Aspects of hydrological impacts on the Common Loon at Lake Umbagog, 1976-99

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Abstract

Lake Umbagog's Common Loon population has been monitored for 24 years. In 1993, the level of resolution of reproductive performance was improved with the initiation of a program to uniquely color-mark individuals. Since 1976, the number of territorial pairs has increased from 9 to 28 and reflects a similar increase in loon populations across New Hampshire. However, long-term reproductive measures indicate two major concerns for loon conservation. First, the number of fledged young per territorial pair has significantly declined in the past four years (0.28) and is well below the 24-year mean for Lake Umbagog (0.46). Second, the discrepancy of reproductive measures between the north and south ends of the lake continue to widen. Observations of marked individuals indicate site fidelity (84.5%) and survivorship (93.5%) are above or near average levels of other breeding populations, thereby indicating density dependent factors are not the sole source of impacts for current loon demographics. Water level manipulation and methylmercury availability were investigated and found to be potential sources of impact on healthy breeding populations. Although mean mercury exposure to loons and their prey fish on Lake Umbagog are moderate compared to watershed-wide levels, certain areas of the lake such as the southern end and the Magalloway River carry Hg loads potentially damaging at the molecular, organism, and population levels. The changes in water levels have a dual effect on the viability of Lake Umbagog's loon population. Although positive steps have been taken to minimize waterlevel impacts on loon nesting success, 13% of their nests in the past seven years failed due to floodings and strandings. Changes in water levels, especially during the summer, are also known to exaggerate methylmercury production and create artificially high levels.

Introduction

In 1853, a dam built on Lake Umbagog's outlet, the Androscoggin River, considerably increased the lake's surface water level. Although the impact from this hydrological change to the Common Loon breeding population is undocumented, a region wide decline for the species during the mid-1900s galvanized attention for its conservation and potential anthropogenic impacts such as changing water levels. An additional conservation issue related to Lake Umbagog's hydrology is related to methylmercury (MeHg) availability.

Since 1976, the Loon Preservation Committee (LPC) has closely followed loon reproductive success on Lake Umbagog. Monitoring soon showed dam-related fluctuating water levels in June and July to severely curtail the number of nesting attempts and successes. A handshake agreement in 1984 soon followed by a written one between the Federal Energy Regulatory Commission, Central Maine Power Company (CMP), and LPC set certain limits on water level changes during the loon's June-July nesting period. CMP agreed to maintain water levels based on a level set on June 1, to change no more than a six-inch increase or a one-foot decrease. In response to increased sensitivity and interest by the U.S. Fish and Wildlife Service and the formation of the Lake Umbagog National Wildlife Refuge, this collaborative agreement was further modified in 1998.

Lake Umbagog and other reservoirs in New England are subject to higher than acceptable amounts of atmospherically deposited mercury. Once this inorganic mercury is on the landscape, it is converted to methlymercury and becomes far more toxic form that bioaccumulates and biomagnifies in biota.

Due to high concentrations of MeHg reported in fish from New England lakes, ponds, rivers, and streams, each state has issued a statewide fish consumption advisory. Impacts on wildlife, however, are less well known in New England. Recent ecological concerns were highlighted at the "New England Governors and Eastern Canadian Premiers" conference sponsored by the U.S. EPA and Maine Department of Environmental Protection. Recommendations from the report 'Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action' stated: "conduct additional research on the cycling and bioavailability of mercury in aquatic ecosystems and on the ecological impacts of elevated fish mercury levels, particularly for fish-eating wildlife such as eagles, loons, osprey, otter, and mink" (NESCAUM 1998). In addition, strategy 9 from "Mercury in Maine," a report by the Land and Water Resources Council to the Maine legislature in January 1998, recommends "focus biological research efforts on the effects of mercury on the health of loons, fish and other wildlife with elevated mercury levels." Policy responses in New Hampshire are now nearing similar conclusions as Maine's.

How water levels continue to be manipulated on Lake Umbagog heavily impacts wildlife, particularly loons. Holding water levels steady from late spring through mid summer will reduce the flooding or stranding of loon nests. Secondly, changes of water levels on some reservoirs is related to methylmercury (MeHg) availability and there is now evidence that minimal changes in hydrology during the summer can reduce this impact (Evers and Reaman 1998). To determine the impacts of water level changes on (1) reproductive success and (2) methylmercury availability, loons were captured and uniquely marked to measure individual performance and mercury exposure.

