nursery or brooding area. In some cases, this may mean crossing a high-traffic area for the family. At this early stage, chicks are vulnerable to separation from adults by boats. Field biologists work in cooperation with volunteers to establish "chick patrols" during busy weekends.

2. Separated Chicks. Separated chicks can be reunited with the family with the use of a boat. First, try to herd family together. If this is not successful, retrieve chick by using a net. (Soft hooting vocalizations may be helpful in luring chick close to boat for retrieval.) Bring chick in close proximity to adults and shut propeller off. While adult is looking, toss chick a short distance so that it will not wedge itself against side of boat. (Try a peenting vocalization to gain the adult's attention.)

3. Sibling Rivalry. Sibling rivalry occurs when the first-born chick establishes dominance by intimidating and abusing the younger chick. In some cases, this can lead to the death of the younger chick through repeated abuse coupled with neglect and abandonment by the adults. This is a natural behavior. It is also difficult to watch and quite disturbing to volunteers. Educate as much as possible about this being a natural occurrence in loon-family dynamics.

C. Enforcement

1. If illegal harassment or taking of loons is witnessed, collect the following information:

- Boat bow numbers and plate numbers.

- Car-plate number and state of registration if there is a car involved.

- Description of boats, cars, and individuals involved.

- Note time of day.

Note: If there is a carcass involved and any evidence, such as a projectile etc., be certain that NH Fish & Game or LPC retrieves it. (LPC cannot authorize non-permitted individuals to collect loons or loon eggs without risk of losing its own permit.)

2. Call Operation Game Thief 1-800-344-4262. Notify the Senior Biologist. The dispatcher will contact the local Conservation Officer. Allow the Conservation Officer to conduct the investigation, but assist as needed.

IV. Public Education

1. Formal Education. Presentations are requested by various organizations. Field biologists present popular programs on loon natural history and the work of the Loon Preservation Committee. The Senior Biologist or Naturalist will assist in putting together a slide program. Field biologists receive half of the presentation fee.

2. Informal Education. Take every opportunity to educate the public about the habits, needs, and threats to loons. Distribute non-lead sinker samples and/or provide LPC literature. This type of outreach goes far to promote a greater understanding of this bird.

V. Schedules and Expenses

1. Staff Meetings. Brief staff meetings will be held at The Loon Center each Thursday for the first two weeks, bi-weekly after this period. Submit data sheets at this time, discuss problems, catch-up on paperwork or phone calls etc.

2. Work Schedule. Avoid being off on weekends. Contact the Senior Biologist if a weekend or critical period cannot be covered.

3. Pay. Pay comes from ASNH on the 1st and 15th of each month. Checks come to The Loon Center unless otherwise arranged at orientation.

4. Expenses. Travel - $.25 per mile reimbursed. Submit mileage form.

Phone - Use LPC calling card. Note personal calls.

Other - Collection bags, postage, camp sites etc. Check office for supplies first. Submit reimbursement form (same as mileage form). Contact Senior Biologist for approval on any other purchases.

Note: For everything; use statements, attach receipts, names, dates. Reimbursements should come weekly.

5. Loon's Feather Gift Shop. Field biologists receive a 30% discount at the shop.

APPENDIX

Beaufort Wind Scale

Beaufort Number	Wind Speed (mph)	Indicator of Wind Speed

0	Less than 1	Smoke rises vertically
1	1 - 3	Wind direction shown by smoke drift
2	4 - 7	Wind felt on face; leaves rustle
3	8 - 12	Leaves, small twigs in constant motion; light flag extended
4	13 - 18	Raised dust and loose paper; small branches are moved
5	19 - 24	Small trees in leaf sway; crested wavelets on inland waters

APPENDIX F SICK/INJURED LOON HANDLING

Loon Preservation Committee

Field Program

Protocol for Handling Sick/Injured Loons

Revised 5/98

I. Introduction

Loon Preservation Committee's (LPC's) Field Biologists respond and aid distressed or moribund loons. The primary objective in rescue is to release the bird to water as quickly as possible. In cases where this is not possible, birds are to be brought to Dr. David Cote or Dr. Ellen Tighe at the Plymouth Animal Hospital, Plymouth NH. It is LPC's philosophy that outstanding medical treatment (procedures that require rehabilitation or prolonged captivity) should not be an option. Recovered carcasses are sent to Tufts University Wildlife Clinic, Grafton, MA, for full necropsies, as part of an on-going loon mortality study.

