Winter 2010

An evaluation of habitat models for the common loon (Gavia immer)

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AN EVALUATION OF HABITAT MODELS
FOR THE COMMON LOON (*Gavia immer*)

BY

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Bachelors of Science: Field Biology, Friends University, 2007

THESIS

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Master of Science

in

Natural Resources: General

December, 2010

This thesis has been examined and approved.

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12/6/10
Date

ACKNOWLEDMENTS

I thank my advisor, Dr. Russell G. Congalton who provided me with guidance and support throughout this project. I am forever grateful for his teaching and taking me on as his student.

I thank my committee members: Dr. Mark W. Brennan for providing me with data from his dissertation to start this project, serving on my thesis committee and for helping me throughout this process by answering E-mail and meeting for breakfast to mull over loons; and Dr. Mimi L. Becker for serving on my thesis committee and providing support throughout this project. I also thank the Loon Preservation Committee who collected all the field data for this project and John Cooley of the Loon Preservation Committee who provided me with this data to complete this project.

I also thank separate contributors including: Dr. Anne Kuhn-Hines (US Environmental Protection Agency) for allowing me to work with her thesis as well; Deb Soule (New Hampshire Department of Environmental Services) for providing me with data from DES that is not publically accessible; and Meghan Graham MacLean who has supported me in many ways throughout this project, particularly, helping me to understand statistics.

Finally, I thank my friends and family for supporting me throughout graduate school: Mom, Steve, Jaime, Jeremy, & the three minions. A special thanks goes to my Dad for editing my thesis and correcting my horrendous grammar. Another special thanks goes to Alan for keeping me sane and providing support through this time.

Partial funding for this project was provided by the New Hampshire View Project, which is a part of America View, without which I wouldn't have been able to complete this project.

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ABSTRACT

AN EVALUATION OF HABITAT MODELS
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The Loon Preservation Committee (LPC) has been collecting field data for the common loon (*Gavia immer*) in New Hampshire for thirty-six years. A habitat model for lakes throughout New Hampshire was created by Dr. Mark Brennan for the time period 1980-2002. This project re-evaluates Brennan's habitat model using new data from 2003-2008. Two additional models, one with all lakes and another with the three largest lakes excluded, were created and compared to Brennan's model to see if the overall accuracy improved. These models show which lakes have high and low potential for loon habitat. The results of the re-evaluation of Brennan's model show that his model fits well using the new data. The first new model has similar overall accuracy to Brennan's model. The second new model has higher overall accuracy than Brennan's model.

CHAPTER I

INTRODUCTION

The common loon (*Gavia immer*) is a large water bird that lives throughout northern North America. These birds are important to monitor because they are considered a bio-indicator species for the environment. A bio-indicator species is an animal that is sensitive to environmental changes or pressures and we can measure their breeding success as a measure of health for an ecosystem. A classic example of a bio-indicators species success is the tree frog. Tree frogs absorb water through their skin and therefore absorb any chemicals contained in the water. If a large die-off of frogs is observed, then that is an indication that there is something wrong with the water supply that they use, which may also be the same water supply for the local people.

Loons are a special case of bio-indicator species because they are particularly sensitive to the presence of mercury and lead found in freshwater lakes. Both lead and mercury are toxic to humans and can cause psychological and physiological defects. Loons accumulate mercury in their systems by eating fish that have mercury in their systems. Blood and feather samples are taken every year from loons on various lakes throughout New Hampshire (NH) to monitor the levels of mercury in the water. Loons contract lead poisoning usually by ingesting lead sinkers or lures used by anglers. A loon with lead poisoning always dies.

Loons are also important to people. In general, people like loons and want to see them on the lake at their summer cottage. This quality is good not only for the loon, but for the entire environment. Only healthy environments that have an abundance of prey and plant species can support a top predator. If loons, a top predator, are found at a lake, it is a good indicator of a healthy environment. People protect the environment to keep these top predators like loons.

Common loons in NH have been monitored by the Loon Preservation Committee (LPC) since 1975. LPC recruits field biologists every year for the May to August summer season. With the help of an extensive and dedicated volunteer network, these field biologists track loons on various lakes in NH throughout the summer. The data they collected over thirty years makes up LPC's long-term database. This dataset has been used by various people to create habitat suitability models to track loon distribution in NH.

Dr. Mark Brennan, who conducted his dissertation research on loon distribution in NH, converted the long-term dataset from hard copy to digital format (Brennan, 2005). Using the digital database, he created a habitat suitability model to predict where future loon occupancy may occur based on parameters determined to be statistically significant. The model was then applied to lakes throughout NH to indicate where to monitor future loon activity on lakes not yet occupied by loons.

The project described here continues Brennan's work. Brennan's habitat model was created from lake occupancy data collected between 1980-2002. This project first evaluates Brennan's model using new data collected from 2003-2008. Second, it also re-evaluates the parameters selected in Brennan's original model to see if these or other parameters are statistically significant. Brennan assessed his model using a selected subset of 100 lakes from the original model dataset. In this project, a more extensive accuracy assessment is conducted by segmenting Brennan's model by year and occupancy level.

In addition to evaluating Brennan's original model, two new models were created as part of this study. These models included the newly collected data from 2003-2008. The model results were applied to lakes throughout NH to provide a rating of how likely it was for a loon to occupy a given lake. The combination of Brennan's model and these new models will help LPC and others to more effectively monitor for loons in NH.

The overall objective of this project was to re-evaluate Brennan's previous common loon habitat model and to create a new model using the most recent (2003 – 2008) field data available. The specific objectives of this project were:

1) To evaluate the original habitat model created by Brennan (2005) using field data collected after he completed his project.
2) To combine data from Brennan's habitat model with new factors acquired from different sources to create new models for predicting loon habitat.
3) To compare all models and their accuracies to see which model predicts loon occupancy better; or to determine if a combination of multiple models works best.

CHAPTER II

LITERATURE REVIEW

To understand why and how to create a habitat suitability model, for the common loon, an understanding of the species being monitored and its ecological needs are presented. The specific analysis tools used to explore the data associated with the loon are also discussed to show why these tools were chosen. The literature regarding habitat suitability models and its assessment are also presented.

Common Loons (*Gavia immer*)

The common loon (*Gavia immer*) is a familiar sight on summertime lakes in the northernmost reaches of the United States. Common loons, considered long lived, are recorded to live from twenty to thirty years (Schoch, 2006). These birds are renowned for their different calls and tend to be loved by the people who view them. The four calls a loon can make are the wail, tremolo, yodel and hoot. The yodel, used only by males, is usually used for territorial purposes (Henry, 2007). The wail has a particularly mournful quality and the Ojibwa Native Americans consider it to be an omen of death (Drummond, 1996).

Loons in New England tend to have a larger body mass than other loons because they do not have to migrate as far as other loons to reach their ocean wintering grounds and therefore can have more caloric intake. For example, in New England, males typically weigh 5.89 kg (13 lbs) and females weigh about 4.63 kg (10.2 lbs) (Brennan, 2005). Both male and female loons have identical plumage but this plumage changes from winter to summer. The winter plumage is brown with a white belly, while summer plumage (or breeding plumage) has a black head, white and black checkered back, and a white belly. There is also a distinctive white "necklace" on the back of the bird's neck in summertime. A common loon's eyes are always red while the beak and feet are always black (see Figure 1) (LPC, 2010).

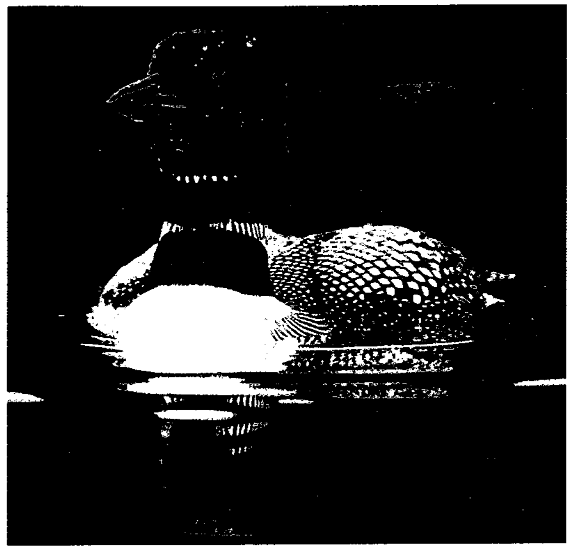

Figure 1: Common loon (National Audubon Society, 2010)

Loons have a unique morphology with bodies designed for swimming and diving, but still capable of flight. Their feet are pushed very far back on their bellies (Figure 2), which makes them very awkward on land. Loons will push themselves on land with their bellies scraping the ground, which is why they only venture on land to nest. However, the placement of the feet makes them ideal for swimming,

Figure 2: Common loon swimming (Gullette, 2007)

because it creates a streamlined profile when in the water. Loons also have denser bones allowing them to sink underwater, and require very long runways approximately a quarter mile to take-off for flight (LPC, 2010).

Loons are top predators on fresh water. They feed mostly on a diet of fish (primarily yellow perch, pumpkinseed & bluegill) as well as aquatic invertebrates, amphibians, crustaceans, mollusks, and occasionally vegetable matter (Barr, 1996). However, raccoons, minks, and foxes have been known to kill a loon when it is on land (Henry, 2007).

Reproduction

During the winter months, loons will travel to and live on the ocean coast. Loons will sometimes travel hundreds of miles to reach the ocean from inland lakes such as Lake Michigan (McIntyre, 1978). New Hampshire loons only travel a short distance to the Atlantic Ocean off the coast of New England. This gives New Hampshire loons a small advantage because they can grow heavier and have more fat stored in their bodies to help them through the winter.

In mid-March, lakes begin to thaw, and loons begin returning to lakes to breed (Daub, 1989). A pair of loons will establish a territory on a lake to build a nest and mate. Usually a pair of loons is loyal to a territory if established in previous years. There are different environmental conditions that a loon will consider when choosing a lake, additional conditions necessary when choosing a nesting site and even more conditions required to raise chicks. When choosing a lake to establish a territory, some minimal requirements must be met. Loons prefer deeper lakes with lots of fish, but also with shallow areas for feeding chicks (Strong & Bissonette, 1989). Loons also prefer lakes with islands to nest on with little human disturbance (Vermeer, 1973).

Nesting is a vulnerable period for loons. The adult loons have to be out of the water to sit on the eggs and can be preyed upon. Loons usually have only one nesting attempt per season; so if predators destroy their nest or eggs, they are not likely to reproduce for that year. For predation reasons, nests locations are chosen very carefully. If possible, loons prefer to nest on an island. Nesting on an island reduces the risk of land predators disturbing the nest (DeSorbo et al, 2007). Usually the nest will be near cover, such as trees, brush or undergrowth to help shield the nest from direct sunlight and aerial predators. Nests are almost always located within a meter of the water's edge, which helps the adults reach the water if escape becomes necessary. Loons have a difficult time with terrestrial locomotion, so close proximity to the water's edge reduces the distance loons have to travel on their belly (Vermeer, 1973). Loons also prefer to have nests in a cove-like area to protect the nests from being washed out by waves, usually caused by storms, speedboats and jet skies (Vermeer, 1973).

In 1985, artificial nest platforms, or "rafts" were introduced for common loons use in New England (DeSorbo et al., 2007). Loons benefit from rafts for a variety of reasons. Primarily, rafts provide places to nest where there is no suitable shoreline. Lakes within NH are popular recreational areas for people and thus many lakes have highly developed shorelines. Another major benefit of rafts is that the nests won't be washed out due to waves. Rafts are designed to float regardless of summer rainfall; the raft will accommodate the changing levels of the water (DeSorbo, 2007). Though rafts are great management tools to help loons find suitable nesting sites, they should not be a substitute for protecting valuable shoreline for wildlife. The ecosystem as a whole must be maintained for loons to survive and rafts are not always successful.

Loon chicks are born nidifugous, which means they have down and can swim upon hatching. However, loon chicks are completely dependent on their parents for the first two months after hatching and will usually ride on a parent's back for the critical first two weeks. A chick will "fledge", or leave the care of its parents, by eight weeks old. A chick is considered to have successfully survived if it lives past four to five weeks, however they will not be able to fly until three months of age (McIntyre, 1983). Adult loons don't generally raise their chicks in the same habitat that the nest was located and there are several characteristics that determine the selection of the nursery area.

A study by McIntyre (1983) shows nurseries generally consist of soft mucky bottoms, a gradual slope and lots of shelter from predators, wind and waves. A similar study done by Strong and Bissonette (1989) shows that chick-rearing habitat generally consists of shallow water of a meter or less and usually about fifty-one to one hundred and fifty meters from shore. Chicks also tended to stay in smaller cove-like areas that are protected from wind and waves.

Eggs are generally laid in pairs and will incubate for about twenty eight days. Eggs can be predated by many creatures if the parents leave them unprotected, however, chicks are usually preyed upon by bald eagles, snapping turtles, gulls, and large fish. Therefore, young chicks will often ride on their parent's back to cool off, rest and avoid being eaten. If a chick survives to become a juvenile, it will migrate with its parents in November to the ocean to spend its next five years or so without returning to fresh water.

The chick will mature and molt into breeding plumage, returning to its natal lake which may become its new territory if not already occupied (LPC, 2010).

Common Loon History in New Hampshire

One of the first pieces of legislation that helped the common loon was the Migratory Bird Treaty Act (MBTA) of 1918, which prohibited the taking or killing of loons, their nests and their eggs (U.S. F&W, 1918). This treaty between the United States and Canada protected the species that migrated from one country to another. There have been multiple amendments to this treaty to add new countries including Mexico, Japan, and Russia and new species including barn owl, common raven and Canada goose (U.S. F&W, 1918). This legislation helped stop the rapid decline of the loon; however, there are still many threats to the common loon that prevent it from fully recovering its original status.

Even though loons were protected under the MBTA, poachers took their toll on loons. Anglers in particular were killing loons because of the misconception that loons were eating game fish, such as bass. This is not true because loons prefer fish with an erratic swimming behavior or "fusiform" shape, which does not include bass (Barr, 1996). In NH, habitat loss and illegal hunting almost reduced the loon population to near-extinction until the NH Audubon Society got involved with their preservation in the 1970's. This public show of support and education of the public stopped the loons' decline. Today, the biggest threat to loons in NH is the loss of suitable shoreline habitat for nesting.

In NH, the common loon was listed as “threatened” by the NH Fish and Game Department in 1980 under the NH RSA 212-A, the Endangered Species Conservation Act (Vogel & Taylor, 2006). The status “threatened” means that if the habitat around the animal declines further from its current status, then the animal may be moved to “endangered” status. The status “endangered” means the prospects for survival for a native species of animal is in danger due to loss, damaged, or declining habitat, overexploitation, predation, competition, disease, disturbance or contamination. Assistance is therefore needed to ensure their continued survival (NH F&G, A., 2008). The NH list of endangered and threatened species was supposed to be reviewed every eight years to maintain its up-to-date status (NH F&G, B., 2008). However, the list has only been revised in 1987, 2000 and 2008 and loons maintain their “threatened” status (NH F&G, A., 2008).

Through the efforts of the LPC the common loon population has improved significantly (LPC, 2010). Today, the common loon is still a state listed threatened species, but this is subjective because it is unknown if the common loon has reached carrying capacity in NH. This is because not all habitat is occupied within the state. There is room for more loons to live in NH but their status has not improved. There are many lakes in NH that have pristine habitat but no loons, as well as over-crowded lakes with too many loons. There is no single explanation for why some loons seek out new lakes and some do not. One possible explanation is the maturity of the loon and the experiences it has had in trying to attract a mate and to establish a territory for breeding. An older loon is a much more successful at survival because it simply has more knowledge and experience.

However, in NH the common loon seems to have recovered many of the losses suffered from poaching and habitat loss. According to Brennan's (2005) research, the common loon is surviving well in NH compared to the 1970's when the population was down to 21 successful breeding pairs with 91 total breeding pairs on 55 lakes in 1976. This number increased through time to 136 lakes with territorial pairs in 2002 (Brennan, 2005). However, Brennan's data analysis stopped in 2002, which is all the data he had up to that point.