Using Birds as bioindicators of MeHg availability

Piscivorous birds are useful as general ecological indicators of aquatic ecosystem integrity and especially the presence and effects of environmental stressors. The use of piscivorous birds as indicators of contaminants is common (e.g., Frederick et al. 1997, Wolfe 1998, Nichols et al. 1999). And, the emphasis on higher trophic level piscivorous wildlife (i.e., loons) now provides the best insight into the ability of mercury to bioaccumulate and biomagnify (Scheuhammer 1991, Thompson 1996, U.S. EPA 1997).

Mercury deposition and MeHg availability is now sufficiently elevated in the Northeast region to cause impacts on wildlife (Welch 1994, Burgess et al. 1998, Nocera and Taylor 1998, Evers et al. 1999). Based on U.S. EPA probability-based sampling efforts in U.S. EPA's Region 1 and 2, Yeardley et al. (1998) predicted that 98% of New England's lakes contained fish with MeHg levels exceeding critical values for piscivorous birds. In corroboration, Evers et al. (1998a) found Common Loons breeding in Region 1 (MA, ME, NH, RI, VT) had the highest mean blood Hg levels in the United States, while juvenile loon blood Hg levels were four times those at the designated reference site in Alaska. Further studies on a suite of five piscivorous birds in Maine indicated over 70% of lakes have the capacity to produce MeHg at levels above designated risk categories (Evers et al. 1998b). These studies demonstrate that extensive mercury contamination and MeHg availability exists in New England.

Yeardley et al. (1998) also found from analyzing 11 metals in fish throughout New England that, "MeHg was determined to be the elemental contaminant of regional concern to fish consumers." His study focused, in part, on assessing the ecological risk of Hg in a piscivorous bird. We chose the loon as our bioindicator because there exists a significant amount of information collected on its demographics (e.g., Piper et al. 1997a, Piper et al. 1997b, Evers et al. In Press), behavioral ecology (e.g., Evers 1993, Nocera and Taylor 1998, Gostomski and Evers 1998, Paruk In Press), toxicology (e.g., Evers et al. 1998a, b, Meyer et al. 1998, Scheuhammer et al. 1998), and local breeding population status (Brennan In Press, Taylor and Vogel In Press, LPC unbpubl. data).