In the state of New Hampshire, the Common Loon is listed as a "threatened species". LPC holds permits from NH F&G, US F&WS, and the State of Maine which grant authorization to handle and transport loons. LPC is not authorized to grant non-permitted individuals to conduct activities involving direct contact with loons.

II. Purpose of Methods

Due to the potential hazard to both loon and LPC staff, the following procedure outlines methods to be used in cases where recovery and handling of sick/injured loons is necessary.

III. Apparatus

A. Capture Box: A high walled cardboard box with an interior width sufficient to securely contain a loon while allowing reasonable/minimal movement.

1. Line bottom of container with plastic garbage bags and secure edges with tape. Remove or tape open top portion of box.

2. Place one (1) standard orange personal flotation device (PFD) in box to provide keel support.

3. A screen may be placed over the top opening. This helps create a quiet dark environment while allowing cross-ventilation. A towel may also be used.

B. Emergency Kit: A first-aid kit containing the following:

1. One (1) pair safety glasses: to provide eye protection.

2. One (1) blunt-tipped scissors: for use in monofilament removal. If monofilament appears to be going down throat, DO NOT attempt to remove.

3. Two (2) large towels: to be used during handling of body and wings, and to be wrapped around ice packs.

4. One (1) small towel: to be used during handling of head and bill.

5. Three (3) ice packs: wrapped in a towel, ice packs are placed under keel of bird to aid

in cooling.

6. One (1) bottle rubbing alcohol: To be poured over feet and legs to counter the effects of overheating.

7. One (1) bottle water: To be used as a precaution against overheating.

8. Four-five (4-5) gauze pads: to be soaked with rubbing alcohol and placed on top of foot webbing for additional cooling.

9. Two (2) pairs of latex gloves: to protect hands from isopropyl alcohol, loon droppings, etc.

10. One (1) pair fishing pliers: Hook removal where possible. DO NOT attempt to pull out ingested or deeply embedded hooks.

11. One (l) list of emergency numbers.

IV. Procedures

A. Phone Assessment. When possible, the following information will be collected from the individual who reports an injured/moribund loon and provided to the responder prior to departure to the rescue site.

DO NOT INSTRUCT CALLER TO HANDLE BIRD

OBSERVATIONS ONLY

1. Verification the emergency involves a loon.

    a. physical description - color/plumage

    b. behavioral description - diving, calling

2. Physical description of loon.

    a. Loon in water:

        How is it swimming?

        How is it holding head/neck?

        Is it gaping? Is mucous visible in mouth? head shaking?

        Has it been beaching?

        Any obvious bleeding, injuries or entanglement?

    b. Loon on land:

        How long has it been out of the water?

        What is the condition of the soles and nail?

        Overheating-panting?

Color of feces?

Any obvious bleeding, injuries or entanglement?

3. Location.

a. Directions to site.

b. Access to water.

c. Crowd conditions.

D. Contact person/phone number.

V. <u>On the Scene</u>

It is necessary that field staff arriving at the scene take control of the situation. Gaining control of a situation means allowing time for critical thought so that actions are conducted in a clear, calm, methodical manner. Upon arrival, begin by stepping back and assessing the scene. Formulate a plan before attempting capture.

A. <u>Loon in Water</u>. There is a high likelihood that pursuing a free-swimming sick/injured loon will cause further damage. It is therefore recommended that volunteers be organized to keep the bird under surveillance and call LPC as soon as possible if it beaches.

B. <u>Control the Crowd</u>. Instruct any gathering crowd to maintain a distance from the bird and stress the need for silence. Briefly discuss the capture procedure and offer to provide more information once the bird is secured.