As of 2008, the overall loon population appears to be holding steady; with 520-530 adult loons with 103 surviving chicks in 2007, and 542 adult loons with 106 surviving chicks in 2006 (Cooley, 2008). However, the current population of loons in NH is not enough to remove loons from the threatened species list for NH because habitat loss is still increasing for loons. The "threatened" status means that if the habitat for a particular species (in this case common loons) declines further, it will be assigned an "endangered" status. Human encroachment upon loon habitat, which is on lake shores, is only increasing in NH and shows no sign of stopping. In a report issued by BioDiversity Research Institute (BRI) of Gorham, Maine, habitat degradation and loss from shoreline development is responsible for population declines and lower reproductive success in common loons (Evers, 2004). Human presence causes increases in predators of adult loons and nests (Evers, 2004).

Major Threats to Common Loons

Common loons are susceptible to a variety of environmental pressures. This section describes some of the most detrimental pressures loons struggle to survive with.

Some pressures are caused by humans and others are natural phenomena, but all contribute to lower a loon's fecundity (breeding success). It is important to address these threats because some affect human health as well.

<u>Shoreline Development</u>

Loons require shorelines to nest. In NH, lakes are a common recreational location. Many shorelines are prime areas for summer cottages for tourists which conflict with a loon's needs. In a study done by Heimberger et al. (1983) concerning the impact of cottage development on common loons, they found that loons can adapt to human presence; however some shoreline must be available and undisturbed for loons to nest successfully. Heimberger found that once chicks are hatched, the adult loons are not disturbed by human presence when they are sitting on the nest. This study characterized the human disturbance as being relatively "low". In other studies, loons have been negatively impacted by high presence of humans, causing nests to fail (Vermeer, 1973).

In 1992, the Comprehensive Shoreline Protection Act (CSPA) was enacted to protect the water quality of lakes. The CSPA act provides rules for construction on shorelines to preserve the natural ecosystem to the best extent. Beginning July 1, 2008, a more restrictive state shoreline permit is required to conduct any construction on the shoreline of a water body (NH DES, A., 2008). The new CSPA act is an additional step forward to protect the nesting habitat for loons as well as other waterfowl in NH; however it is not enough to remove loons from the "threatened" status. It is also difficult for state and local agencies to monitor permits and to enforce all violations of the CSPA act.

Fluctuating Water Levels

Natural events can cause fluctuations in water level on a lake. A drought or excessive rainfall can lower and raise the level of a lake. A loon will nest within a meter of the shoreline, and a severe drought can leave a nest stranded or excessive rainfall can flood a nest. Fortunately, many lakes in NH have hydro-electric dams and are periodically drained during the summer and fall to maintain an even lake level. However, sometimes a loon will nest on a lake that has excess water and needs to be drained. As LPC and BRI monitor many lakes, artificial rafts have shown to be successful in combating changing lake levels. However, as loons usually nest on land if the shoreline is available. The changes in lake level can lead to nest failure or worse; leaving a loon trapped on a lake too small to take-off. A lake too small to take-off from can cause a loon to stay on that lake into the winter and the loon can freeze to death, thus thinning the gene pool. The problem of changing lake levels is usually solved by close connections between LPC and volunteers who live on a particular lake. LPC is active in communicating with lake managers to inform them when the loons are no longer nesting or on the lake completely, so that it is safe to drain the lake after a rainy summer.

Mercury (Hg)

There are many toxic substances in the environment that hurt a common loon. Mercury (Hg) is a naturally occurring element in our environment. However, mercury can be converted into an organic form called methylmercury (CH_3Hg^+), which is a neurotoxin and can accumulate in organisms (USGS, 2008). In the environment, mercury exists in rock and fossil fuels usually in cinnabar, a solid form of mercuric sulfide (HgS).

Mercuric sulfide can be released into the air primarily by incineration and burning fossil fuels (Gover, 2000). In the United States, the majority of our sources of mercury being released into our atmosphere are combustion sources. Medical and municipal waste incinerators and coal-fired utility boilers account for more than eighty percent of the mercury emitted into the atmosphere from point sources (Gover, 2000). Mercury can then enter water bodies through the form of acid rain. When the mercury enters a lake it can come in contact with sulfate-reducing bacteria which converts it to methylmercury (Mitro et al., 2008). Once ingested by an animal, methylmercury is absorbed through the circulatory system and can cause kidney, liver and brain damage (Pokras et al., 2008). In mammals, methylmercury can cross the placental barrier, therefore increasing a fetus' level of mercury before it's born, which can cause serious damage to the brain and central nervous system (Pokras et al., 2008).

Loons are considered to be environmental indicators of the water quality of our freshwater lakes, especially lakes with high levels of mercury contamination. Since loons are long lived, have a primary diet of fish and would accumulate mercury in their blood, the long term effects of sustained mercury poisoning can be observed (Mitro et al., 2008). Mercury levels in loons reflect the mercury levels in their prey and therefore give an estimate as to how much mercury is contained in fish from a particular lake (Evers et al., 2008). Humans consume freshwater fish, so it is important to know the most current levels of mercury in a lake to prevent people from contracting mercury poisoning. Knowledge of current mercury levels in a lake is especially important for pregnant women because mercury can cross the placental barrier to her fetus and cause brain damage to the fetus.

Mercury poisoning causes physiological, behavioral and reproductive changes in the common loon and usually results in a lower success rate for reproduction (Evers et al., 2008). Loons release some mercury from their systems through feathers and eggs, thereby lowering the total amount of mercury present in their blood. Even with sequestering some mercury from their systems, loons still exhibit behavior and physiological signs of mercury poisoning over a long term basis (Mitro et al., 2008). Some of these behavioral changes are increased time preening, less time incubating an egg in a nest, less time feeding, and lethargy (Evers et al., 2008). However, studies have shown that adult loons tend not to suffer a shorter lifespan even with increased mercury levels in their blood (Pokras et al., 2008). Loon chicks with mercury poisoning exhibit behavioral changes that tend to lead to the chicks' demise because of their youthful vulnerability. Some behavioral changes include decreased time back riding on an adult and less time spent feeding, which can lead to being preyed upon or starvation (Evers et al., 2008).

Biological "hotspots" of mercury have been identified in New York, New England and Nova Scotia, where mercury levels in fresh water bodies have been identified to be higher than other parts of the United States (Evers et al., 2008). Of these hotspots, the southeast part of NH has been shown to have the highest levels of mercury in water bodies in the entire United States (Evers et al., 2008).

<u>Lead (Pb)</u>

Lead is a substance that is usually fatal to a loon should it be ingested. A loon that ingests lead shows behavioral changes such as physical weakness, breaching, dropped wing posture, head tremors and dyspnea (open-mouthed breathing) (Sidor et al., 2003). When a loon is poisoned by lead, other infections and diseases usually occur because of the loon's lowered immune system. Mortality of a loon was usually seen in 20-40ppm of lead for full loon body weight, but loons can ingest as little as 7.5ppm of lead in total body weight and still show signs of poisoning (EPA, 1994).

In New England, lead poisoning is a leading cause of loon deaths, with 118 carcasses collected from 1987 to 2000 with confirmed lead ingestion (Pokras et al., 2009). The most common form of lead for a loon to ingest is a lead sinker (Pokras et al., 2009). Because loons are piscivores (primarily fish-eating) birds and therefore have lower stomach pH then omnivorous birds, they ingest stones to help digest food in their gizzards (Pokras et al., 2009). When searching for a stone to ingest, a loon searches the bottom of the lake for round objects and may pick up a lead sinker by mistake (Pokras et al., 2009). Loons can also ingest lead from fishing lures and jigs caught inside a fish.

Not only does lead affect common loons, but also mute swans, trumpeter swans and sandhill cranes (Pokras et al., 2009). The unnecessary deaths of different birds are a poor development because alternatives exist to using lead when making certain objects. Steel, iron, tin, bismuth and other non-toxic substances have proved to be just as effective as lead in their usage and do not cause avian deaths (EPA, 1994).

In 1994, the environmental protection agency proposed a ban on the manufacture, sale and use of lead sinkers under one inch in size (EPA, 1994). Other materials such as zinc and brass are also banned for hunting and fishing purposes to certain degrees (EPA, 1994). The cost for the change over for the average angler was calculated to be about $4.00 per year, viable for individual fishermen to accomplish (EPA, 1994). However, this does not mean that the ban is in effect; it has only been proposed. Individual states such as NH, Maine and New York have passed limited laws to ban either the manufacture, sale or use of lead sinkers (Thomas, 2003).

Important Contributors to Loon Research in NH

The first organization involved with gathering data for this project is the Loon Preservation Committee (LPC). LPC was established in 1975 as a self-funded branch of the NH Audubon Society when certain residents on Squam Lake in NH started noticing a decline in the lake's population of common loons (LPC, 2010). The LPC Center is located in Moultonborough, NH on the shore of Lake Winnipesauke. LPC works with researchers and an extensive volunteer network to manage the loon population within the state of NH. LPC also works with many organizations within the region to help manage the common loon including Biodiversity Research Institute (BRI) in Maine, Tufts University in Massachusetts, New Hampshire Fish & Game (NH F&G), United States Fish and Wildlife (U.S. F&W) service and The New Hampshire Wetlands Bureau under the New Hampshire Department of Environmental Services (NHDES).

The mission of LPC is to, "restore and maintain a healthy population of loons throughout New Hampshire; to monitor the health and productivity of loon populations as sentinels of environmental quality; and to promote a greater understanding of loons and the larger natural world" (LPC, 2010). LPC accomplishes this mission through their work described as, "to preserve loons and their habitats in New Hampshire through programs of monitoring, research, management, and public education, all fostered by an extensive grassroots network of dedicated members and volunteers" (LPC, 2010). The research and efforts done through LPC have been recognized world-wide as providing methods to help reverse the decline of a species. Their efforts have also benefitted shoreline protection and other species that are within the same habitats. LPC recognizes that, by protecting a habitat and ecosystem as a whole, it provides a way to save some larger species that are more easily susceptible to habitat disturbance and to protect smaller species lower down the food chain that may go unnoticed (LPC, 2010).

LPC has been spatially tracking loon nests since the late 1970's, but all the data were recorded onto 1:24000 United States Geological Survey (USGS) topographic maps. As part of Dr. Mark Brennan's dissertation research, these data were converted to digital format in a Geographic Information System (GIS) database for LPC to better keep track of and manage the common loons within NH (Brennan, 2005). Additionally, Brennan introduced LPC to hand-held GPS technology for collecting nest site specific georeferenced data. All new data collected are added into the GIS on a yearly basis to maintain an up-to-date database.

The staff at LPC and the field biologists, who routinely collect field data each summer, provided critical raw data and significant help with this thesis. The field biologists are recruited by LPC every summer to track the loons in their natural environment. These field biologists must first determine which lakes have adult loons occupying them, follow loons throughout the summer to determine where a nest site is located, determine if chicks hatch and then determine if the chicks survive to fledge. The number of chicks surviving in a year to fledge is considered to be the measure for how well the species is surviving for the year. Usually loons will have a lower success rate of reproducing if some sort of environmental stressor, such as mercury poisoning or human disturbance, is present.

LPC has about 750 lakes in their database for monitoring. Based on the history of loon presence or absence on a lake determines if it continues to be monitored or taken off the “tier 1” list. A “tier 1” lake must be monitored at least three times a summer by the field biologist assigned to that lake. There are also “tier 2”, “tier 3”, and “tier 0” levels for monitoring. A lake that has had no loon presence for three years in a row may be bumped down a tier until it is off the monitoring list for LPC field biologists. However, it is rare that a “tier 1” lake is bumped down because they are usually well established lakes with continuous loon presence (LPC, 2010). Whether or not LPC changes its’ monitoring level for a lake doesn’t mean that NHDES, which assesses water quality for NH lakes, changes its’ monitoring rate for a lake. Therefore, some lakes in this dataset may be monitored by the LPC for loon presence may not be in the monitoring list for NHDES and vice-versa. For this project, LPC provided the 2009 list of lakes that are monitored by the summer field biologists. This list stays relatively the same year to year for larger, more established lakes, such a Lake Winnipesaukee, but may change for the smaller ponds that don’t always have a loon occupying them.

Another organization that helps gather data for LPC is the Biological Research Institute (BRI) located in Gorham, Maine. BRI has done extensive research with mercury and its effect on loons. BRI works very closely with LPC helping collect and maintain field data on loons in Maine and NH. The mission of BRI is, “to assess ecological health through collaborative research, and to use scientific findings to advance environmental awareness and inform decision makers” (BRI, n.d.). BRI also organizes yearly capture and banding exercises with LPC in NH to collect blood and feather samples from loons on various lakes.

One last organization that helped provide data for this project is the New Hampshire's Department of Environmental Services (NHDES). Ms. Deb Soule of NHDES queried a database that is not publically accessible for attribute data used in this project. These data were used in the creation and testing of the new models presented in this project.

Analysis Tools Used for this Project

There were five major tools used in this project to create the habitat suitability models. Each tool is briefly discussed with specific roles they played in the project. The tools used were: Geographic Information Systems (GIS), R statistical software, M.S. Excel®, Kappa and logistic regression.

Geographic Information Systems (GIS)

A Geographic Information System (GIS) is a, "system for entering, storing, manipulating, analyzing and displaying geographically referenced data. These data are represented by points, lines and polygons along with their associated attributes" (Congalton and Green, 1992, p.13). There are four components to a GIS: hardware, software, data and people (Congalton and Green, 1992). People are the most important part of a GIS because they need to be trained to use the ever-changing software. Even with training, the people who use GIS need to be able to adapt to new situations for each project and to be able to problem-solve using the skills they have acquired with previous GIS experience.

All data within a GIS are considered "spatial" data and these data have real world locations associated with them. The data are displayed in layers on a computer monitor in either raster or vector format. Raster data consists of cells or equal-area grids. Vector data are made up of points, lines and polygons. For example with vector data, one layer can be made up of polygons representing lakes and another layer may be made up of lines representing roads. Layers can overlay each other, allowing for many types of analysis, such as exploring the relationships between layers (Bolstad, 2005). The results of this project are presented in cartographic or map format that show which lakes are best suited for loon habitat.

The GIS software package used for the spatial analysis part of this project was, Environmental Systems Research Institute's (ESRI) ArcGis® 9.3. ArcGis 9.3 was used to view and create data layers for this project. All layers in this project were in vector format.

Software Used for this Project

R, an open source statistical software package, was used to perform the statistical analysis portion of this project. R was created by John Chambers and colleagues at Bell Laboratories (formerly AT&T, bought out by Lucent Technologies) (The R Project, n.d.). R is written in the S language, has good graphics, and is considered to be one of the better statistical packages for doing spatial statistical analysis (Burns, 2006).

Microsoft Excel®, which is primarily a spreadsheet tool, was used to manage the several databases of information and to perform the accuracy assessments presented in this thesis. The accuracy assessments were performed by creating multiple error matrices within Excel. The data for this project were provided from several places and were organized in ways not suitable for R because of gaps within the data; therefore Excel was used more than any other tool simply because of the many hours spent organizing the data into a combined dataset.

The last software program used in this project was the KAPPA program written by Dr. Russell G. Congalton at the University of New Hampshire (UNH) (Congalton, 1991). This program allowed for the calculation of the KHAT and Z statistics for specific error matrices generated for this project.

Logistic Regression

Logistic regression is a specialized case of a General Linear Model (GLM) and is a method used to predict the probability of an event to occur. GLMs show the relationship between the independent variables and the dependant variable and are a more general form of a linear model. A GLM will combine the independent variables into an equation and the resulting dependant variable is a function of that equation (Adler, 2010).

Logistic regression uses the same principle of a GLM by combining independent variables into an equation with a dependant variable being a function of that equation. Logistic regression starts with many potential independent variables which are then regressed or whittled down to the significant parameters that determine the predicted probability of an event to occur (or the "model output"). This process is done using a statistical software package that calculates the significance of each variable from the dataset provided by the user. The higher the significance of a variable, the better the variable will determine probability of an event to occur. These significant variables are then combined into a final model to be used to calculate predicted probabilities (or "model output").

The numerical result from a logistic regression will be in a continuum from 0 to 1. This continuum is then converted into a binary format using a threshold value that is chosen by the user. Everything above the threshold is considered a success and is represented by "1" and everything below the threshold is considered a failure and is represented by "0" (Adler, 2010).

Using Logistic Regression to Create Habitat Suitability Models

Logistic regression can be used to create habitat suitability models for a target species. A habitat suitability model is a model that is used specifically for modeling potential habitat for a target species. Logistic regression is used when working with binary predictive data or presence/absence models, because it's considered the best method. A presence/absence model is a type of habitat suitability model that focuses specifically on whether a target species is present or absent in its environment. The resulting model output values, ranging from 0 to 1, are assigned a habitat suitability threshold usually at 0.5. Anything below the habitat suitability threshold is considered to be predicted "absent", or *not containing* the species of interest (for this project: a common loon) and anything at or above the threshold is considered to be predicted "present", or *containing* the species of interest (Hirzel et al., 2006).