Hg risk in New England loons

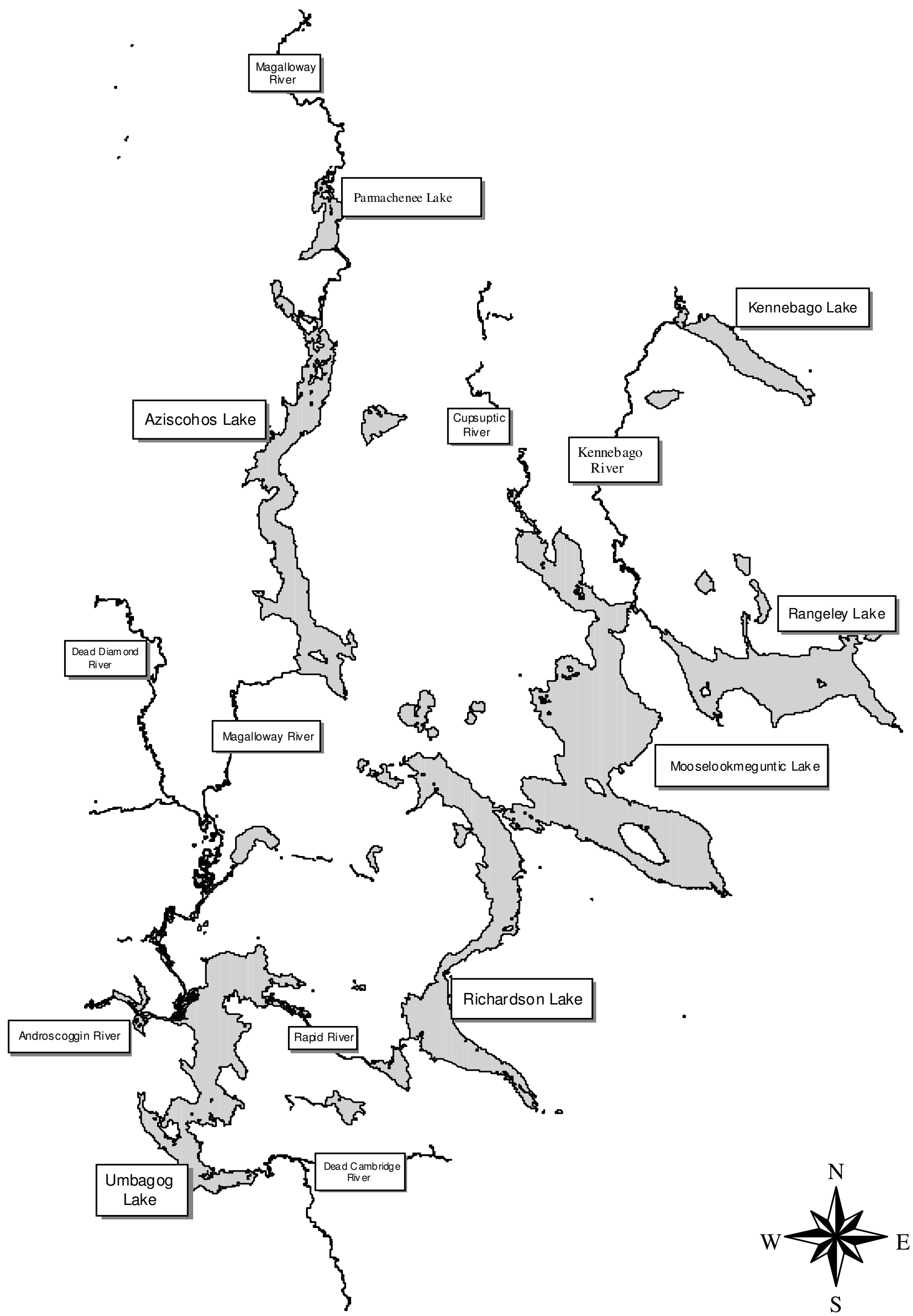
An estimated 21-35% of the New England Common Loon breeding population has Hg levels that exceed wildlife safety thresholds designated by other studies (e.g., Barr 1986, Scheuhammer 1991, Thompson 1996, Burgess et al. 1998, Meyer et al. 1998, Evers et al. 1998). In addition, over 60% of abandoned loon eggs collected in New England (n=305) have Hg levels considered elevated (i.e., 0.5 ppm) by laboratory studies (Fimreite 1971, Heinz 1979) and 5% have lethal levels (i.e., 2.0 ppm) (Thompson 1996). These and previous studies documenting exposure in Maine loons (Evers and Reaman 1998, Evers et al. 1998b) predict that impacts occur in New England.

Study Area

BioDiversity Research Institute (BRI) has worked with members of NELSWG to collect toxicological, demographic, and physiological information on New England's breeding loon populations since 1993. Much of this research has been based in the upper Androscoggin and Kennebec River watersheds (e.g., Evers and Reaman 1997, Evers and Reaman 1998, Evers et al. 1998b). Because of this knowledge base and some of the highest Hg levels recorded for Common Loons in North America, we chose the Rangeley Lakes area for a high resolution study on the potential impacts of Hg to wildlife (Figure 1). Lake Umbagog is on the western edge of our Rangeley Lakes study area.

Lake Umbagog is a 7,850 acre waterbody with water levels manipulated through the year by a dam in Errol, New Hampshire. Its watershed comprises 1,045 square miles (+Dead Cambridge) and includes three major inputs (Magalloway, Rapid, and Dead Cambridge Rivers) and one major output (Androscoggin River) (Figure 2). Of the major watershed inputs, the Magalloway River represents the greatest areas (573 square miles) and also carries known elevated mercury levels originating from Aziscohos Lake (Evers and Reaman 1998). The watershed input associated with the Rapid River is 472 square miles and conversely has comparatively low mercury levels as measured in the loons and their prey in three of the four upstream reservoirs (Kennebago has yet to be sampled but samples have been collected from Richardson, Mooselookmeguntic, and Rangeley). The Dead Cambridge watershed is smaller ( ), however the associated mercury input is relatively unknown. For purposes of this study, Lake Umbagog was classified into north and south ends. This was primarily based on speculation of watershed input and flow. Whereas the Rapid River supplies the north end, the Dead Cambridge River watershed is the primary input for the southern end. The Magalloway River input in the north end is likely minimized by the juxtaposition with Lake Umbagog's primary outlet, the Androscoggin River.