1. <u>Select Handlers</u>. A maximum of 3 people are to be involved in the capture. Trained staff first; if necessary, select calm individuals who are comfortable with assisting.

2. <u>Discuss Procedure</u>. The most-experienced LPC staff is in charge of the effort and should give clear instructions and assignments.

3. <u>Appoint Assignments</u>. The person in charge is assigned handling of the wing and body. The second most-experienced person is assigned to the head and bill. (These two will need to be able to work in concert in order to move the bird to safety.) The third person is assigned as back-up and should be prepared to meet the needs of the handlers.

VI. <u>Approaching the Bird</u>

A. Put on safety glasses if the bird is active or aggressive.

B. If possible, approach bird from behind, slowly and quietly. Throw large towel over body if necessary. If the bird is close to water, the approach will need to be quick.

C. Head/Bill Handler: Cover head with towel. Take hold of bill at the center (so as to not cover nostrils). If the bird is panting, do not hold bill closed.

D. Body/Wing Handler: Pin wings with thumb and curl rest of fingers under body so that wings are secure and feet are tucked under body. Be careful not to scrape or cut feet and legs. If wings are open, gently fold wings. A large towel may be used to cover body prior to handling.

E. Third person passes necessary items, aids in handlers' needs, and maneuvers capture box into position.

F. Using a count of three, simultaneously move bird into box. Remove towel from head.

G. As with initiation, conclude capture procedure by assessing condition of bird and begin formulating a transportation plan.

VI. Transport

The most serious threat to a loon in transport is overheating. Overheating is a critical condition which may result in death from hyperthermia or heatstroke. The following precautions are designed to minimize the risk of overheating and should be practiced as standard protocol.

A. Aid in the Field. Gently spray/mist bird with water, concentrating on the feet. The evaporative nature of rubbing alcohol also works to counter the effects of overheating as well. It can be generously poured over legs and feet, or can be applied by gauze. Note: If there are cuts or abrasions, the bird will react strongly. Do not use in this case.

B. Capture-Box Structure and Assembly. A cardboard box minimizes any damage a loon may incur due to thrashing and poking. Towel-wrapped ice packs are placed under a PFD so that they are exposed through the head opening of the PFD. A screen or towel can be placed over the open top to help calm the bird.

C. Placement inside the Capture Box. The loon is placed so that the chest is resting on the ice packs, protected from direct exposure by the towel. The keel is then supported , and wings secured by the design of the PFD itself.

D. Vehicle Transportation. If possible, the captured loon should be kept on the shaded side of the vehicle. Open windows or air conditioning will aid in maintaining a cool environment. In transit, small amounts of water can periodically be poured around edges of the PFD holding the loon. If the feet feel hot, reapply water or rubbing alcohol with gauze.

APPENDIX G ARTIFICAL NESTING ISLANDS

Loon Preservation Committee

Field Program

Protocol for the Use of Artificial Nesting Islands

Revised 5/99

I. Introduction

Artificial nesting islands, or "rafts" were developed as management tools in the Midwest, and were first used for loons in New Hampshire in 1977. Rafts are deployed and used as nesting platforms in order to mitigate potential human impacts to incubating loon pairs until such time as these impacts can be addressed by more permanent solutions. Because rafts are meant as temporary solutions, the United States Fish and Wildlife Service (USFWS) considers the use of rafts on interior lands or as part of Federal Energy Regulatory Commission (FERC) relicensing activities only when all other options of stabilizing water levels has been exhausted (A. Major pers. comm.). The Loon Preservation Committee (LPC) considers raft usage only for established pairs experiencing successive nest failure due to artificial water level fluctuations or shoreline predation, and on loon lakes having a suitable flotation site (LPC, 1985, 1990, 1997). Rafts do not serve to attract loons to a waterbodies with unsuitable territories (McIntyre, 1977). LPC strictly monitors the construction, placement, and use of all rafts under the authority of the State of New Hampshire Marine Patrol. Permission to use rafts falls under the authority of New Hampshire Fish and Game and USFWS as co-trustees under the Migratory Bird Treaty Act.