Habitat suitability models allow us to understand a specific species' ecological niche in the wild. The goal of habitat suitability models is to produce a map that graphically shows the best locations for a species of interest. This map can be produced using a GIS. Hirzel et al. (2006) describe a habitat suitability map as being, "composed of cells (or rasters) whose quantitative values range from 0 to 1. These values indicate how close the local environment is to the most suitable areas, higher values standing for the most suitable areas" (p. 143). The higher the model output value from the habitat suitability model, the more suitable the habitat for the species of interest. The description from Hirzel et al. describes a habitat suitability map using a raster map; however the same principle can be applied to vector data. A value ranging from 0 to 1 would be assigned to a polygon in a vector data layer rather than an individual cell as with raster data.

The Akaike Information Criterion (AIC), a measure of a model's predictive accuracy, was used to determine which models to use for this project. The models with the lowest AIC score were chosen because the lower the AIC score the better the model's predictive accuracy (Adler, 2010).

To avoid overfitting the model, the model must contain enough data points and be tested using an independent dataset also with enough data points. A model that is not overfit is considered "robust" and makes better predictions of unknown data. A good rule of thumb for the proper amount of data points is 10 points for every variable tested in the creation of a habitat suitability model (Hardy & Bryman, 2009).

Previous Habitat Occupancy Model

In 2005, Dr. Mark Brennan completed his dissertation research in which he created a habitat model for the common loon in NH (Brennan, 2005). This research took the historic loon data in NH from USGS 7 ½ minute topographic quads and digitized them into ESRI's ArcView® 3.0 GIS. The lakes with loons were used to evaluate the parameters of a lake that would be suitable for loon habitation. Brennan originally had twenty potential independent variables, but the analysis using logistic regression only found four that were significant. Brennan originally had a total of 533 lakes in his dataset but he chose to exclude the three largest lakes. Lake Winnipesauke, Squam Lake and Lake Umbagog are over 5000 acres in surface area and are considered outliers due to their large size. Excluding the largest lakes in NH left Brennan's dataset with 533 lakes. Brennan then created a stepwise binary logistic regression model with the presence or absence of loons as the dependant variable. The resulting output values from the model were a probability that predicted a loon's presence on a lake with a value from 0 – 1. Brennan set his "threshold value" at 0.2 to convert the output from the model into binary format. Brennan chose this threshold because, based on loon observation data from 1980 – 1996, there is a 19% chance of a loon being present on a lake in NH (Brennan, 2005). Any lake with a model output of 0.2 – 1 was coded as a "1" and predicted to have loon presence, and any lake with a model output of 0 – 0.19 was coded as "0" and predicted to have loon absence (Brennan, 2005).

Brennan acquired field observation data of loons from LPC for years 1980 – 2002. The data were divided into two parts: from years 1980 – 1996 and from years 1997 – 2002. The data for years 1980 – 1996 were used to create the model and the data from years 1997 – 2002 were used to test the model. The model generated by Brennan (2005) using logistic regression is as follows:

$$p(loon\ presence) = -3.4683 + 0.000021(\text{PERIMETER}) + 0.045810(\text{DEPTH}) - 0.000096(\text{DISTANCE to LOON}) + 0.000936(\text{ELEVATION}) + \varepsilon$$

For the accuracy assessment performed on Brennan's model, a subset of a 100 of the 533 lakes was used for the error matrix. This subset used loon field data collected from years 1997 – 2002. The overall accuracy of the model from this 100 lake subset was 78%.

The results from this model are presented in Brennan's dissertation as three GIS layers. They are High Occupancy Habitat, Medium Occupancy Habitat and Low Occupancy Habitat (see Figure 3). Each layer has lakes in specific colors that correspond to the level of how likely a loon will occupy a lake according to the model output. For example, in Figure 3 the High Occupancy Habitat lakes are colored red with model output of 0.5 – 1, Medium Occupancy Habitat lakes are colored orange with model output of 0.2 – 0.49 and Low Occupancy Habitat lakes are colored green with model output of 0 – 0.19 . Medium and High Occupancy Habitat have model output above 0.2, which means they are all lakes coded as a "1" for presence. All the Low Occupancy Habitat lakes have model output below 0.2, which means they are coded with a "0" and all are predicted to have loon absence. These GIS layers were given to LPC in order to graphically see which lakes are more likely to have a loon occupying it and to help the field biologists make the most efficient use of their time.

This project tested Brennan's model for accuracy using new field data collected

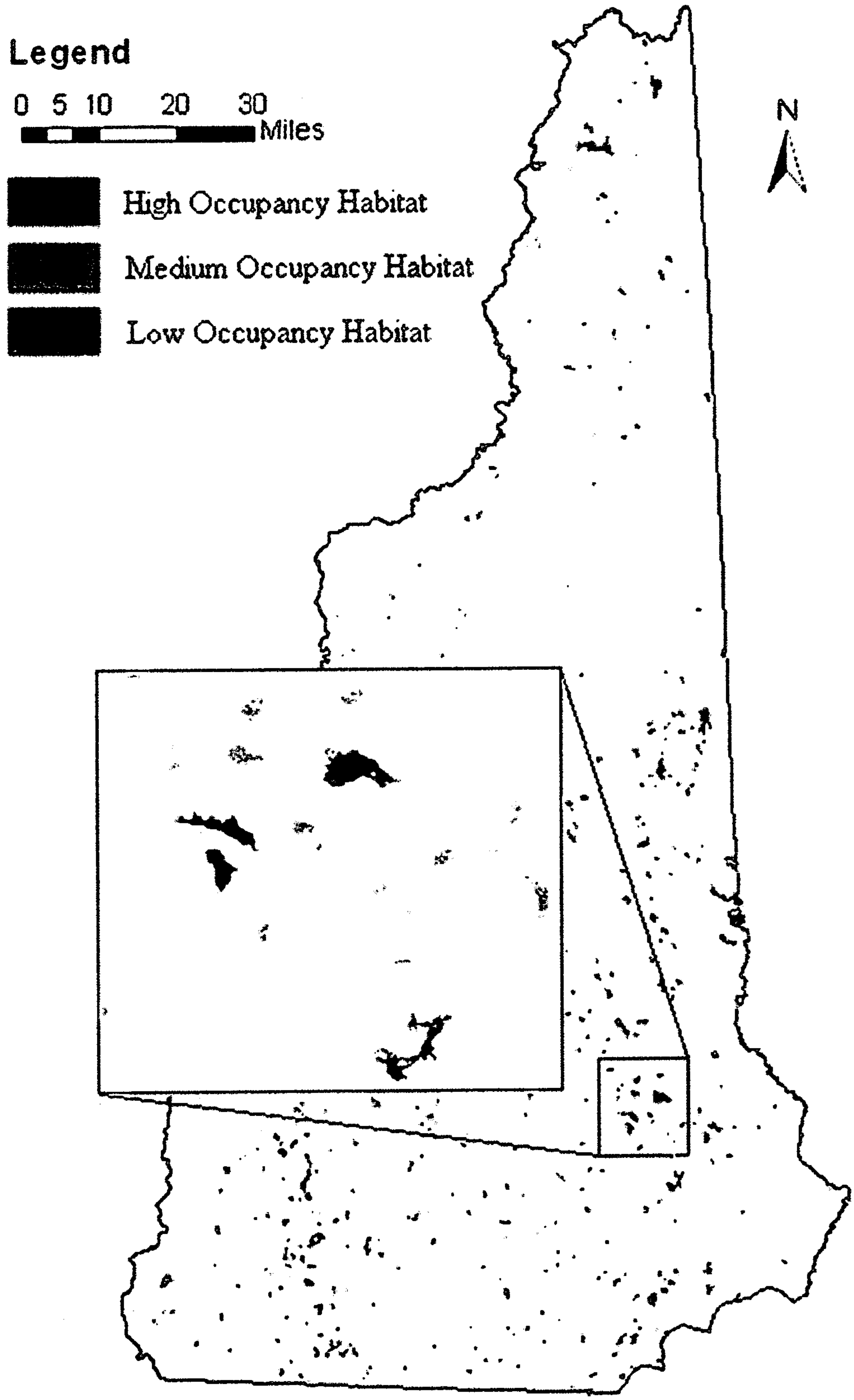

Figure 3: High, Medium & Low Occupancy Habitat Layers after Brennan (2005)

from 2003 – 2008 by LPC. The objective was to evaluate Brennan's model to see if it could still predict potential loon habitat in NH. Brennan's model was then compared to the two new models created in this project.

New Models

The second objective of this project was to create two new habitat suitability models using new field data collected from 2003 – 2008. These new models were created to compare to Brennan's model to see which of the models best predicts potential loon habitat. To accomplish the second objective, there was a substantial amount of initial preparatory work to perform before the analysis could begin. Several databases were provided for this project from various sources and all needed to be reviewed prior to analysis. These databases were sorted and compiled to condense the information into a more manageable layout.

Data for some of the potential model parameters came from sources other than LPC. A number of new potential model parameters came from Dr. Anne Kuhn-Hines (2009), who also studied potential habitat models for common loons. Another source of parameters investigated in the new models came from Ms. Deb Soule from the New Hampshire Department of Environmental Services (NHDES). Soule queried the NHDES's database for lake attributes that were not publically accessible on their website and provided valuable information used in this project.

LPC's 2009 lake-list was used as a baseline for lakes to use in creating new habitat suitability models. The information from the compiled databases was combined with the 2009 LPC lake-list to create a database of information about lakes in NH and their attributes. However, many of the lakes monitored by one agency (such as LPC) were not monitored by another agency (such as NHDES) and therefore there was the potential for incomplete data collection. Logistic regression models require that there can be no "gaps" in the data, which means if a lake is missing a measurement for any one of the parameters being tested for significance, it has to be excluded from the dataset. For example, Ayers Pond in Barrington, NH, which has confirmed loon presence for multiple years, had to be excluded from the dataset because there was no record for the number of islands, distance to nearest lake with a loon, pH, or secchi disk depth for this pond. Therefore, the combined final dataset was left with 303 lakes to be entered into R statistical software for the creation of the two new habitat suitability models.

For the first new model created for this project: the 303 lakes entered into R statistical software were randomly split into two parts. The first part, containing 152 lakes, was used to build the model and the second part, containing 151 lakes, was used to test the model's accuracy.

For the second new model created in this project: the three largest lakes (Winnipesauke, Squam and Umbagog) were removed from the dataset. These lakes are much larger than the rest of NH lakes and are considered outliers. The dataset then contained 300 lakes which were randomly split evenly to use one part for creating the model and one part for testing the model. This second new model is more similar to Brennan's (2005) model than the first new model because of the absence of the three largest lakes.

Accuracy Assessment

To quantify how well a habitat model predicts suitable habitat, you need to assess the accuracy of the model. For this project, the accuracy assessments were performed using error matrices and Kappa analysis. Habitat suitability models are addressed with an independent dataset that evaluates the model to see how well it predicts species presence. In most field biology datasets, especially over a large area, time and money are a constraint and the data you can collect are usually split in two random parts with the first part of the data used independently to create the model and the second part to perform the accuracy assessment. Another common method, which Brennan used, is to split the dataset by year and use the older data to create the model and use the newer data to test the model.

Error Matrix

Congalton and Green (2009) describe an error matrix as a "square array of numbers set out in rows and columns that expresses the number of sample units assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification" (p. 57). An error matrix consists of rows and columns. The columns represent the reference data that are considered to be correct. The rows represent the classified data (as in image classification); but for this project, the rows represent the model output from the habitat suitability models. Producer's and user's accuracies were also calculated for each error matrix performed (Story and Congalton, 1986). Table 1 is an example of a basic error matrix.

Table 1: Example Error Matrix

		Reference Data		Margin Sums
		Presence	Absence	
Model Output	Presence	n_{11}	n_{12}	n_{1*}
	Absence	n_{21}	n_{22}	n_{2*}
Margin Sums		n_{*1}	n_{*2}	**N (total)**

Kappa Analysis

According to Congalton and Green (2009), Kappa is a discrete multivariate technique used to determine if one error matrix is statistically significant from another error matrix. A Kappa analysis is performed as part of an accuracy assessment of land cover classification; however the principles can be applied to almost any mapping project such as a loon habitat analysis.

There are three different calculations that can be performed as part of any Kappa analysis. The first calculation is a KHAT statistic, which measures overall accuracy. The second calculation is a single error matrix Z statistic to determine if an error matrix is statistically better than random. If the absolute value of a Z statistic is greater than 1.96, then the error matrix is significantly better than random. The third calculation produces a Z statistic for a pair-wise comparison of two error matrices to each other to see if they are statistically significantly different from one another. If the absolute value of the Z statistic is greater than 1.96, then the two error matrices are significantly different than each other. This test then allows the analyst to conclude that one matrix (and thereby, technique) is significantly better than another matrix.

CHAPTER III

METHODS

This project's goal was to evaluate habitat occupancy models for the common loon in NH. Brennan (2005) created a habitat model for the common loon for his research and that model is evaluated several ways as part of this project. Data acquired after Brennan (2005) completed his model were used to create two new habitat models. All three models were evaluated to compare the models to find which predicts potential loon habitat the best.

Study Area Description: New Hampshire (NH)

The study area for this project included all freshwater lakes and ponds within the state of NH. Loons arrive to summer breeding grounds in March and return to their ocean wintering grounds in October or November. This study area was chosen because it is the same used in Brennan's (2005) research. Common loons are well-studied in the state of NH by LPC and have long-term field data available for use.

NH is located in the northeastern part of the continental United States bordering the states of Maine, Vermont, Massachusetts, the country of Canada and the Atlantic Ocean. According to the National Oceanic and Atmospheric Administration (NOAA), for 2008 in NH the average temperature was 44.1^{0}F with an average precipitation of 60.65

inches (NOAA, 2010). In general, the temperature ranges in NH from 83^0F to 9^0F. The highest point in NH is the summit of Mt. Washington at 6,288 feet and the lowest at sea level, however, the average elevation for the state is about 1,000 ft above sea level. The majority of NH is covered in temperate deciduous forest. The seasons are very distinct in NH with long cold winters and hot summers. Spring and fall are generally shorter than the other two seasons but fall is particularly impressive in NH with the foliage of the temperate deciduous trees undergoing senesce. The total area of NH is 9,351 square miles with 382 square miles being water.

For NH, there is an online repository of free GIS datalayers called GRANIT (Geographically Referenced Analysis and Information Transfer System). In the GRANIT repository, there is a Hydrography layer for NH that was extracted from the high-resolution National Hydrography Dataset of the USGS. The NH Hydrography layer shows 941 larger lakes and ponds with unique ID numbers. These lakes all have attribute information including the name, area and perimeter of each lake (Complex Systems Research Center, 2010).

In this project, not all 941 lakes from the NH Hydrography layer could be used because most of these lakes lacked essential attribute information such as total surface area and secchi disk depth. Therefore, the total amount of lakes used to create the two new models in this project was only 303. The three largest lakes in NH are Lake Winnipesaukee, which is 44,586 acres, Squam Lake, which is 6,791 acres, and Lake Umbagog, which is 7,850 acres. The three largest lakes were not used for the second new model because the average size of the remaining 300 lakes was about 148 acres. Figure 4 shows the NH state boundary with the GRANIT Hydrography acquired from the GRANIT website and shows all NH water bodies.

Evaluating Brennan's (2005) Habitat Model

The first objective of this project was to re-evaluate the original model created by Brennan (2005) to see if it still accurately predicted loon habitat with data collected from 2003 – 2008. To accomplish the objective, an accuracy assessment was performed on the original model by creating a series of error matrices (Congalton and Green, 2009). The field data collected from LPC from the years 1997 – 2008 was used as the reference data to compare with Brennan's model output. A series of error matrices were created to test each year's field data (or reference data) against the results from Brennan's model to perform an accuracy assessment on Brennan's model.

Brennan used 36 lakes in the high level of occupancy, 102 in the medium level of occupancy and 395 in the low level of occupancy for a total of 533 lakes in his dataset. However, an issue discovered during this part of the project was the incompleteness of the field data acquired from LPC. Not every lake in Brennan's dataset was monitored every year by LPC, so there were gaps in the data from one year to the next. As a result, the total number of lakes monitored by LPC for the high occupancy lakes may have 33 for 2007, but only 30 for 2008 and so forth. This problem is true for the medium level of occupancy lakes and especially for the low level of occupancy lakes.