Figure 1. Rangeley Lakes Region Study Area



Methods

Monitoring of individual performance

LPC surveyed nesting and non-nesting territorial loon pairs on Lake Umbagog from ice off (early May) until mid-August. Surveys typically consisted of locating loon pairs every 3-5 days from a boat with 10x binoculars, documenting territorial duration, nest attempts, number of eggs laid, incubation efforts, causes for nest abandonment/failure, hatch rates, fledge rates, and causes for chick loss. Human disturbance, evidence of predators, and frequency of intruding loons were also documented at this time. Reproductive information has been annually gathered by LPC for the past 24 years (since 1976).

The reproductive measures used here are territorial pair, nesting pair, hatched chicks (small young), and fledgedg juveniles (large young). A territorial pair can be either established or transitional. An established territorial pair is present for at least three years and is independent of the number of nesting attempts. A transitional territorial pair only occurs in an area for one or two years and may attempt nesting and produce young. A nesting pair lays at least one egg. The construction of a nest or dish does not constitute a nesting pair. A hatch is from at least one egg and the chick has fully emerged from the shell. A large young is the measure of a surviving or fledged individual. Mortality of loon chicks after six weeks of age is typically less than 5%, therefore this reproductive measure is used to determine fledging success.

Sediment and Fish Collection

Lake sediment cores were collected from reservoirs and natural lakes to determine recent and historical levels of Hg deposition. Mercury deposition among lake sediments were compared to identify potential relationships between sediment and concentrations of Hg measured in loon and fish tissues. Sediment samples were analyzed for total Hg and Total Organic Carbon (TOC).

Fish were captured in 1996-97 using electrofishing and Swedish experimental gill nets in the Three Island Cove territory. In an effort to correlate fish and loon blood Hg levels fish species and size class were prioritized according to findings by Barr (1996). Yellow perch (*Perca flavescens*) was the preferred species in Barr's study and were targeted for collection on Lake Umbagog. The size classes of perch and other fish used were according to the following:

a. Yellow Perch - Non-fusiform, first fit is weight.
   small (5-20g, 2-4" / 5-10cm, 1-2 yrs.)
   medium (20-35g, 4-6" / 10-15cm, 3-4 yrs.)
   large (35-60g, 6-8", 15-20cm, 5-6 yrs)
   extra-large (60-80g, 8-10", 20-25cm, 6+ yrs)

b. White Sucker - Fusiform, first fit is weight.
   small (5-25g, 5-13cm, 2-5")
   medium (25-75g, 13-20cm, 5-8")
   large (75-200g, 20-30cm, 8-12")

c. Opportunistic Sample - First fit is weight and size fit follows one of the two categories, according to fish shape.

Field Capture and Loon Tissue Collection

From June through September, 1993-99, 3-15 people assisted with the capture of adult and juvenile loons at night on Lake Umbagog. Crews used boats powered with 10-50 hp outboard motors, 400,000 to 1.5 million candlepower spotlights. Loon call playbacks and mimicked vocalizations of chick calls were used to attract family groups. Loons were netted with large landing nets, restrained, then transported to shore. One to three plastic color bands were placed on the leg with a U.S. Fish and Wildlife Service band accompanying one of the plastic bands on the left leg for juveniles and on the right leg for adults. Remote identification of individuals was typically made the following year in May or June.

The second secondary flight feathers were removed by cutting the calamus (i.e., below the base of the vane). Blood samples were taken by venipuncture from either the cutaneous ulnar vein or the medial metatarsal vein. We used 20-

25 gauge straight needles with 1-12 cc syringes, or direct collection with 21-25 gauge needles and 7 inch tubing with multiple sample Luer adapter into 2-10 cc Vacutainers,, or combinations of the above. All loons were marked with a USFWS aluminum and 1-3 plastic color leg bands glued with an acetone-based adhesive cement.

The feathers were placed in polyethylene bags, labeled, and refrigerated within 12 hours of collection. The initial selection of remigials was based on sufficient mass and removal that would not negatively impact loon behavior (e.g., flight). Loons exhibit simultaneous remigial molt therefore selection does not bias analysis.

Blood was collected in 2-10 cc green top Vacutainers, (with powdered sodium heparin) for subsequent Hg analysis. Due to logistical and field limitations 10% formalin was added to preserve the blood following U.S. Fish and Wildlife Service protocol (0.05 cc of formalin / one cc of whole blood) (Stafford and Stickel 1981, Wiemeyer et al. 1984).