II. Purpose

The following procedure outlines methods to be used in cases where raft deployment has been approved. Rafts unused by loons for three (3) successive breeding seasons are removed. All rafts are floated no later than the third week of May.

II. Materials and Methods

A. Materials and tools needed:

1. 6' x 8" untreated cedar posts with bark removed.

2. 5' x 5' piece of plastic dune fencing.

3. 8 x 8 x 16 cement blocks.

4. 4-8 3/8" threaded rods (and associated washers and nuts), 8-10 cable clamps, heavy duty 1 1/2" fence staples (galvanized), and 40' 3/16 plastic coated wire cable anchor lines.

5. Chain saw, buck saw, or power "skillsaw"; hatchet, axe; carpenter's hammer; wire cutters; and adjustable wrench.

B. Construction (Figure 1)

1. Notch cedar posts "Lincoln log" style. Using the 3/8" threaded rod, drill through logs and put nuts and washers on both ends to make a log frame. Hammer ends of rods to prevent nuts from coming off. (Add a fifth log across the center for extra buoyancy and rigidity if logs are less than 8" diameter.)

2. Staple fencing about every 4" to the bottoms of the logs, wrapping it halfway up the sides from underneath.

3. Secure mesh all the way around the sides making sure there are no protrusions or wild wire ends which may injure a bird.

4. Attach anchor lines, one on each opposite corners using 1 clamp on each line.

5. Attach one cement block to each line using the 2 other clamps, running line through garden hose where it contacts cement block.

III. Raft Inspection, Preparation, Placement, and Storage

A. Inspection of raft. Check condition of raft to be sure that:

1. All corners of structure are firmly fastened with spikes.

2. Plastic mesh (dune fence) contains holes small enough to prevent a chick from falling through.

3. Mesh is tacked down securely along entire edge without any sharp edges protruding.

4. Raft floats at an acceptable level without the need for an exceptional amount of flotation materials (if not, it may be time to retire raft).

B. Preparation of raft

1. Place raft in water so that mesh covering is hanging over raft sides.

2. Place a large pile of vegetation on raft collected from shoreline or from forest floor. Lay down a solid layer of sod, decayed weed or duff, then cover with mosses, pine needles, wetland vegetation or any other plant material available that would serve as nest building material for the loons.

3. If possible, plant some sort of shrub on the raft to create cover for the incubating bird.

4. Check flotation level of raft after vegetating it, allowing for the addition of another 10 pounds of bird mass. If more than half of the log sides are submerged, tie plastic milk bottles to underside of raft with string and secure them under the raft.

C. Selecting a site (Figure 2)

1. Choose a location within a territory that is protected from prevailing winds and wave action, preferably a cove (see illustration).

*Awareness of direction of prevailing winds is critical.

2. Place raft approximately 50-100 m from shore in at least 2-3 m of water.

*Be aware of potential water fluctuations on this particular body of water and allow for this when determining adequate distance from shore and depth of water.

3. Drop anchors at a 45 degree angle from raft, leaving some slack in lines (0.5 m) to allow for fluctuations in water levels (too much slack could

cause the raft to whip back and forth in heavy winds).

4. Avoid placing a raft near submerged boulders or other objects that may become exposed with a decrease in water level and serve as a perch for predators such as gulls.

D. Storage

1. At the end of the season, field biologists are responsible for pulling rafts in their territory. Refer to last season's Final Site Survey Reports for storage locations.

2. Make note of any maintenance needed or other pertinent information in the Individual Raft Final Report.

Literature Cited

Loon Preservation Committee. 1990. Turning Point: The Calling Continues: LoonPreservation Committee 1976-1990 15-year report. LPC, Meredith, N.H.

McIntyre, J. 1975. Biology and Behavior of the Common Loon (Gavia immer) with reference to its adaptability in a man-altered environment. Ph.D Dissertation, Univ. Minn., Minneapolis.

Taylor, K., H. Vogel. 1998. Summary of Loon Preservation Committee Research and Management Activities for the 1997 Field Season. LPC, Moultonboro, N.H.