Brennan's results are split into high, medium and low levels of occupancy. High

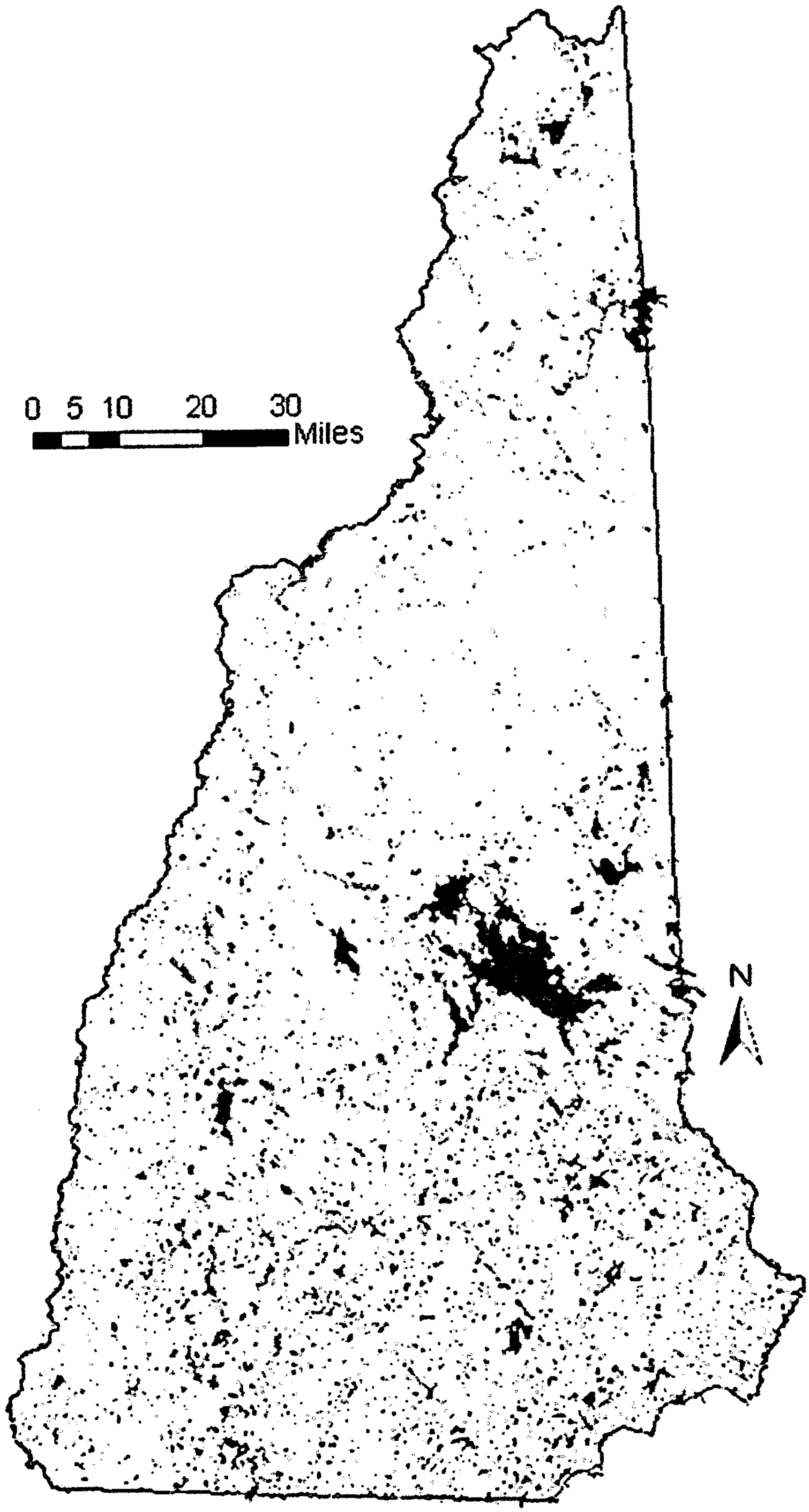

Figure 4: NH boundary with GRANIT Hydrography layer overlaid

and medium levels of occupancy had model output above 0.2 so they were all coded as a "1" for presence. Low level of occupancy had model output below 0.2, coding low level lakes as "0" for absence. The accuracy assessment performed on Brennan's model was done five different ways. For the first assessment, each set of lakes from each level of occupancy had a year-by-year (1997 – 2008) accuracy assessment performed on them using error matrices. For example, an error matrix was created for 1997 for all the high occupancy lakes. The analysis was also done for medium and low occupancy lakes and for each year through 2008. The result was 36 total error matrices for the first assessment. This evaluation was done to see the year to year variation within each level of occupancy to see how well each level predicted loon presence. This process tested to see if Brennan was justified in splitting his results into three occupancy layers (High, Medium & Low) instead of two.

The second assessment combined all 533 lakes in Brennan's dataset regardless of level of occupancy and had the same year-by-year (1997 – 2008) assessment performed on them. This assessment was done to see if the model predicted loon occupation better when all lake levels were combined rather than separated. The high and medium level of occupancy may be better at accurately predicting occupancy, and low level of occupancy may be worse at accurately predicting occupancy but averaging the three allows for evaluating the overall predictability of the model.

The third assessment combined the reference data for the years 1997 – 2002 into a single majority value of either "0" (absent) or "1" (present) for the six-year time span for each of the 533 lakes in the dataset. The description means the field observations for each of the six years were found to be either "present" or "absent" based on which observation was more frequent. This outcome was then used to compare against the model output. The groups of lakes in high, medium and low occupancy habitat each had an error matrix for the combined years of 1997 – 2002. All the levels of occupancy were then combined into the total 533 lakes and a single error matrix was produced for the combined years of 1997 – 2002. The third assessment was done because Brennan also used the majority value from his reference data from 1997 – 2002 to perform his accuracy assessment on his data.

The forth assessment is exactly the same method as the third assessment except the six year time span is now 2003 – 2008. There were four error matrices produced for the same high, medium and low occupancy levels and then all lakes regardless of occupancy levels. The fourth assessment was done to test if Brennan's model still predicted common loon occupation with new field data. This combination of years from 2003 – 2008 was also used for the two new habitat models created for this project using the same methods of taking the majority value for each lake for the six-year time span.

The last assessment replicated Brennan's 100 lake subset which was what was used to perform the original accuracy assessment reported in his dissertation. The subset then had the same year-by-year (1997 – 2008), combined years of 1997 – 2002 and combined years 2003 – 2008 assessments performed on it. Unfortunately not all of these lakes were able to be accounted for because of changes in the dataset provided by LPC, so the assessment was done with lakes as close to the original 100 lakes as possible. This assessment was done to compare to Brennan's original accuracy assessment reported in this research.

All five assessment methods were performed to calculate overall accuracies using an error matrix approach. For the all lakes category, where all 533 lakes are calculated together; overall accuracy can also be calculated using proportions (weights). For the first method of assessment, the three categories of high, medium, and low occupancy were calculated separately for each of the twelve years of data. The second method of assessment took these three categories and combined them into one category and calculated overall accuracy for each of the twelve years of data. However, if you simply average the overall accuracies for high, medium, and low occupancy for a single year, it will not equal the overall accuracy for the combined dataset in the second method of assessment for the same year. The reason for the overall accuracies not being equal is because the high and medium occupancy have a lower weight than the low occupancy. Therefore, any error matrix using all 533 lakes can be calculated using an error matrix or by calculating the individual proportions (weights) of each occupancy level of lakes.

New Habitat Models

In this project, two new habitat suitability models were created using field data collected by LPC from 2003 – 2008. Logistic regression was performed on the data to investigate the habitat features' influence on loon presence. These models were then compared to the previous model created by Brennan through error matrices and a Kappa analysis to determine which model better predicts suitable loon habitat.

The LPC provided the 2009 list of lakes that they monitored for the year. This list stays relatively the same year to year for larger, more established lakes, such a Lake Winnipesaukee, but may change a bit for the smaller ponds that don't always have a loon occupying it. All the data acquired for this project had to be carefully reviewed and compiled to create a final dataset that could be inputted into R statistical software. The review of the data was done manually in Excel and the original 2009 LPC lake list ended up with 303 lakes that were useable for modeling.

New Model #1

After the preparatory work was completed on the data, the final dataset contained 303 lakes available to be used in the analysis. Prior to any statistical analysis; the dataset in Excel was randomly split in two parts. The first part, containing 152 lakes, was used to create the first habitat suitability model; the second part, containing 151 lakes, was set aside to be used to test the first habitat suitability model's ability to make predictions. The eleven proposed variables for the new model were:

1) pH
2) Secchi disk depth (measure of water clarity)
3) Number of islands
4) Surface area (hectares)
5) Lake elevation (meters)
6) Maximum depth (meters)
7) Mean depth (meters)
8) Lake area (acres)
9) Lake perimeter (meters)
10) Distance to loon lake (meters)
11) Distance to no loon lake (meters)

The model avoided being overfit by having enough sample points in both the creation of the model and the independent dataset to test it. With eleven proposed variables for the model, the ideal number of data points would be 110 to create the model and an additional 110 to test it. This model used 152 data points to create it and 151 data points to test it, therefore the sample size for this model is enough to avoid overfitting.

The eleven variables were put into R statistical software and the significant variables were identified using logistic regression. The eleven variables were tested using different variations of these variables, such as taking the square or log of individual variables. The final model was determined by the lowest AIC score among the models.

New Model #2 (3 largest lakes excluded)

The second new habitat suitability model created for this project used the same dataset used to create the first new habitat suitability model except the three largest lakes in the dataset were removed. These lakes were: Lake Winnipesaukee, Squam Lake and Lake Umbagog. The dataset now contained 300 lakes, with 150 lakes used to create the model and 150 lakes to test it. The eleven proposed variables for the first habitat suitability model were the same for the second habitat suitability model and they were analyzed using logistic regression in R statistical software the same way in the second new model as in the first new model. The AIC score was again used to determine which combination of regressors had the best predictive accuracy.

Accuracy Assessment of All Habitat Suitability Models

For the third objective of this project, which was to determine which of the three models predicts loon habitat the best, an error matrix were created for each of the two new models using the forth assessment method described previously. The observational data for the two new models only contained the years 2003 – 2008 because that is when Brennan's (2005) data ended. Therefore, the error matrix from the forth assessment method of Brennan's model of combined years 2003 – 2008 for all lakes was used to compare to the error matrices for the two new models.

An accuracy assessment was performed on the two new models using error matrices with overall, user's and producer's accuracies. The models were tested with the second part of the dataset to create output for individual lakes ranging on a continuum from 0 – 1. The model outputs were converted to a binary value of either 0 for "absence" or 1 for "presence" with a threshold of 0.5. The threshold of 0.5 is often chosen when creating habitat suitability models (Hirzel et al., 2006). The resulting value means that any lake with a model output ranging from 0.0 – 0.49 was coded as "0" or predicted to *not contain* the species of interest (in this case, the common loon) and any lake with a model output ranging in 0.5 – 1 was coded as "1" or predicted to *contain* the species of interest. The field data collected by LPC from 2003 – 2008 were averaged to get a value of either "1" for "presence" or "0" for "absence", which was used as the reference data for the error matrices of the two new models.

The error matrices of the two new models as well as the error matrix of Brennan's original model for the combined years of 2003 – 2008 were all put into the KAPPA program to obtain the KHAT value and Z statistics for all three models. All three error matrices were compared to each other using a pair-wise comparison with a Z statistic as well as the overall accuracies from each error matrix.

CHAPTER IV

RESULTS

The section presents the results of the analysis performed in this project. First, the results of re-evaluating Brennan's model are presented. Many error matrices were needed to adequately represent these results. Second, the results of the new models are presented. Finally, a comparison between all models is shown.

Evaluating Brennan's (2005) Habitat Model

The model output threshold for Brennan's model was 0.2, meaning any lake with more than a 20% chance of seeing a loon was considered prime habitat. A lake with a model output above 0.2 was predicted "present" while a lake with a model output below 0.2 was predicted "absent". Brennan further divided his results by splitting the lakes with model output from 0.2 – 0.49 into "medium level of occupancy" and 0.5 – 1.0 into "high level of occupancy". The lakes with model output of 0.0 – 0.19 were "low level of occupancy". To test the accuracy of his model, Brennan took the majority of observed presence or absence over the 1997 – 2002 year period and created a single value to use as reference data. Brennan conducted an accuracy assessment on his model using a subset of 100 random lakes from his data. The accuracy assessment results reported from Brennan's model for this 100 lake subset was 78% (Brennan, 2005). For this project, Brennan's model was evaluated five different ways including the 100 lake subset presented by Brennan (2005).

High, Medium & Low Levels of Occupancy and All Lakes Combined

The results from the first and second methods of assessment on Brennan's model are presented in Table 2. Table 2 shows a summary of the overall accuracy for each of the three levels of occupancy by year from 1997 – 2008 as well as all the lakes combined for each year. See Appendix A1 and A2 for all error matrices generated from the first and second methods of assessment.

Table 2: Overall accuracy for each level of occupancy and all lakes combined.

Year	High (0.5-1)	Medium (0.2-0.49)	Low (0-0.19)	All lakes
1997	74%	54%	72%	66%
1998	86%	64%	56%	64%
1999	76%	62%	46%	59%
2000	80%	59%	71%	68%
2001	83%	59%	61%	64%
2002	77%	58%	62%	63%
2003	77%	59%	65%	65%
2004	86%	69%	55%	66%
2005	81%	64%	51%	64%
2006	86%	69%	51%	63%
2007	79%	55%	52%	58%
2008	90%	64%	46%	60%

Notice how the overall accuracy for all lakes in Table 2 fluctuates between levels of occupancy and within years monitored. The "all lakes" column presents a weighted average of the three levels of occupancy. This average is not a simple adding of the three occupancy levels together and dividing by three because the different proportions (weights) of the high, medium and low occupancy lakes. For the "all lakes" category, which includes all 533 lakes in dataset, the overall accuracy can be calculated either using the error matrix approach or by an alternative method using the proportions (weights) of the three categories. To clarify, an example calculation for the year 2008 (see Table 2) is shown Table 3:

Table 3: Calculation of Overall Accuracy using Proportions Method for all lakes in 2008.

	Overall Accuracy	Number of Lakes	Calculation of Percent of Overall Accuracy
High Level of Occupancy	90%	30	90%*30 lakes/103 lakes = 26.2136%
Medium Level of Occupancy	64%	73	64%*73 lakes/103 lakes = 45.3592%
Low Level of Occupancy	46%	83	46%*83 lakes/186 lakes = 20.5369%
Calculation for combined High & Medium Overall Accuracies			26.2136% + 45.3592% = 71.5728%*103lakes/186lakes = *39.6344%*
Adding all percentages for total Overall Accuracies			39.6344% + 20.5269% = 60.1613% ~ **60%**

The method for calculating the overall accuracy using the weights of each category of lakes was used in this project, but through an error matrix approach as in Table 2. The example using the calculated proportion method is presented in Table 3 to show how the total lakes category for each method of assessment was not equal to the simple average of the high, medium, and low occupancy levels.

<u>Combined Years of 1997 – 2002</u>

For the third method of assessment of Brennan's model, historical data obtained from LPC were used as reference values for years 1997 – 2002. Over this six-year time span, the reference values were combined and used as a single majority value to compare to the model output for each lake. Table 4 shows a summary of calculated overall accuracies for each level of occupancy (high, medium and low) and all lakes combined for 1997 – 2002. See Appendix A3 for all error matrices generated from the third method of assessment.

Table 4: Overall accuracy for combined years 1997-2002 for all levels of occupancy and all lakes combined.