Egg materials have been collected from abandoned nests since 1993 by LPC biologists. Eggs, eggshell membranes, and eggshells were placed in polyethylene bags and then frozen. Volume, weight, length, and width were measured for each whole egg and the contents placed in I-Chem jars. Volume was either measured by water displacement and weighed on an electronic balance to the nearest 0.001g (n=22) or calculated (n=11) by multiplying 0.51 times egg length times egg width squared (Stickel et al. 1973). Egg weight was also weighed to the nearest 0.001g. The egg length and width were measured with calipers to the nearest 0.001 mm. Contents were categorized into one of five developmental stages (Table 1). Some eggs could not be scored for development because they were autolyzed (18%). Shells and outer egg membranes were dried and archived and have not been analyzed. Inner egg membranes were included with whole egg analysis. Eggs before 1997 were archived in freezers for up to 3 1/2 years. All eggs were adjusted for moisture loss by dividing the total egg weight by the egg volume (Stickel et al. 1973).

Table 1. Embryological developmental scale used for Common Loon eggs.

NA (not assessable): Developmental stage could not be determined. Contents were gray or yellowish-tan in color and typically had a foul smell. A darker color suggested some degree of development had occurred, whereas a yellow homogenous liquid may be sifted through and if no dark spots or hardened areas were found we classified the egg as infertile (0).

0: No development was evident. Egg had a yellow/orange or yellow/tan yolk (intact or broken down into a liquid). A translucent jelly-like mass surrounded the yolk sac and showed no sign of embryonic development (e.g, mass not dark or hardened).

1: Embryo was viable (length was up to 1.5 cm). The jelly like mass (embryo) was dense and hardened. Small dark (red) eye spots were sometimes visible at this stage.

2: Developing embryo (length was 1.5 – 2.0) had an apparent central nervous system. Cranial development and visible eyes were apparent. Feathers were absent.

3: The embryo showed advanced development (length was 2-3 cm). Bill was developed (e.g. egg tooth present but soft). Legs and wings were visible but not fully developed. Some feathers were present (first seen in tail).

4: The fully developed embryo was completely covered by feathers. Appendages were completely developed. Vent, preen gland was visible. A small portion of yolk sac remained attached to belly.

Tissue analyses

All feather and blood samples in 1996-99 and eggs from all years were analyzed at the University of Pennsylvania under the supervision of Dr. Bob Poppenga. Samples from 1994-95 were analyzed at the Animal Health Diagnostics Laboratory at Michigan State University under the supervision of Dr. Emmett Braselton. Dr. Bob Taylor from the Trace Element Lab at Texas A&M analyzed the fish and sediment sample in 1996 and Dr. Bob Poppenga analyzed fish samples for total and methylmercury in 1997. Blood-Hg was measured in 1 ml heparinized whole blood by continuous flow cold vapor atomic absorption spectrophotometry using a Perkin-Elmer 3030b spectrophotometer (Scheuhammer and Bond 1991). The Hg residues measured in feather (fresh weight) and blood (wet weight) represent total Hg and are shown in ppm. Reagents were periodically tested to ensure low acceptable background levels of Hg contamination. Tests for residual Hg in the heparin and formalin were negative.

Feathers were analyzed for trace metal and mineral content using inductively coupled argon plasma (ICP) emission spectroscopy (Thermo Jarrell Ash Polyscan 61E). Feathers were cut, calamus discarded, and washed 3 times in acetone (chromatography grade, Burdick and Jackson, Muskegon, MI), 3 times in ultra pure water (4 bowl MilliQ System, Millipore Corp, Bedford, MA) one additional time in acetone, then allowed to dry overnight in a fume hood. Feather Hg strongly binds to disulfide linkages of keratin (Crewther et al. 1965) and is not disturbed by washing episodes (Applequist et al. 1984) or previous environmental exposure (Goede and de Bruin 1984). An 0.25-0.5 g aliquot of feathers was digitally weighed and digested overnight with 2 ml conc. HNO3 (Instra-analyzed grade, J.T. Baker Inc., Phillipsburg, NJ) in a closed, 30 ml Teflon container (Savillex Corp., Minnetonka, MN) at 90°C. The samples were quantitatively transferred to a 10 ml volumetric flask, mixed with 100 mg yttrium (JMC Specpure ICP/DCP Analytical Standards, Johnson-Matthey/Aesar, Ward Hill, MA) as internal standard, and diluted to volume. Samples were initially analyzed by inductively coupled plasma-atomic emission spectroscopy (Polyscan 61E, Thermo Jarrell-Ash Corp, Franklin, MA) (Stowe et al. 1985). An aliquot of the sample was then taken from the 10 ml volumetric flask and diluted an additional 1000 fold for analysis of Hg by cold-vapor atomic absorption spectroscopy (LDC mercury Monitor 3200, Thermo Separation Products, Riviera Beach, FL). Accuracy was monitored by concurrent analysis of procedural blanks (in triplicate), NIST Oyster Tissue SRM 1566a with Hg certified at 0.0642 +/- 0.0067 ppm (National Institute of Standards and Technology, Gaithersburg, MD) and NRC Tort 2 Lobster Hepatopancreas with Hg certified at 0.27 +/- 0.06 ppm (National Research Council of Canada, Ottawa, Canada).