Wood, R., J. Fair, C. Mauhs-Pugh, and K. Neilsen. 1985. The Calling Continues: Loon Preservation Committee 1976-1985 10-year report. LPC, Meredith, N.H.

APPENDIX H WATER BODY PARAMETERS

Field	Field Name	Type	Width	Key
1	LAKEID	Character	3	Id Number of Lake
2	LAKENAME	Character	30	Name of Lake
3	LAKETOWN	Character	25	Principal Town of Lake
4	LAKECOUNTY	Character	15	Principal County
9	LAKEACRE	Numeric	8	Size: Acres
10	LAKEHACRE	Numeric	7	Size: Hectares
11	LAKEMILE	Numeric	6	Size: Sq. Miles
12	LAKEMETER	Numeric	8	Size: Sq. Meters
13	LAKEELEVAT	Numeric	6	Elevation above sea level
14	LAKEMAXDEP	Numeric	5	Max Depth
15	LAKEMEANDP	Numeric	5	Mean Depth
16	LAKEFULLPD	Numeric	5	Full Pond
17	CETERLAT	Numeric	8	Latitude at center of lake
17	CETERLAT	Numeric	8	Longitude at center of lake

APPENDIX I FISH SPECIES DEFINITIONS FOR WARM AND COLD WATER BODIES

Species Key	
1	Brook trout
2	Rainbow trout
3	Brown trout
4	Salmon
5	Lake trout
6	Whitefish
7	Splake
8	Smallmouth bass
9	Largemouth bass
10	Pickerel
11	Horned pout
12	White perch
13	Northern pike
14	Walleye
15	Black crappie
16	Bluegill
17	Tiger trout

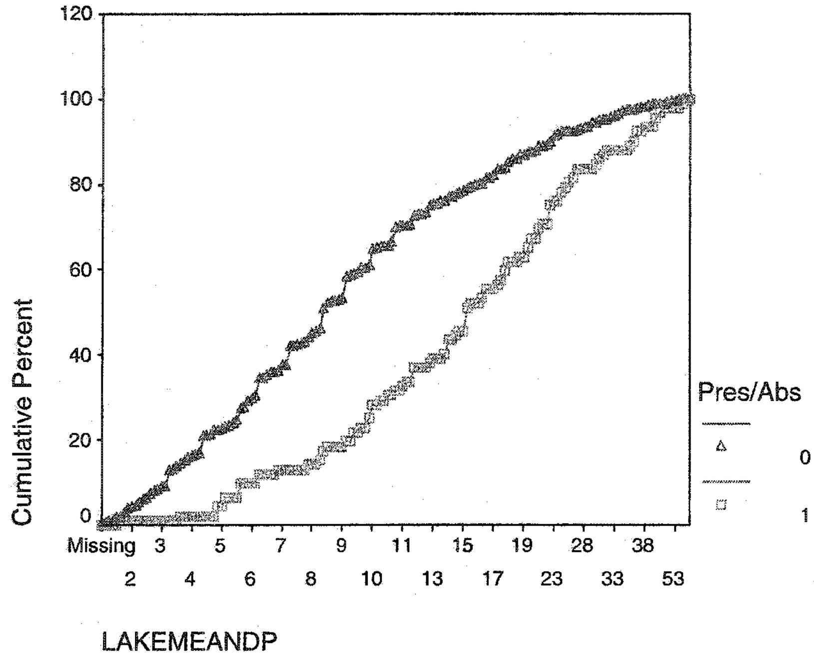
APPENDIX J HUMAN DISTURBANCE DEFINITIONS

Accessibility Codes

A	Accessible by conventional vehicles
R	Remote Pond (walk-in access)
I	Inaccessible by conventional vehicles
HA	Handicapped Accessible