Level of Accuracy		Overall Accuracy for 1997 – 2002
High	(0.5 – 1)	76%
Medium	(0.2 – 0.49)	56%
Low	(0 – 0.19)	74%
All lakes		68%

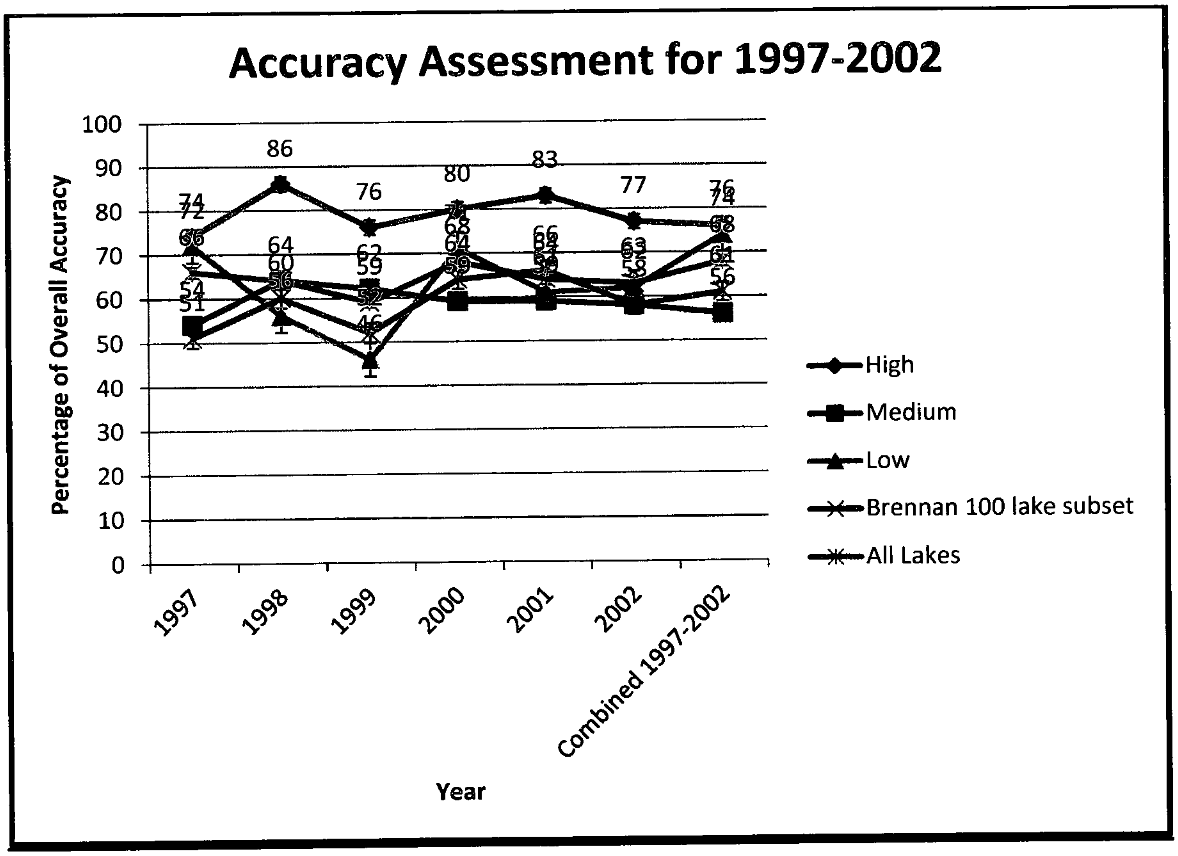

Figure 5: Accuracy Assessment for 1997 - 2002 Dataset

Figure 5 graphically presents the results of the third method of accuracy assessment of the original model applied for years 1997-2002.

<u>Combined Years of 2003 – 2008</u>

The data for the original model created by Brennan (2005) ended in 2002, therefore an accuracy assessment was performed on the original model using new reference data from 2003 – 2008 testing to see if the original model still has a high enough accuracy usable for management decisions. Over this six-year time span, the reference values were combined and used as a single majority value to compare to the model output for each lake. Table 5 shows a summary of the calculated overall accuracy for each level of occupancy (high, medium and low) and all lakes combined for 2003 – 2008. See Appendix A4 for all error matrices generated from the fourth method of assessment.

Table 5: Overall Accuracy for combined years 2003-2008 for all levels of occupancy and all lakes combined.

Level of Accuracy		Overall Accuracy for 2003 – 2008
High	(0.5 – 1)	79%
Medium	(0.2 – 0.49)	53%
Low	(0 – 1.0)	73%
All lakes		67%

Figure 6 graphically presents the results of the fourth method of accuracy assessment of the original model applied for years 2003-2008.

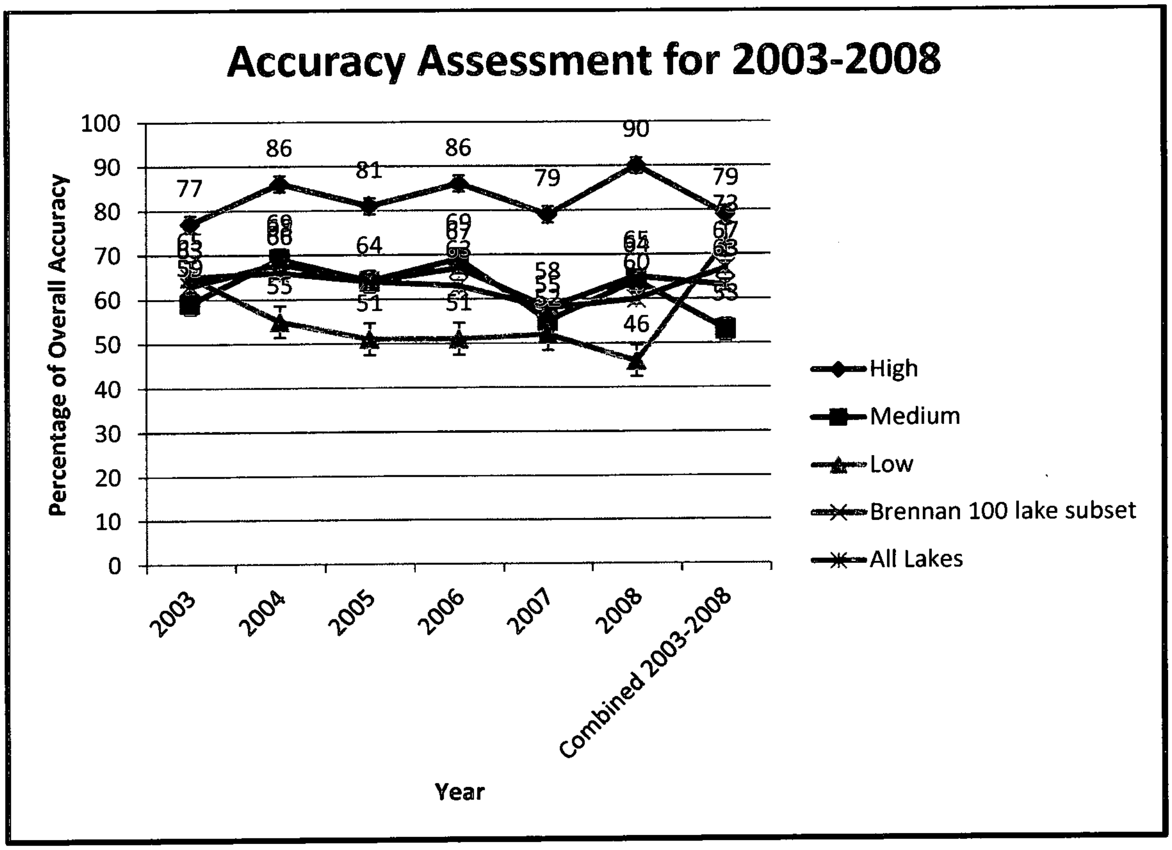

Figure 6: Accuracy Assessment for 2003 - 2008 Dataset

Brennan's 100 Lake Subset from Original Model

Brennan (2005) reported his overall accuracy in his dissertation as a 100 lake subset of his total dataset for combined years 1997 – 2002 by taking the majority value for the 100 lakes. The data for this project that were recently obtained from LPC were used with the same 100 lake subset to detect changes in the overall accuracies. Table 6 shows a summary of the overall accuracy for the subset of 100 lakes for the combined years of 1997 – 2008 with the recently acquired data from LPC. See Appendix A5 for all error matrices generated from the fifth method of assessment. Please note that the original dataset used in creating Brennan's (2005) reported overall accuracy is no longer available, also the 100 lake subset used in this analysis was as close to the original 100 lake subset as possible, but they are not exactly the same. This analysis of the 100 lake subset with recently acquired data from LPC were added into this project for comparison to the reported 78% overall accuracy in Brennan's (2005) dissertation. Notice combined years of 1997 – 2002 show an overall accuracy of 61% whereas in Brennan's (2005) dissertation, it was reported to be 78%.

Table 6: Overall Accuracy for original (Brennan, 2005) model 100 lake subset.

Year	**Overall Accuracy**
1997	51%
1998	60%
1999	52%
2000	64%
2001	66%
2002	58%
2003	63%
2004	68%
2005	64%
2006	67%
2007	58%
2008	65%
1997 – 2002	**61%**
2003 – 2008	63%

New Habitat Models

There was a significant amount of data preparation before any model could be generated. The data collected for this project were spread over multiple M.S. Access® databases and M.S. Excel® spreadsheets. These databases and spreadsheets were manually cross-referenced to determine which lakes matched between multiple datasets. Cross-referencing datasets was difficult because not all datasets used the same identifier for individual lakes. The data for each lake were compiled into a final dataset that was formatted for R, which is the statistics package used for this project.

New Model #1

For the first new habitat suitability model, of the original eleven parameters entered into logistic regression, only four were found to be significant at the 0.05 level of significance. These were: distance to the nearest lake with a loon, sechhi disk depth (water clarity), perimeter of the lake & perimeter of the lake squared. The model was chosen based on the significance of the factors and the Akaike Information Criterion (AIC) score (between different amounts of regressors), which is an estimator of predictive accuracy for a model. The first model was:

$$p(\text{loon presence}) = .2320349 + .05770603(\text{SECHHI}) - .00003767921(\text{DISTTOLOON}) + .00001862571(\text{PERIMETER}) - .00000000006771735(\text{PERIMETER}^2) + \text{€}$$

This model was then assessed for accuracy using the second part of the dataset that had been set aside for validation. Table 7 presents the error matrix including the overall accuracy of the New Model #1 and Table 8 shows the producer's and user's accuracies of New Model #1. The resulting error matrix shows an overall accuracy of 69%.

Table 7: Error matrix for overall average accuracy for New Model #1 for combined years 2003 – 2008

	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	39	23	62
Observed Loon Absence (0)	25	66	91
Totals	64	89	153
		Overall Accuracy	**69%**

Table 8: Producer's & user's accuracies for New Model #1 for combined years 2003 – 2008

Producer's Accuracy			User's Accuracy		
Loon Presence	39/64	61%	Loon Presence	39/62	63%
Loon Absence	66/89	74%	Loon Absence	66/91	73%

Figure 7 is an outline of the state of NH with two of four new GIS layers created for this project. The two layers on Figure 7 show the model output of lakes using New Model #1. These lakes had the model applied to them and their model output values resulted. The model output values were split at the 0.5 threshold. The lakes with model output above 0.5 are in blue and labeled "High Suitability Habitat Model 1" and the lakes with model output below 0.5 are in pink and labeled "Low Suitability Habitat Model 1".

New Model #2 (3 Largest Lakes Excluded)

In Brennan's model, the three largest lakes (Lake Winnipesaukee, Squam Lake and Lake Umbagog) were excluded because they were considered outliers because of their size. For the second new model created in this project, these three lakes were also excluded from the dataset of 303 lakes. The significant parameters were again determined by logistic regression with the final model determined from the AIC score. The second new model that resulted from this process is as follows:

p(loon presence) = .1378030730 + 0.0000323335(ACRES) + 0.0523998824(NUMBER of ISLANDS) – 0.0013491729(NUMBER of ISLANDS^2) + 0.0657163594(SECHHI) + €

New Model #2 was then assessed for accuracy using the same method used to test New Model #1. Table 9 presents the error matrix including the overall accuracy of New

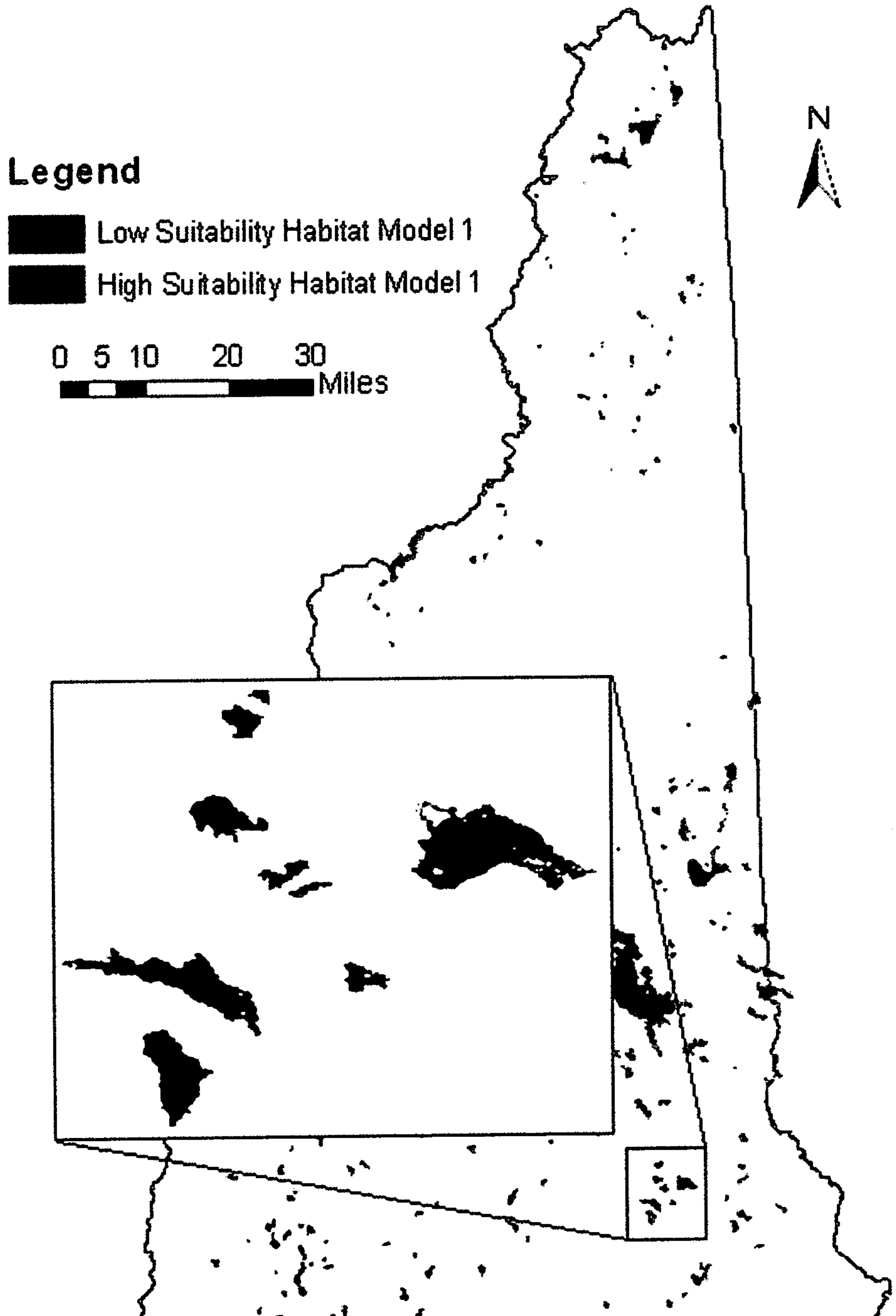

Figure 7: High & Low Suitability lakes from New Model #1

Model #2 and Table 10 shows the producer's and user's accuracies of New Model #2. The resulting error matrix shows an overall accuracy of 74%.

Table 9: Error matrix for overall accuracy for New Model #2 for combined years 2003 – 2008

	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	39	20	59
Observed Loon Absence (0)	19	72	91
Totals	58	92	150
		Overall Accuracy	**74%**

Table 10: Producer's & user's accuracies for New Model #2 for combined years 2003 – 2008

Producer's Accuracy			User's Accuracy		
Loon Presence	39/58	67%	Loon Presence	39/59	66%
Loon Absence	72/92	78%	Loon Absence	72/91	79%

Figure 8 is an outline of the state of NH with two of four new GIS layers created for this project. The two layers show the model output of lakes using New Model #2. These lakes had the model applied to them and model output values resulted. The model output values were split at the 0.5 threshold. The lakes with model output above 0.5 are in orange and labeled "High Suitability Habitat Model 2" and the lakes with model output below 0.5 are in purple and labeled "Low Suitability Habitat Model 2".