Whole blood was thoroughly mixed and homogenized. From the whole blood sample, a 100 mg aliquot was placed into a 15 ml Teflon container, mixed with 2 ml conc. HNO3, sealed, and digested overnight at 90°C. Samples were quantitatively transferred to 25 ml (juveniles) or 100 ml (adults) volumetric flasks and diluted to volume with ultra pure water. Samples were analyzed as above by cold-vapor atomic absorption spectroscopy (CVAA) using the same quality assurance protocol. Egg contents were also homogenized and prepared similarly as the blood. CVAA analysis provided values of total Hg in ppm for wet weight.

Establishing Hg risk categories

Samples collected from lakes in other New England states, the Great Lakes region, and the Canadian Maritimes, were used in regional comparisons and for measuring some Hg effects endpoints. We categorized loon territories according to known exposure to MeHg (indicated by blood or eggs). The four risk categories were based on literature and *in situ* studies by the authors and their collaborators for four matrices (Table 2). Low risk indicates background Hg levels that are minimally impacted by anthropogenic inputs. Loon territories that are in the moderate risk category have elevated MeHg availability but levels most likely do not impact individuals. Individual loons that are designated in the high risk category are exposed to toxic levels of environmental Hg that potentially have molecular, organism, and/or population effects. The extra high Hg category is designated based on known impacts on loons and other birds. Prey fish Hg levels listed in each category reflect the risk to loons (Evers and Reaman 1998).

Table 2. Risk categories for MeHg (ppm) availability in the Common Loon

Matrix	Low	Moderate	High	X High	Reference Base
Egg	0-0.5	0.5-1.0	1.0-2.0	>2.0	Barr 1986
Blood-Adult	0-1.0	1.0-3.0	3.0-4.0	>4.0	BRI[1], inferred by Barr 1986 [2]
Blood-Juvenile	0-0.1	0.1-0.3	0.3-0.4	>0.4	Meyer et al. 1998[3], BRI[1]
Feather	0-9	9-20	20-35	>35	Thompson 1998, BRI[1]
Prey Fish	0-0.1	0.1-0.3	0.3-0.4	>0.4	Barr 1986

[1] BRI refers to unpublished data by BioDiversity Research Institute
[2] Adult blood Hg levels are generally 10x higher than prey Hg levels (Evers and Reaman 1998) and Barr 1986 found lower reproduction of loons with prey Hg levels of 0.3 ppm and no reproduction at 0.4 ppm.
[3] Applies to 4-6 week-old juveniles, only.

Results:

Productivity:

A total of 28 established territorial pairs currently occupy Lake Umbagog (Table 3, Appendix 1). This is a substantial increase from the nine territories found in 1976 (Table 4, Appendix 2). Of the 480 potential years for an established territorial pair to attempt nesting, 71% nested (i.e., nesting success). Some established territories were more

Table 3. Summary of established loon territories, their years of occupancy, measured and calculated reproductive measures[1], and rating of reproductive success on Lake Umbagog, 1976-99.