APPENDIX K CORRELATION ANALYSIS AND FREQUENCY DISTRIBUTIONS FOR SIGNIFICANT EXPLANATORY VARIABLES

	Constant	LAKEDEPTH	PERIMETER	AREA	RATIO	ELEV	NOLOONDIS	DISTOLOON	FLUSHRAT
Constant	1.000	-.416	.517	-.432	-.775	-.469	-.159	-.207	.086
LAKEDEPTH	-.416	1.000	-.106	.015	.161	.139	.001	-.049	.133
PERIMETER	.517	-.106	1.000	-.950	-.862	.042	.036	.002	.185
AREA	-.432	.015	-.950	1.000	.753	-.041	-.021	.018	-.148
RATIO	-.775	.161	-.862	.753	1.000	.057	.009	.022	-.250
ELEV	-.469	.139	.042	-.041	.057	1.000	-.137	.057	.033
LOONDIST	-.159	.001	.036	-.021	.009	-.137	1.000	-.089	-.021
NOLOONDIST	-.207	-.049	.002	.018	.022	.057	-.089	1.000	-.018
FLUSHRATE	.086	.133	.185	-.148	-.250	.033	-.021	-.018	1.000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3
4
5
6
7
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11
13
15
17
19
23
28
33
38
53
LAKEMEANDP
Pres/Abs
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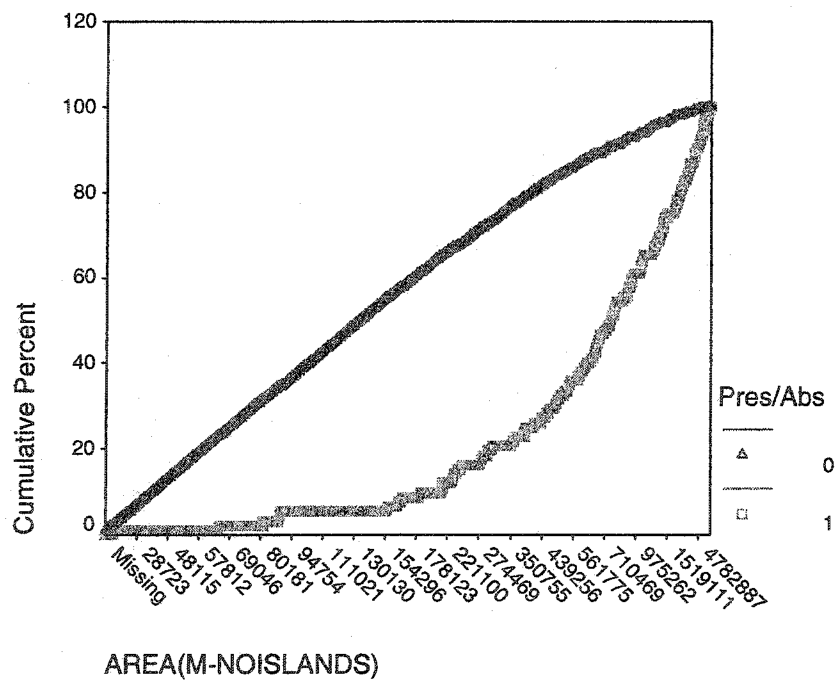
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AREA(M-NOISLANDS)
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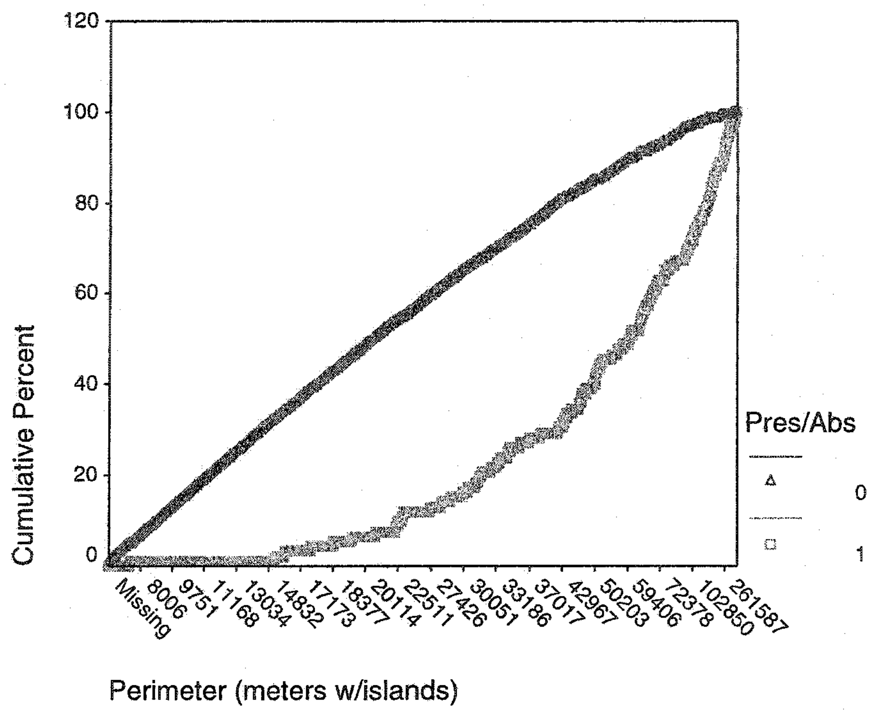