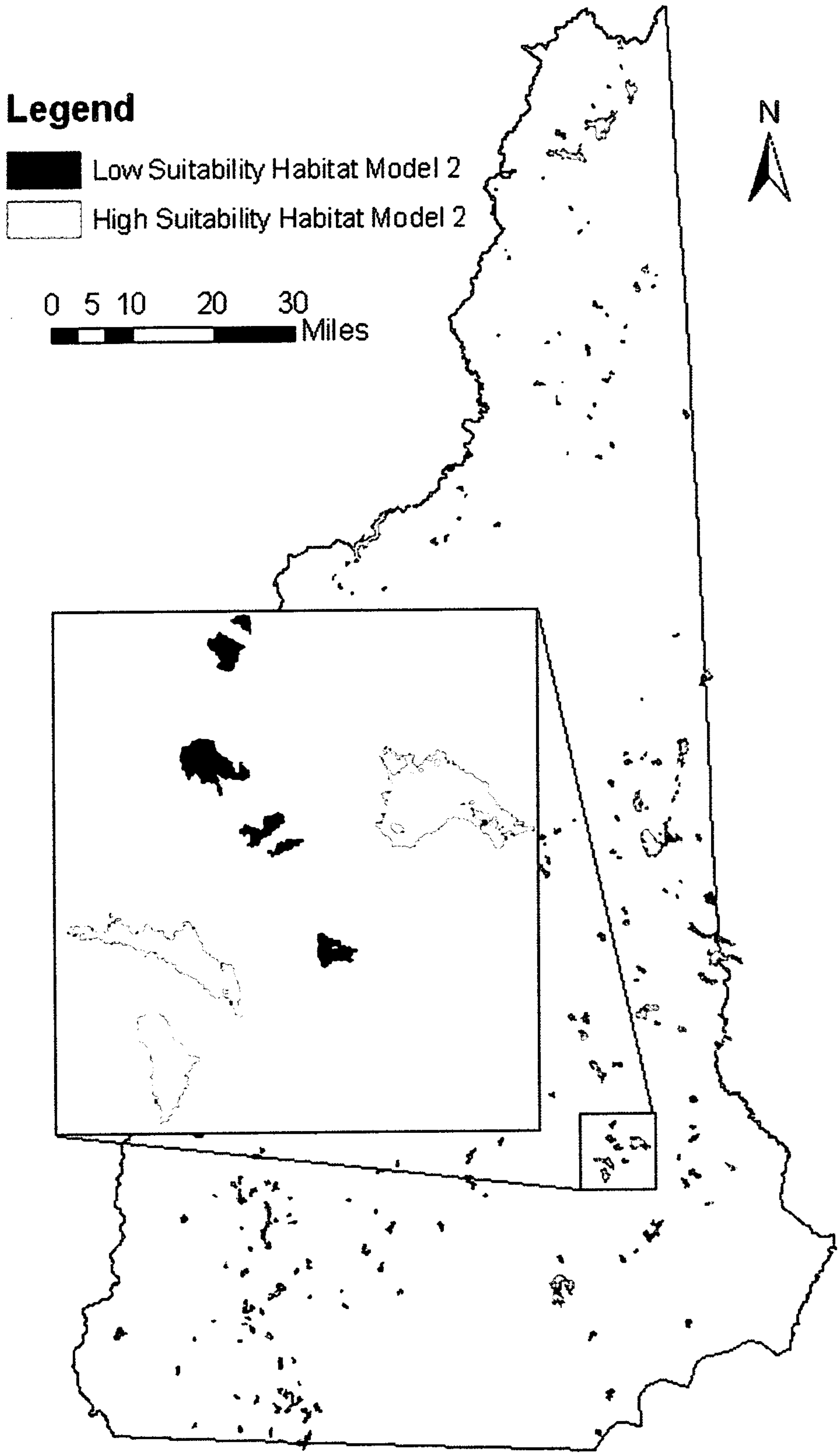

Figure 8: High & low suitability lakes from Model #2

Kappa Analysis

The results from the KAPPA analysis performed on the error matrices of New Model #1 and New Model #2 (see Table 7 and Table 9) as well as Brennan's (2005) model are presented in Table 11. The error matrix used for Brennan's model combined all lakes regardless of occupancy level. These three error matrices combined reference values for years 2003 – 2008 to create a single majority value for each lake. These error matrices are from the fourth method of assessment performed in this project.

Table 11: KHAT and Z statistic Results

Model	KHAT	Z Statistic
Original Model combined years 2003 – 2008 with all lakes	0.3299430	5.6162954
New Model #1	0.3524952	4.5950379
New Model #2	0.4535774	6.0855152

Notice the three KHAT values are between 32% and 45%, indicating that there is some agreement between the model output and the reference data (Landis & Koch, 1977). The Z statistic for all three models is greater than 1.96 for the 95% confidence interval, which means all three models are better than a random matrix.

Table 12 presents a pairwise comparison of Brennan's model, New Model #1 and New Model #2. A Z statistic for the pairwise comparison lower than 1.96 means that the error matrices are not significantly different at the 95% confidence level. A comparison of the three matrices in Table 12 show that none are significantly different than the others.

Table 12: Pairwise comparisons between Brennan's (2005) original model, New Model #1 and New Model #2

Models	Z Statistic
Original Model combined years 2003 – 2008 with all lakes vs. New Model #1	0.2334037
Original Model combined years 2003 – 2008 with all lakes vs. New Model #2	1.3027462
New Model #1 vs. New Model #2	0.9450633

CHAPTER V

DISCUSSION

All three models in this project had some similar parameters. Each parameter has a biological reason for being significant which is explained in the discussion for all three models. For this project, Brennan's model had a new accuracy assessment performed on it using five different methods of assessment. New Model #1 and New Model #2 both had an error matrix and kappa analysis and each are discussed. Conclusions are drawn from a combination of field observations and the statistical assessments performed on each model.

Evaluating Brennan's (2005) Habitat Model

The four significant parameters in Brennan's (2005) model were perimeter, depth, distance to nearest loon nest, and elevation. All of these parameters make sense biologically when observing loon behavior in the wild. Loons tend to prefer, deep clear lakes not occupied by other loons, with plenty of places to nest that are in the higher, cooler air of the mountains. Some of these parameters in Brennan's (2005) model are found in the two new models, which indicate how important those parameters are in predicting loon habitat. The parameters that were the same in the Brennan's (2005) model and New Model #1 are: distance to nearest loon nest and perimeter of the lake. None of the parameters from Brennan's (2005) model were significant in the New Model #2.

Accuracy Assessment of Brennan's (2005) Model

The first method of assessment on Brennan's (2005) model was to take each level of occupancy (high, medium & low) and perform a year-by-year error matrix for years 1997 – 2008 (see Table 2). This assessment resulted in 36 error matrices, all of which are found in Appendix A1. This method of assessment allowed us to see the yearly overall accuracies of each level of occupancy for the entire twelve-year span. There were large fluctuations in overall accuracies between levels of occupancy and between years within each level of occupancy. These fluctuations are explained by the difficulties in collecting field data, improvements made in sampling schemes throughout the years, natural events that either constitutes a major die off in the species or a particularly good year in which the species flourishes.

Brennan chose his habitat model threshold to be 0.2, which means any lake with model output above 0.2 was predicted to have loon presence and any lake with model output below 0.2 was predicted to have loon absence. The high level of occupancy had model output from 0.5 – 1, which means all lakes in this category were predicted to have loon presence. For the high level of occupancy the overall accuracy went from a high of 90% to a low of 74%. The high level of occupancy was very accurate in predicting potential loons' habitat. However, the lakes in this category are all well established, large lakes. The medium level of occupancy had model output from 0.2 – 0.49, which means all lakes in this category were also predicted to have loon presence. For the medium level of occupancy, the overall accuracy had a high of 69% to a low of 54%. In ecological modeling, the ranges for the high and medium level of occupancy are considered normal. These ranges are normal because ecological modeling of actual habitat in the wild contains far too many variables to control versus a lab setting which is in a more contained and controlled, closed space. There is no possibility to control every variable encountered in a natural setting and therefore a large range in accuracy values is accepted. The low level of occupancy had model output from 0 – 0.19, which means all lakes in this category were predicted to have loon absence. In the low level of occupancy, the overall accuracy went from a high of 72% to a low of 46%. The range of overall accuracy in the low level of occupancy is much larger than in the high and medium levels of occupancy. However, overall accuracies in the low level of occupancy are too poor and not adequate even for ecological modeling.

The second method of assessment for Brennan's (2005) model combined all 533 lakes from Brennan's (2005) dataset regardless of level of occupancy and performed the same year-by-year error matrix for years 1997 – 2008 (see Table 2) as in the first method of assessment. This second method of assessment resulted in 12 error matrices, all of which are found in Appendix A2. This second assessment shows the yearly overall accuracies for the entire dataset over the twelve-year span. The overall accuracies ranged from a high of 68% to a low of 58%. The first method of assessment shows the high level of occupancy is very accurate in predicting potential habitat and shows the medium level of occupancy predicting potential habitat to be fairly average. The first assessment also shows the low level of occupancy predicting potential habitat very poorly. However, by combining all three levels of occupancy, the model then predicts potential habitat within the expected ranges for ecological modeling.

For the third method of assessment for Brennan's (2005) model, the reference values for years 1997 – 2002 were combined into one majority value of either "0" or "1" for each lake (see Table 4). An error matrix was generated for each of the high, medium and low levels of occupancy as well as the combined 533 lakes. This third method of assessment resulted in 4 error matrices, all of which are found in Appendix A3. Figure 5 is a line graph showing the fluctuations over this six-year time span with all levels of occupancy, all lakes combined, and Brennan's original 100 lake subset represented. For all 533 lakes combined in the dataset, the overall accuracy was 68% for combined years 1997 – 2002. Sixty-eight percent is a new average estimate of accuracy for Brennan's model over this six year time-span.

For the fourth method of assessment for Brennan's (2005) model, the reference values for years 2003 – 2008 were combined into one majority value of either "0" or "1" for each lake (see Table 5). An error matrix was generated for each of the high, medium and low levels of occupancy as well as the combined 533 lakes. This fourth method of assessment resulted in 4 error matrices, all of which are found in Appendix A4. Figure 6 is a line graph showing the fluctuations over this six-year time span with all levels of occupancy, all lakes combined, and Brennan's original 100 lake subset represented. For all 533 lakes combined in the dataset, the overall accuracy was 67% for combined years 2003 – 2008.

The average accuracy value for Brennan's (2005) over the years 2003 – 2008 is 67%. This range of accuracy from 68% to 67% shows very clearly that the overall accuracy over a twelve year time-span has not significantly varied. A 68% or 67% overall accuracy is slightly below average, but when modeling wildlife habitat, it is acceptable (Scott et al., 1991).

In Brennan's (2005) dissertation, the overall accuracy for combined years of 1997 – 2002 was reported as 78%. This 78% accuracy used a random subset of 100 lakes from Brennan's total dataset of 533 lakes. For the fifth method of assessment on Brennan's (2005) model, approximately the same lakes from Brennan's 100 lake subset were used. The overall accuracy of the 100 lake subset from the combined years of 1997 – 2002 using majority values for reference values for each lake was 61%. The differences in the percentage reported in Brennan's (2005) dissertation and from the fifth method of assessment can be explained by the differences in the two 100 lake subsets. Trying to re-create the same 100 lake subset was difficult because the original list of 100 lakes had some lakes that were not contained in the dataset that was obtained from LPC for this project. However, the drop in overall accuracy does not mean the original model was not valid, but the subset of lakes may not be the best way to report overall accuracy. By extending the assessment with the new data from 2003 – 2008, the 100 lakes subset has an average accuracy of 63% for this combined six year time-span, which is an improvement. Brennan's (2005) model predictability stays relatively the same over time and therefore is a good model for predicting potential loon habitat.

New Habitat Models

The two new habitat suitability models created for this project had different significant parameters and overall accuracies from both each other and the original model created by Brennan (2005). New Model #1 uses all 303 lakes available to this project after the data were combined from various sources. New Model #2 is more like Brennan's (2005) model because it does not include the three largest lakes in NH. The accuracies for both new models are presented from combined years 2003 – 2008 using a majority value for reference data for each lake. The only error matrix used from Brennan's (2005) model is from the fourth method of assessment which combined years 2003 – 2008 using all lakes. This error matrix from the fourth method of assessment is used to compare to the new models because it uses the newly acquired data from 2003 – 2008.

New Model #1

There were four parameters that were found to be significant in New Model #1. These parameters are secchi disk depth (water clarity), distance to nearest lake with a loon on it, perimeter of the lake and perimeter of lake^2. Perimeter of lake – perimeter of lake^2 is considered one measurement variable because it uses the same value. New Model #1 contained all 303 lakes available in the dataset, including the three largest lakes in NH. All four parameters that were found to be significant are easy to explain by observing a loon's behavior in the wild.

One of the new parameters in this model is secchi disk depth. This parameter was also used in several of Kuhn-Hine's (2009) models. The data for secchi disk came from NH Department of Environmental Services (NHDES). The collection for secchi disk depth was performed by a network of trained volunteers through the Volunteer Lake Assessment Program (VLAP) who followed a protocol for field data collection (NH DES

B, 2008). At least once per summer each lake monitored had a DES biologist assist the volunteer collecting data to assure quality control.

By observing loon behavior in the wild, sechhi disk depth makes sense as a significant parameter because loons hunt using their vision with a behavior called “peering”. If the sechhi disk is depth for a lake is very shallow, then loons will not be able to see prey, making this variable positively correlated. The higher the water clarity of a lake equals the higher the lake will potentially have loons occupying it.

The next parameter, the distance to the nearest lake with a loon on it, is significant because loons are territorial. Rival loons will fight for territory or mates and sometimes kill another loon’s chicks as well as each other. Loons signal their territory to other loons with vocal calls. Loons on nearby lakes would hear another loon in their territory and avoid another loon, therefore making this variable negatively correlated.

The last two model parameters are: perimeter of the lake and perimeter of lake^2. These parameters are explained because loons need shoreline on which to nest. Loons tend to prefer lakes with islands on it to make their nests safer from terrestrial predators, but not all lakes in NH have islands so a substantial amount of shoreline is crucial for nesting habitat. The parameters, perimeter of a lake and perimeter of a lake^2, were correlated (correlation coefficient: 0.91416423). Even though these two parameters were correlated, it was decided to include them in New Model #1. When plotted, the two parameters form a parabola. The parabola limits the measurement variable perimeter which reduced its importance for loons as the perimeter of a lake grows larger. The limitation allows the model to have an optimum quality of a lake, meaning there is a high point of suitability that a lake can reach at a certain size. If the perimeter was left as linear, it would mean that more perimeter is always better, which isn't the case when observing loon behavior in the wild. The quadratic shape of the two parameters combined may be explained by the three outlier lakes that are significantly larger than all other lakes in the dataset. Because of the three outlier lakes, a second model was created without these lakes to see if the significant parameters change.

Accuracy Assessment of New Model #1

The error matrix of New Model #1 (see Table 7) showed an overall accuracy from the combined years of 2003 – 2008 to be 69%. The overall accuracy for Brennan's (2005) model for combined years of 2003 – 2008 from the accuracy assessment in this project was 67%. The overall accuracy from New Model #1 is slightly better than Brennan's model; however they are not significantly different from each other. The differences in overall accuracy can be explained in a variety of ways. Field monitoring practices change over time and certain lakes get prioritized differently based on which organization is monitoring them and what parameters need to be measured at the time. Not all lakes used to create Brennan's (2005) model are still being monitored by LPC and thus deleted when calculating the accuracy assessment, thereby reducing the overall accuracy of the original model. However, since both models are not significantly different from each other, either model is acceptable to use when predicting potential habitat.

New Model #2 (3 largest lakes excluded)

Utilizing the same dataset to create and test New Model #1, the second model was created but with Lake Winnipesaukee, Squam Lake and Lake Umbagog taken out of the dataset. The results after removing these three lakes were quite interesting because the significant parameters were different.

The first parameter was surface area of the lake. This parameter makes sense for loon habitat because loons require a minimum size for a lake. Loons cannot take-off from land because of the placement of their feet on their body. They are also heavy birds and need at least a quarter of a mile to take-off from the surface of a lake (LPC, 2010). A large lake will give a loon plenty of room to take-off and land safely, which makes this parameter positively correlated.