Territory	Year	#Yrs	#TP	#NP	#NA	Renest	#SY	#LY	LY/SY	NP/TP	SY/NP	LY/NP	SY/TP	LY/TP	Rating[2]
NORTHERN END															
Chewonki	93-99	7	6	3	3	0	3	3	1.00	0.50	1.00	1.00	0.50	0.50	ML
Harper's Meadow	86-99	15	14	11	11	0	16	16	1.00	0.79	1.45	1.45	1.14	1.14	XH
Lawrence	83-99	17	12	4	4	0	6	4	0.67	0.33	1.50	1.00	0.50	0.33	ML
Leonard Marsh	76-99	24	22	20	21	1	24	16	0.67	0.91	1.20	0.80	1.09	0.73	MH
Leonard Pond	77-99	23	23	20	21	1	21	13	0.62	0.87	1.05	0.65	0.91	0.57	MH
L. Magalloway	83-99	17	17	13	13	0	13	6	0.46	0.76	1.00	0.46	0.76	0.35	ML
Magalloway	89-99	11	11	11	12	1	17	12	0.71	1.00	1.55	1.09	1.55	1.09	XH
Pine Point	76-99	24	24	19	19	0	25	18	0.72	0.79	1.32	0.95	1.04	0.75	H
Rapid River	76-99	24	24	19	19	0	17	10	0.59	0.79	0.89	0.53	0.71	0.42	ML
Sturtevant	77-99	23	22	19	22	3	15	15	1.00	0.86	0.79	0.79	0.68	0.68	MH
Sunday	76-99	24	24	21	27	6	25	18	0.72	0.88	1.19	0.86	1.04	0.75	H
Sweat Meadow	92-99	8	8	7	8	1	12	8	0.67	0.88	1.71	1.14	1.50	1.00	XH
Thibodeau	96-99	4	4	1	1	0	0	0	0.00	0.25	0.00	0.00	0.00	0.00	XL
NORTH SUM		221	211	168	181	13	194	139	0.68	0.74	1.13	0.82	0.88	0.64	
(+/- SD)									0.26	0.23	0.44	0.36	0.42	0.33	
SOUTHERN END															
Absalom	87-99	14	10	8	10	2	8	5	0.63	0.80	1.00	0.63	0.80	0.50	ML
B Brook	78-99	22	18	5	5	0	0	0	0.00	0.28	0.00	0.00	0.00	0.00	XL
Bear Island	76-99	24	24	18	19	1	6	5	0.83	0.75	0.33	0.28	0.25	0.21	L
Big Island - N	85-99	15	14	8	10	2	5	3	0.60	0.57	0.63	0.38	0.36	0.21	L
Big Island - S	76-99	24	20	14	14	0	16	8	0.50	0.70	1.14	0.57	0.80	0.40	ML
Black Is. Cove	76-99	24	23	17	21	4	12	11	0.92	0.74	0.71	0.65	0.52	0.48	ML
Glassby Cove	77-99	23	22	21	22	1	20	5	0.25	0.95	0.95	0.24	0.91	0.23	L
Gull Island	94-99	6	6	4	5	1	1	1	1.00	0.67	0.25	0.25	0.17	0.17	L
Metallak	80-99	20	19	12	15	3	5	4	0.80	0.63	0.42	0.33	0.31	0.25	L
Potter	94-99	6	6	4	5	1	6	1	0.17	0.67	1.50	0.25	1.00	0.17	L
Sargent	79-99	21	19	5	4	0	2	1	0.50	0.26	0.40	0.20	0.11	0.10	XL
Southeast Arm	76-99	24	24	16	20	4	17	16	0.94	0.67	1.06	1.00	0.71	0.67	MH
Stateline	79-99	21	21	15	18	3	6	4	0.67	0.71	0.40	0.27	0.29	0.19	L
Three Island	81-99	19	19	16	18	2	15	7	0.47	0.84	0.94	0.44	0.79	0.37	ML
Thurston	76-99	24	24	22	24	2	17	9	0.53	0.92	0.77	0.41	0.71	0.38	ML
SOUTH SUM		287	269	185	210	26	136	80	0.59	0.68	0.70	0.39	0.52	0.29	
(+/- SD)									0.29	0.19	0.40	0.24	0.32	0.17	
Grand Summary	76-99	508	480	353	391	39	330	219	0.63	0.71	0.90	0.59	0.68	0.46	
(+/- SD)									+/-0.28	+/-0.21	+/-0.46	+/-0.37	+/-0.41	+/-0.31	
Statewide Mean									0.76	0.68	1.00	0.76	0.68	0.52	
(+/- SD)									+/-0.06	+/-0.06	+/-0.13	+/-0.11	+/-0.11	+/-0.10	