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100
80
60
40
20
0
Cumulative Percent
Pres/Abs
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Missing
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18377
20114
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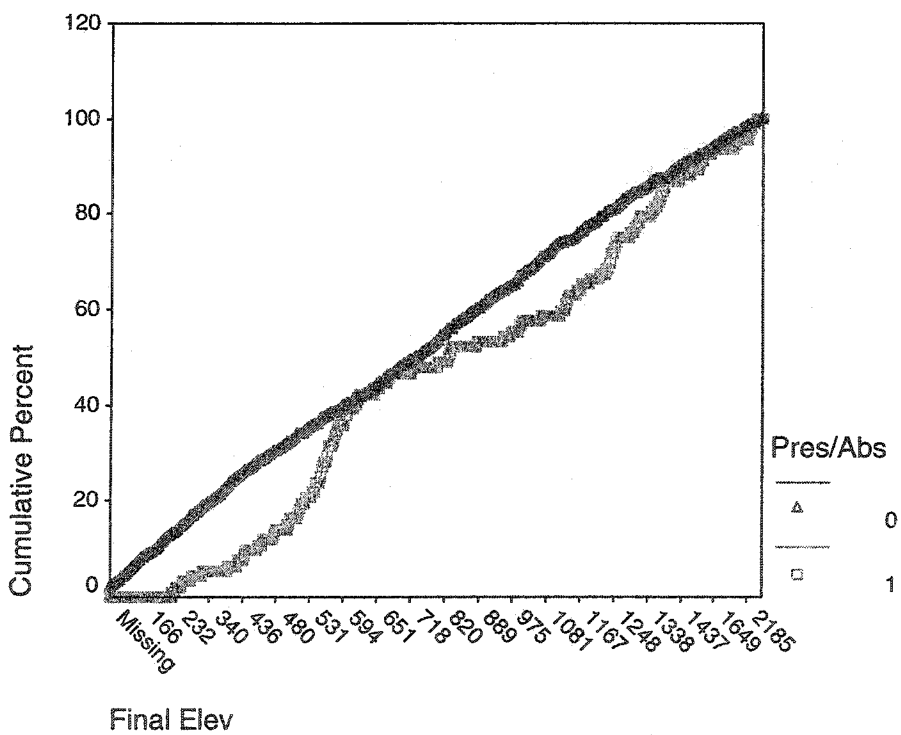
50203
59406
72378
102850
261587
Perimeter (meters w/islands)