The second and third parameters were number of islands, and number of islands^2. If available on a lake, loons prefer to nest on islands for their protection from terrestrial predators; however, if no island is available, loons can successfully nest on shore. The parameters, number of islands and number of islands^2, were correlated (correlation coefficient: 0. 90231136). Even though these two parameters were correlated, it was decided to include them in New Model #2 in order to create a quadratic model variable (number of islands^2). When plotted, the two parameters form a parabola. The parabola limits the measurement variable number of islands which reduces its importance for loons as the number of islands on a lake increases. This limitation allows the model to have an optimum quality of a lake, meaning there is a high point of suitability that a lake can reach at a certain number of islands. Loons are visual animals, and when they are flying overhead to find a suitable lake on which to dwell, spotting a lone island on a medium to smaller lake may be preferable than a larger lake with many islands.

The final variable for this second new model is sechhi disk depth. This parameter was also a significant variable in New Model #1, which means it's a very significant variable for loons when choosing habitat.

Accuracy Assessment of New Model #2

Through this study, New Model #2 is 74% overall accuracy and Brennan's model was 67% overall accuracy and both are significantly different from each other.

The error matrix of New Model #2 (see Table 9) shows an overall accuracy from combined years of 2003 – 2008 to be 74%. The overall accuracy for the New Model #1 for combined years of 2002 – 2008 from the accuracy assessment in this project was 69%. The overall accuracy of New Model #2 is better than New Model #1, but they are not significantly different than each other. Both models can be used to predict potential loon habitat. The producer's and user's accuracies for New Model #2 were also higher than the New Model #1's producer's and user's accuracies.

Kappa Analysis for all Three Models

The Kappa analysis in this project was performed on the original model created by Brennan (2005), and the two new models created for this project. The results of the three KHAT values were all between 32% to 45%, indicating that there is some agreement between the model output and the reference data. Since the KHAT is another measure of overall accuracy it does show that the models could be improved upon because of how low the KHAT scores were for all three models. If additional data are collected for each lake in the NH Hydrography dataset and the dataset compiled for this project can be expanded, then these KHAT values will increase (Congalton, 1991).

The Z statistics for each model were all above 1.96 indicating that each model was better than random. All of the Z statistics comparing the three models together had values below 1.96 indicating that none of the models were significantly different from one another. Since none of the three models are significantly different than each other, it means that both creators of the models did an equal job at modeling the data. All models can be used to predict potential loon habitat and perform well enough to be used in making management decisions.

Conclusions

The first conclusion of this project is there are several parameters that can be used to predict a loon's presence or absence on a lake. Combining all parameters from all three models would be: depth of the lake, elevation of the lake above sea level, perimeter of the lake, the distance to the nearest lake with a loon on it, sechhi disk depth (or water clarity), surface area of lake (or total acres), and the number of islands on a lake. Using all of these parameters when making field observations of a lake would give the best estimate for the suitability of that lake for loon occupation. However, for the results of this project to be used for management decisions concerning common loons by organizations such as the LPC or BRI, there must exist a statistically valid model that can be used over a large geographic area to give a general sense of the suitability of a lake. Having three different models to choose from will allow LPC to more easily identify potential habitat for a loon.

If model variables are unavailable for one model, then another model can be used which has all model variables measured.

From the fourth method of assessment performed on Brennan's (2005) model, the overall accuracy was 67%. This 67% overall accuracy was very similar to the overall accuracy from two new models created for this project, therefore making Brennan's model still statistically sound and still viable for use in management decisions. New Model #1, at 69%, had a small increase in overall accuracy from Brennan's (2005) model, but the two models are not significantly different. New Model #2 had an increase in overall accuracy at 74% because the three outlier lakes of Lake Winnipesaukee, Squam Lake and Lake Umbagog were removed from the dataset. At 74% overall accuracy, New Model #2 has the highest overall accuracy in this project and can be used for predicting potential loon habitat. However, none of the models were significantly different from one another and therefore all three models predict potential loon habitat equally well.

Future Work

A large component of setting up this project was to organize the data from various sources in order to create a dataset that could be used for the habitat modeling. A big issue encountered in this process was the inconsistency of datasets acquired from different sources. Some lakes were missing from one dataset that appeared in another but that were supposed to be from the same source. Since LPC is in charge of collecting field data for common loons in NH, it is a recommendation that the current dataset containing all field data be checked for consistency with historical datasets. In this way, lakes that are not currently being monitored will not be lost. Another recommendation is a structural change in the LPC long-term dataset to organize records by individual lake with attributes attached rather than in one long datasheet with all attributes listed out by year.

A recommendation to NH Fish & Game is to help LPC in providing more education to the public about lead. An ideal time to educate the public about lead and its harmful effects on the environment would be when a person purchases a fishing license. Educating anglers about the dangers of lead to an aquatic ecosystem and suggesting viable alternatives allows for a more substantial spread of information to the public. This information can help anglers make better decisions when buying fishing supplies and help lower the influx of lead into water bodies.

Finally, future activity should include monitoring more lakes in NH to add to the dataset that was compiled for this project. Adding more lakes would entail substantial field work to acquire every measurement variable that requires testing to be used with any one of the three models.

All three models can be used by organizations other than LPC that monitor loon activity. Vermont, Maine, and New York all have similar climates to NH and all contain loons for the summer breeding season. Each state has their own organizations that monitor loon activity. Field data from these states could also be added into the compiled dataset from this project to create a larger dataset to use with these models.

GIS layers for loon nests in NH were created by different organizations. These GIS layers have potential for creating new habitat suitability models that focus specifically if the habitat is suitable for nesting. Loons will try to nest in hidden places if they can, so creating a statistically valid model that predicts future loon nest sites would be a valuable for loon habitat management.

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APPENDIX

APPENDIX A

SUMMARY TABLES AND ERROR MATRICES PERFORMED ON ORIGINAL MODEL CREATED BY BRENNAN (2005) FOR THIS PROJECT

A1: First method of assessment

Summary table and error matrices for high occupancy

High Occupancy		Producers Accuracy		Users Accuracy	
Year	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
2008	90	90	0	100	0
2007	79	79	0	100	0
2006	86	86	0	100	0
2005	81	81	0	100	0
2004	86	86	0	100	0
2003	77	77	0	100	0
2002	77	77	0	100	0
2001	83	83	0	100	0
2000	80	80	0	100	0
1999	76	76	0	100	0
1998	86	86	0	100	0
1997	74	74	0	100	0

Overall, producer's & user's accuracies for high occupancy 2008

2008	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	27	0	27
Observed Loon Absence (0)	3	0	3
Totals	30	0	30
		Overall Accuracy	90%

Producer's Accuracy			User's Accuracy		
Loon Presence	27/30	90%	Loon Presence	27/27	100%
Loon Absence	0/0	0%	Loon Absence	0/3	0%

Overall, producer's & user's accuracies for high occupancy 2007

2007	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	26	0	26
Observed Loon Absence (0)	7	0	7
Totals	33	0	33
		Overall Accuracy	79%

Producer's Accuracy			User's Accuracy		
Loon Presence	26/33	79%	Loon Presence	26/26	100%
Loon Absence	0/0	0%	Loon Absence	0/7	0%

Overall, producer's & user's accuracies for high occupancy 2006

2006	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	4	0	4
Totals	28	0	28
		Overall Accuracy	86%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/28	86%	Loon Presence	24/24	100%
Loon Absence	0/0	0%	Loon Absence	0/4	0%

Overall, producer's & user's accuracies for high occupancy 2005

2005	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	25	0	25
Observed Loon Absence (0)	1	0	1
Totals	26	0	26
		Overall Accuracy	81%

Producer's Accuracy			User's Accuracy		
Loon Presence	25/26	96%	Loon Presence	25/25	100%
Loon Absence	0/0	0%	Loon Absence	0/1	0%

Overall, producer's & user's accuracies for high occupancy 2004

2004	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	4	0	4
Totals	28	0	28
		Overall Accuracy	86%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/28	86%	Loon Presence	24/24	100%
Loon Absence	0/0	0%	Loon Absence	0/4	0%

Overall, producer's & user's accuracies for high occupancy 2003

2003	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	23	0	23
Observed Loon Absence (0)	7	0	7
Totals	30	0	30
		Overall Accuracy	77%

Producer's Accuracy			User's Accuracy		
Loon Presence	23/30	77%	Loon Presence	23/23	100%
Loon Absence	0/0	0%	Loon Absence	0/7	0%

Overall, producer's & user's accuracies for high occupancy 2002

2002	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	7	0	7
Totals	31	0	31
		Overall Accuracy	77%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/31	77%	Loon Presence	24/24	100%
Loon Absence	0/0	0%	Loon Absence	0/7	0%

Overall, producer's & user's accuracies for high occupancy 2001

2001	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	5	0	5
Totals	29	0	29
		Overall Accuracy	83%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/29	83%	Loon Presence	24/24	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Overall, producer's & user's accuracies for high occupancy 2000

2000	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	6	0	6
Totals	30	0	30
		Overall Accuracy	80%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/30	80%	Loon Presence	24/24	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Overall, producer's & user's accuracies for high occupancy 1999

1999	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	22	0	22
Observed Loon Absence (0)	7	0	7
Totals	29	0	29
		Overall Accuracy	76%

Producer's Accuracy			User's Accuracy		
Loon Presence	22/29	76%	Loon Presence	22/22	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Overall, producer's & user's accuracies for high occupancy 1998

1998	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	4	0	4
Totals	28	0	28
		Overall Accuracy	86%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/28	86%	Loon Presence	24/24	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Overall, producer's & user's accuracies for high occupancy 1997

1997	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	23	0	23
Observed Loon Absence (0)	8	0	8
Totals	31	0	31
		Overall Accuracy	74%

Producer's Accuracy			User's Accuracy		
Loon Presence	23/31	74%	Loon Presence	23/23	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Summary table and error matrices for medium occupancy

Medium Occupancy		Producers Accuracy		Users Accuracy	
Year	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
2008	64	64	0	100	0
2007	55	55	0	100	0
2006	69	69	0	100	0
2005	64	64	0	100	0
2004	69	69	0	100	0
2003	59	59	0	100	0
2002	58	58	0	100	0
2001	59	59	0	100	0
2000	59	59	0	100	0
1999	62	62	0	100	0
1998	64	64	0	100	0
1997	54	54	0	100	0

Overall, producer's & user's accuracies for medium occupancy 2008

2008	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	47	0	47
Observed Loon Absence (0)	26	0	26
Totals	73	0	73
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	47/73	64%	Loon Presence	47/47	100%
Loon Absence	0/0	0%	Loon Absence	0/26	0%

Overall, producer's & user's accuracies for medium occupancy 2007

2007	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	45	0	45
Observed Loon Absence (0)	37	0	37
Totals	82	0	82
		Overall Accuracy	55%

Producer's Accuracy			User's Accuracy		
Loon Presence	45/82	55%	Loon Presence	45/45	100%
Loon Absence	0/0	0%	Loon Absence	0/44	0%

Overall, producer's & user's accuracies for medium occupancy 2006

2006	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	48	0	48
Observed Loon Absence (0)	22	0	22
Totals	70	0	70
		Overall Accuracy	69%

Producer's Accuracy			User's Accuracy		
Loon Presence	48/70	69%	Loon Presence	48/48	100%
Loon Absence	0/0	0%	Loon Absence	0/22	0%

Overall, producer's & user's accuracies for medium occupancy 2005

2005	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	43	0	43
Observed Loon Absence (0)	24	0	24
Totals	67	0	67
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	43/67	64%	Loon Presence	43/43	100%
Loon Absence	0/0	0%	Loon Absence	0/24	0%

Overall, producer's & user's accuracies for medium occupancy 2004

2004	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	46	0	46
Observed Loon Absence (0)	21	0	21
Totals	67	0	67
		Overall Accuracy	69%

Producer's Accuracy			User's Accuracy		
Loon Presence	46/67	69%	Loon Presence	46/46	100%
Loon Absence	0/0	0%	Loon Absence	0/21	0%

Overall, producer's & user's accuracies for medium occupancy 2003

2003	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	44	0	44
Observed Loon Absence (0)	30	0	30
Totals	74	0	74
		Overall Accuracy	59%

Producer's Accuracy			User's Accuracy		
Loon Presence	44/74	59%	Loon Presence	44/44	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Overall, producer's & user's accuracies for medium occupancy 2002

2002	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	45	0	45
Observed Loon Absence (0)	32	0	32
Totals	77	0	77
		Overall Accuracy	58%

Producer's Accuracy			User's Accuracy		
Loon Presence	45/77	58%	Loon Presence	45/45	100%
Loon Absence	0/0	0%	Loon Absence	0/32	0%

Overall, producer's & user's accuracies for medium occupancy 2001

2001	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	45	0	45
Observed Loon Absence (0)	31	0	31
Totals	76	0	76
		Overall Accuracy	59%

Producer's Accuracy			User's Accuracy		
Loon Presence	45/76	59%	Loon Presence	45/45	100%
Loon Absence	0/0	0%	Loon Absence	0/31	0%

Overall, producer's & user's accuracies for medium occupancy 2000

2000	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	47	0	47
Observed Loon Absence (0)	33	0	33
Totals	80	0	80
		Overall Accuracy	59%

Producer's Accuracy			User's Accuracy		
Loon Presence	47/80	59%	Loon Presence	47/47	100%
Loon Absence	0/0	0%	Loon Absence	0/33	0%

Overall, producer's & user's accuracies for medium occupancy 1999

1999	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	41	0	41
Observed Loon Absence (0)	25	0	25
Totals	66	0	66
		Overall Accuracy	62%

Producer's Accuracy			User's Accuracy		
Loon Presence	41/66	62%	Loon Presence	41/41	100%
Loon Absence	0/0	0%	Loon Absence	0/25	0%

Overall, producer's & user's accuracies for medium occupancy 1998

1998	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	47	0	47
Observed Loon Absence (0)	27	0	27
Totals	74	0	74
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	47/74	64%	Loon Presence	47/47	100%
Loon Absence	0/0	0%	Loon Absence	0/27	0%

Overall, producer's & user's accuracies for medium occupancy 1997

1997	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	43	0	43
Observed Loon Absence (0)	36	0	36
Totals	79	0	79
		Overall Accuracy	54%

Producer's Accuracy			User's Accuracy		
Loon Presence	43/79	54%	Loon Presence	43/43	100%
Loon Absence	0/0	0%	Loon Absence	0/	0%

Summary table and error matrices for low occupancy

Low Occupancy		Producers Accuracy		Users Accuracy	
Year	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
2008	46	0	46	0	100
2007	52	0	52	0	100
2006	51	0	51	0	100
2005	51	0	51	0	100
2004	55	0	55	0	100
2003	65	0	65	0	100
2002	62	0	52	0	100
2001	61	0	51	0	100
2000	71	0	71	0	100
1999	46	0	46	0	100
1998	56	0	56	0	100
1997	72	0	72	0	100

Overall, producer's & user's accuracies for low occupancy 2008

2008	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	45	45
Observed Loon Absence (0)	0	38	38
Totals	0	83	83
		Overall Accuracy	46%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/45	0%
Loon Absence	38/83	46%	Loon Absence	38/38	100%

Overall, producer's & user's accuracies for low occupancy 2007

2007	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	41	41
Observed Loon Absence (0)	0	45	45
Totals	0	86	86
		Overall Accuracy	52%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/41	0%
Loon Absence	45/86	52%	Loon Absence	45/45	100%

Overall, producer's & user's accuracies for low occupancy 2006

2006	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	41	41
Observed Loon Absence (0)	0	42	42
Totals	0	83	83
		Overall Accuracy	51%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/41	0%
Loon Absence	42/83	51%	Loon Absence	42/42	100%

Overall, producer's & user's accuracies for low occupancy 2005

2005	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	31	31
Observed Loon Absence (0)	0	32	32
Totals	0	63	63
		Overall Accuracy	51%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/31	0%
Loon Absence	32/63	51%	Loon Absence	32/32	100%

Overall, producer's & user's accuracies for low occupancy 2004

2004	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	29	29
Observed Loon Absence (0)	0	36	36
Totals	0	65	65
		Overall Accuracy	55%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/29	0%
Loon Absence	36/65	55%	Loon Absence	36/36	100%

Overall, producer's & user's accuracies for low occupancy 2003

2003	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	31	31
Observed Loon Absence (0)	0	57	57
Totals	0	88	88
		Overall Accuracy	65%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/31	0%
Loon Absence	57/88	65%	Loon Absence	57/57	100%