120
100
80
60
40
20
0
Cumulative Percent
Pres/Abs
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Missing
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232
340
436
480
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651
718
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1081
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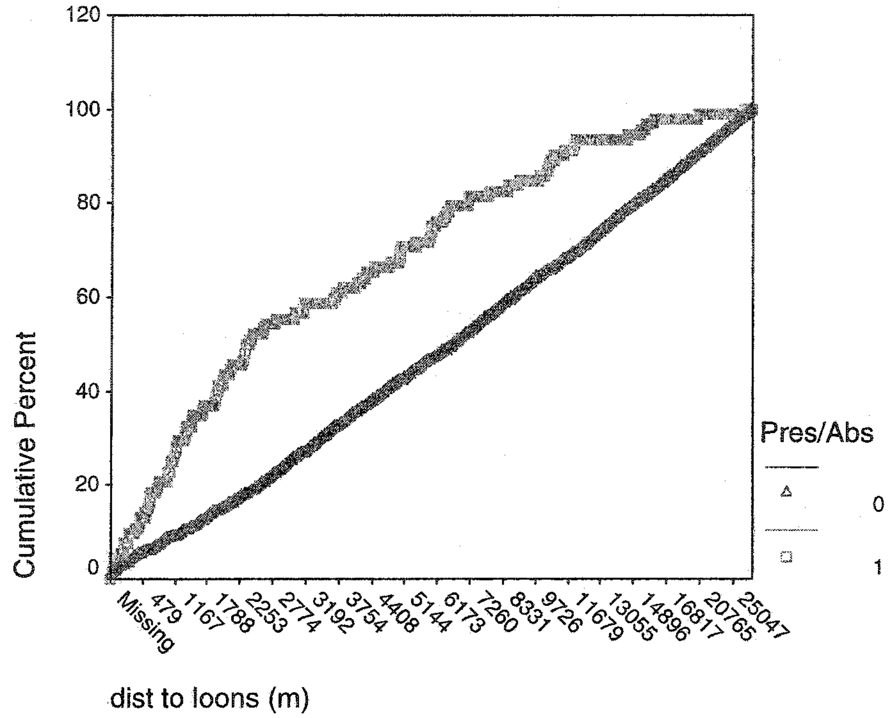
2185
Final Elev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dist to loons (m)
Pres/Abs
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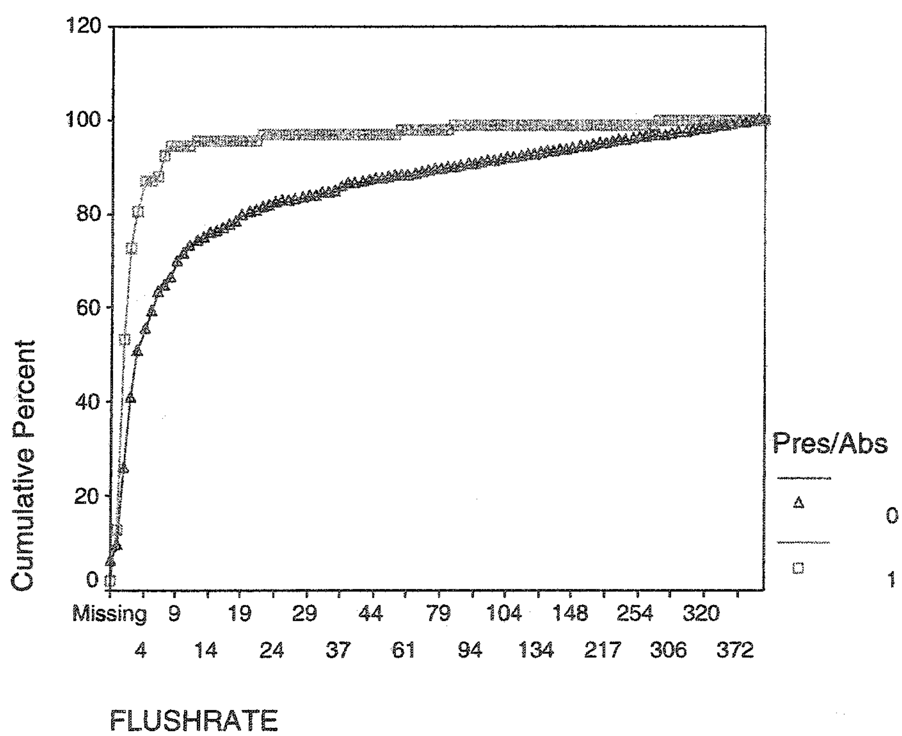
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24
37
61
94
134
217
306
372
FLUSHRATE
Pres/Abs
0
1