Overall, producer's & user's accuracies for low occupancy 2002

2002	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	32	32
Observed Loon Absence (0)	0	52	52
Totals	0	84	84
		Overall Accuracy	62%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/32	0%
Loon Absence	52/84	62%	Loon Absence	52/52	100%

Overall, producer's & user's accuracies for low occupancy 2001

2001	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	31	31
Observed Loon Absence (0)	0	49	49
Totals	0	80	80
		Overall Accuracy	61%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/31	0%
Loon Absence	49/80	61%	Loon Absence	49/49	100%

Overall, producer's & user's accuracies for low occupancy 2000

2000	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	26	26
Observed Loon Absence (0)	0	65	65
Totals	0	91	91
		Overall Accuracy	71%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/26	0%
Loon Absence	65/91	71%	Loon Absence	65/65	100%

Overall, producer's & user's accuracies for low occupancy 1999

1999	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	31	31
Observed Loon Absence (0)	0	26	26
Totals	0	57	57
		Overall Accuracy	46%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/26	0%
Loon Absence	26/57	46%	Loon Absence	26/26	100%

Overall, producer's & user's accuracies for low occupancy 1998

1998	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	28	28
Observed Loon Absence (0)	0	36	36
Totals	0	64	64
		Overall Accuracy	56%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/28	0%
Loon Absence	36/64	56%	Loon Absence	36/36	100%

Overall, producer's & user's accuracies for low occupancy 1997

1997	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	25	25
Observed Loon Absence (0)	0	65	65
Totals	0	90	90
		Overall Accuracy	72%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/25	0%
Loon Absence	65/90	72%	Loon Absence	65/65	100%

A2: Second method of assessment

Summary table and error matrices for all lakes (all 3 levels of occupancy)

All Lakes		Producers Accuracy		Users Accuracy	
Year	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
2008	60	72	46	62	57
2007	58	62	52	63	51
2006	63	73	51	64	62
2005	64	73	51	69	56
2004	66	74	55	71	59
2003	65	64	65	68	61
2002	63	64	52	68	57
2001	64	66	51	69	58
2000	68	65	71	73	63
1999	59	66	46	67	45
1998	64	70	56	72	54
1997	66	60	72	73	60

Overall, producer's & user's accuracies for all lakes 2008 (all 3 levels of occupancy)

2008	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	27+47 = 74	45	119
Observed Loon Absence (0)	3+26 = 29	38	67
Totals	103	83	186
		Overall Accuracy	60%

Producer's Accuracy			User's Accuracy		
Loon Presence	74/103	72%	Loon Presence	74/119	62%
Loon Absence	38/83	46%	Loon Absence	38/67	57%

Overall, producer's & user's accuracies for all lakes 2007 (all 3 levels of occupancy)

2007	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	26+45 = 71	41	112
Observed Loon Absence (0)	7+37 = 44	45	89
Totals	115	86	201
		Overall Accuracy	58%

Producer's Accuracy			User's Accuracy		
Loon Presence	71/115	62%	Loon Presence	71/112	63%
Loon Absence	45/86	52%	Loon Absence	45/89	51%

Overall, producer's & user's accuracies for all lakes 2006 (all 3 levels of occupancy)

2006	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24+48 = 72	41	113
Observed Loon Absence (0)	4+22 = 26	42	68
Totals	98	83	181
		Overall Accuracy	63%

Producer's Accuracy			User's Accuracy		
Loon Presence	72/98	73%	Loon Presence	72/113	64%
Loon Absence	42/83	51%	Loon Absence	42/68	62%

Overall, producer's & user's accuracies for all lakes 2005 (all 3 levels of occupancy)

2005	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	25+43 = 68	31	99
Observed Loon Absence (0)	1+24 = 25	32	57
Totals	93	63	156
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	68/93	73%	Loon Presence	68/99	69%
Loon Absence	32/63	51%	Loon Absence	32/57	56%

Overall, producer's & user's accuracies for all lakes 2004 (all 3 levels of occupancy)

2004	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24+46 = 70	29	99
Observed Loon Absence (0)	4+21 = 25	36	61
Totals	95	65	160
		Overall Accuracy	66%

Producer's Accuracy			User's Accuracy		
Loon Presence	70/95	74%	Loon Presence	70/99	71%
Loon Absence	36/65	55%	Loon Absence	36/61	59%

Overall, producer's & user's accuracies for all lakes 2003 (all 3 levels of occupancy)

2003	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	23+44 = 67	31	98
Observed Loon Absence (0)	7+30 = 37	57	94
Totals	104	88	192
		Overall Accuracy	65%

Producer's Accuracy			User's Accuracy		
Loon Presence	67/104	64%	Loon Presence	67/98	68%
Loon Absence	57/88	65%	Loon Absence	57/94	61%

Overall, producer's & user's accuracies for all lakes 2002 (all 3 levels of occupancy)

2002	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24+45 = 69	32	101
Observed Loon Absence (0)	7+32 = 39	52	91
Totals	108	84	192
		Overall Accuracy	63%

Producer's Accuracy			User's Accuracy		
Loon Presence	69/108	64%	Loon Presence	69/101	68%
Loon Absence	52/84	62%	Loon Absence	52/91	57%

Overall, producer's & user's accuracies for all lakes 2001 (all 3 levels of occupancy)

2001	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24+45 = 69	31	100
Observed Loon Absence (0)	5+31 = 36	49	85
Totals	105	80	185
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	69/105	66%	Loon Presence	69/100	69%
Loon Absence	49/80	61%	Loon Absence	49/85	58%

Overall, producer's & user's accuracies for all lakes 2000 (all 3 levels of occupancy)

2000	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24+47 = 71	26	97
Observed Loon Absence (0)	6+33 = 39	65	104
Totals	110	91	201
		Overall Accuracy	68%

Producer's Accuracy			User's Accuracy		
Loon Presence	71/110	65%	Loon Presence	71/97	73%
Loon Absence	65/91	71%	Loon Absence	65/104	63%

Overall, producer's & user's accuracies for all lakes 1999 (all 3 levels of occupancy)

1999	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	22+41 = 63	31	94
Observed Loon Absence (0)	7+25 = 32	26	58
Totals	95	57	152
		Overall Accuracy	59%

Producer's Accuracy			User's Accuracy		
Loon Presence	63/95	66%	Loon Presence	63/94	67%
Loon Absence	26/57	46%	Loon Absence	26/58	45%

Overall, producer's & user's accuracies for all lakes 1998 (all 3 levels of occupancy)

1998	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24+47 = 71	28	99
Observed Loon Absence (0)	4+27 = 31	36	67
Totals	102	64	166
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	71/102	70%	Loon Presence	71/99	72%
Loon Absence	36/64	56%	Loon Absence	36/67	54%

Overall, producer's & user's accuracies for all lakes 1997 (all 3 levels of occupancy)

1997	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	23+43 = 66	25	91
Observed Loon Absence (0)	8+36 = 44	65	109
Totals	110	90	200
		Overall Accuracy	66%

Producer's Accuracy			User's Accuracy		
Loon Presence	66/110	60%	Loon Presence	66/91	73%
Loon Absence	65/90	72%	Loon Absence	65/109	60%

A3: Third method of assessment

Summary table and error matrices for combined years 1997 – 2002

Years: 1997-2002		Producers Accuracy		Users Accuracy	
Level	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
High	76	76	0	100	0
Medium	56	56	0	100	0
Low	74	0	74	0	100
All lakes	**68**	61	70	74	66
100 lake subset	61	38	97	96	49

Overall, producer's & user's accuracies for high occupancy years 1997-2002

High	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	25	0	25
Observed Loon Absence (0)	8	0	8
Totals	33	0	33
		Overall Accuracy	76%

Producer's Accuracy			User's Accuracy		
Loon Presence	25/33	76%	Loon Presence	25/25	100%
Loon Absence	0/0	0%	Loon Absence	0/0	0%

Overall, producer's & user's accuracies for medium occupancy years 1997-2002

Medium	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	48	0	48
Observed Loon Absence (0)	38	0	38
Totals	86	0	86
		Overall Accuracy	56%

Producer's Accuracy			User's Accuracy		
Loon Presence	48/86	56%	Loon Presence	48/48	100%
Loon Absence	0/0	0%	Loon Absence	0/38	0%

Overall, producer's & user's accuracies for low occupancy years 1997-2002

Low	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	32	32
Observed Loon Absence (0)	0	91	91
Totals	0	123	123
		Overall Accuracy	74%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/32	0%
Loon Absence	91/123	74%	Loon Absence	91/91	100%

Overall, producer's & user's accuracies for all lakes years 1997-2002

All Lakes	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	25+48 = 73	32	105
Observed Loon Absence (0)	8+38 = 46	91	137
Totals	119	123	242
		Overall Accuracy	68%

Producer's Accuracy			User's Accuracy		
Loon Presence	73/119	61%	Loon Presence	91/123	74%
Loon Absence	73/105	70%	Loon Absence	91/137	66%

Overall, producer's & user's accuracies for 100 lake subset years 1997-2002

100 Lake Subset	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	23	1	24
Observed Loon Absence (0)	38	37	75
Totals	61	38	99
		Overall Accuracy	61%

Producer's Accuracy			User's Accuracy		
Loon Presence	23/61	38%	Loon Presence	23/24	96%
Loon Absence	37/38	97%	Loon Absence	37/75	49%

A4: Fourth method of assessment

Summary table and error matrices for combined years 2003 – 2008

Years: 2003-2008		Producers Accuracy		Users Accuracy	
Level	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
High	79	79	0	100	0
Medium	53	53	0	100	0
Low	73	0	73	0	100
All lakes	**67**	60	73	66	67
100 lake subset	63	46	92	90	50

Overall, producer's & user's accuracies for high occupancy years 2003-2008

High	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	26	0	26
Observed Loon Absence (0)	7	0	7
Totals	33	0	33
		Overall Accuracy	79%

Producer's Accuracy			User's Accuracy		
Loon Presence	26/33	79%	Loon Presence	26/26	100%
Loon Absence	0/0	0%	Loon Absence	0/7	0%

Overall, producer's & user's accuracies for medium occupancy years 2003-2008

Medium	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	48	0	48
Observed Loon Absence (0)	42	0	42
Totals	90	0	90
		Overall Accuracy	53%

Producer's Accuracy			User's Accuracy		
Loon Presence	48/90	53%	Loon Presence	48/48	100%
Loon Absence	0/0	0%	Loon Absence	0/42	0%

Overall, producer's & user's accuracies for low occupancy years 2003-2008

Low	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	0	38	38
Observed Loon Absence (0)	0	101	101
Totals	0	139	139
		Overall Accuracy	73%

Producer's Accuracy			User's Accuracy		
Loon Presence	0/0	0%	Loon Presence	0/38	0%
Loon Absence	101/139	73%	Loon Absence	101/101	100%

Overall, producer's & user's accuracies for all lakes years 2003-2008

All lakes	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	26 + 48 = 74	38	112
Observed Loon Absence (0)	7 + 42 = 49	101	150
Totals	123	139	262
		Overall Accuracy	67%

Producer's Accuracy			User's Accuracy		
Loon Presence	74/123	60%	Loon Presence	74/1123	66%
Loon Absence	101/139	73%	Loon Absence	101/150	67%

Overall, producer's & user's accuracies for 100 lake subset years 2003-2008

100 Lake Subset	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	28	3	31
Observed Loon Absence (0)	33	33	66
Totals	61	36	97
		Overall Accuracy	63%

Producer's Accuracy			User's Accuracy		
Loon Presence	28/61	46%	Loon Presence	28/31	90%
Loon Absence	33/36	92%	Loon Absence	33/66	50%

A5: Fifth method of assessment

Summary table and error matrices for 100 Lake Subset

100 Lake Subset		Producers Accuracy		Users Accuracy	
Year	**Overall accuracy**	Loon presence	Loon absence	Loon presence	Loon absence
2008	65	60	80	91	39
2007	58	49	84	90	36
2006	67	60	80	87	49
2005	64	59	82	92	36
2004	68	64	88	96	32
2003	63	47	96	96	47
2002	58	46	89	92	38
2001	66	51	100	100	48
2000	64	44	97	96	51
1999	52	44	82	90	27
1998	60	50	100	100	33
1997	51	33	88	86	39

Overall, producer's & user's accuracies for 100 Lake Subset 2008

2008	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	29	3	32
Observed Loon Absence (0)	19	12	31
Totals	48	15	63
		Overall Accuracy	65%

Producer's Accuracy			User's Accuracy		
Loon Presence	29/48	60%	Loon Presence	29/32	91%
Loon Absence	12/15	80%	Loon Absence	12/31	39%

Overall, producer's & user's accuracies for 100 Lake Subset 2007

2007	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	27	3	30
Observed Loon Absence (0)	28	16	44
Totals	55	19	74
		Overall Accuracy	58%

Producer's Accuracy			User's Accuracy		
Loon Presence	27/55	49%	Loon Presence	27/30	90%
Loon Absence	16/19	84%	Loon Absence	16/44	36%

Overall, producer's & user's accuracies for 100 Lake Subset 2006

2006	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	26	4	30
Observed Loon Absence (0)	17	16	33
Totals	43	20	63
		Overall Accuracy	67%

Producer's Accuracy			User's Accuracy		
Loon Presence	26/43	60%	Loon Presence	26/30	87%
Loon Absence	16/20	80%	Loon Absence	16/33	49%

Overall, producer's & user's accuracies for 100 Lake Subset 2005

2005	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	23	2	25
Observed Loon Absence (0)	16	9	25
Totals	39	11	50
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	23/39	59%	Loon Presence	23/25	92%
Loon Absence	9/11	82%	Loon Absence	9/25	36%

Overall, producer's & user's accuracies for 100 Lake Subset 2004

2004	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	27	1	28
Observed Loon Absence (0)	15	7	22
Totals	42	8	50
		Overall Accuracy	68%

Producer's Accuracy			User's Accuracy		
Loon Presence	27/42	64%	Loon Presence	27/28	96%
Loon Absence	7/8	88%	Loon Absence	7/22	32%

Overall, producer's & user's accuracies for 100 Lake Subset 2003

2003	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	1	25
Observed Loon Absence (0)	27	24	51
Totals	51	25	76
		Overall Accuracy	63%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/51	47%	Loon Presence	24/25	96%
Loon Absence	24/25	96%	Loon Absence	24/51	47%

Overall, producer's & user's accuracies for 100 Lake Subset 2002

2002	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	2	26
Observed Loon Absence (0)	28	17	45
Totals	52	19	71
		Overall Accuracy	58%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/52	46%	Loon Presence	24/26	92%
Loon Absence	17/19	89%	Loon Absence	17/45	38%

Overall, producer's & user's accuracies for 100 Lake Subset 2001

2001	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	25	0	25
Observed Loon Absence (0)	24	22	46
Totals	49	22	71
		Overall Accuracy	66%

Producer's Accuracy			User's Accuracy		
Loon Presence	25/49	51%	Loon Presence	25/25	100%
Loon Absence	22/22	100%	Loon Absence	22/46	48%

Overall, producer's & user's accuracies for 100 Lake Subset 2000

2000	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	1	25
Observed Loon Absence (0)	30	31	61
Totals	54	32	86
		Overall Accuracy	64%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/54	44%	Loon Presence	24/25	96%
Loon Absence	31/32	97%	Loon Absence	31/61	51%

Overall, producer's & user's accuracies for 100 Lake Subset 1999

1999	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	19	2	21
Observed Loon Absence (0)	24	9	33
Totals	43	11	54
		Overall Accuracy	52%

Producer's Accuracy			User's Accuracy		
Loon Presence	19/43	44%	Loon Presence	19/21	90%
Loon Absence	9/11	82%	Loon Absence	9/33	27%

Overall, producer's & user's accuracies for 100 Lake Subset 1998

1998	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	24	0	24
Observed Loon Absence (0)	24	12	36
Totals	48	12	60
		Overall Accuracy	60%

Producer's Accuracy			User's Accuracy		
Loon Presence	24/48	50%	Loon Presence	24/24	100%
Loon Absence	12/12	100%	Loon Absence	12/36	33%

Overall, producer's & user's accuracies for 100 Lake Subset 1997

1997	Predicted Loon Presence (1)	Predicted Loon Absence (0)	Totals
Observed Loon Presence (1)	18	3	21
Observed Loon Absence (0)	36	23	59
Totals	54	26	80
		Overall Accuracy	51%

Producer's Accuracy			User's Accuracy		
Loon Presence	18/54	33%	Loon Presence	18/21	86%
Loon Absence	23/26	88%	Loon Absence	23/59	39%