[1]Headings: #years is number of years pair was on territory; #TP is number of years a territorial pair was present; #NP is number of year a nesting pair was present, #NA is number of nesting attempts, Renest is number of times a pair renested within a year; #SY is the number of young hatched; and #LY is the number of young fledged.
[2]Rating key for categorizing reproductive success by territory: XL=extra low, L=low, ML=moderately low, MH=moderately high, H=high, and XH=extra high (see Figure 3).

likely to have pairs with fewer nesting attempts over time. Five territories (18%) had pairs that nested 50% or less of the time. Conversely, four territories (14%) had pairs that attempted nesting 90% of the time or more (mean occupied territory equaled 20 years) (Table 3). Once an established territory was initiated, it was only unattended 5% of the time (480/508). A total of 39 renests from 18 territories was recorded out of 391 confirmed nesting attempts (rate of 10%). Sunday Cove had the highest rate of renesting at 22%. Of the 391 nesting attempts, a total of 330 young hatched from 592 eggs known to be laid (or a per egg hatch rate of 56%). Survival of chicks living past six weeks of age was 67%, while mean chick survival per territory was 63% +/- 28%. Chick survival was less than 50% in four territories (Glassby Cove, Lower Magalloway, Potter, Three Island) and was over 90% in six territories (Black Island Cove, Chewonki, Gull Island, Harper's Meadow, Southeast Arm, and Sturtevant). Over the past 24 years, 50% of the fledged young were produced by seven territories.

On average, 71% of the territorial-years had pairs that attempted nesting. The mean number of chicks hatched per territorial pair was 0.69 +/- 0.41 and ranged from 0 (B Brook) to 1.55 (Magalloway) with Harper's Meadow (1.14), Pine Point (1.04), Sweat's Meadow (1.50), and Sunday Cove (1.04) having over one chick per year of an occupied territory. Of the pairs that attempted nesting, the mean number of chicks hatched was 0.90 +/-0.46. The final measure of reproductive success, number of large young per territorial pair or overall productivity, was recorded with a mean of 0.46 +/- 0.31 (Table 3) while the statewide, 24-year average was slightly higher at 0.52 +/- 0.10 fledged young /territorial pair.

The number of established territorial pairs have increased since 1976 by three-fold (Table 4). The 5-year mean percent change in territorial pairs between period A and B was a 39% increase. This increase slowed in period C has remained constant for the remaining time periods at a mean of 17%. The number of nesting pairs between periods A and B increased by 62%, but has not continued to increase as in the number of territorial pairs (Table 4). Coincidentally, the number of chicks hatched was 14 in 1976 and 1999, however, the mean increase of hatched chicks per 5-year period has increased each time period except for the last period where the was a 6% decline.

Table 4. Annual summary for established loon territories, measured and calculated reproductive measures, and rating of reproductive success on Lake Umbagog, 1976-99.

Year	#TP	#NP	#NA	#SY	#LY	#eggs	#Renest	Time Period	#TP	#NP	#NA	#SY	#LY	NP/TP	LY/SY	LY/TP
1976	9	9	9	14	13	14	0									
1977	11	9	9	9	9	15	0									
1978	12	6	8	2	0	11	2	76-80	12.4	9.0	9.4	8.0	6.6	73%	83%	0.53
1979	15	11	11	13	10	21	1	(A)								
1980	15	10	10	2	1	16	0									
1981	15	13	13	12	8	24	0									
1982	17	14	14	11	9	21	0									
1983	17	17	19	19	17	31	2	81-85	17.2	14.6	16.6	13.8	11.2	85%	81%	0.65
1984	18	14	20	9	7	28	6	(B)								
1985	19	15	17	18	15	26	2									
1986	19	13	14	18	11	27	1									
1987	18	13	13	15	9	20	0									
1988	22	11	11	10	8	15	0	86-90	20.4	13.0	13.8	14.8	8.8	64%	59%	0.43
1989	22	12	14	13	8	20	2	(C)								
1990	21	16	17	18	8	31	1									
1991	23	15	16	14	9	23	1									
1992	23	16	16	19	14	22	0									
1993	23	22	24	16	12	36	3	91-95	23.8	19.0	21.0	16.8	11.0	80%	65%	0.46
1994	26	21	27	20	13	29	5	(D)								
1995	24	21	22	15	7	35	1									
1996	27	21	25	17	9	38	4									
1997	28	19	22	19	9	37	3									
1998	28	19	22	13	5	25	3	96-99	27.8	18.8	21.8	15.8	7.8	68%	49%	0.28
1999	28	16	18	14	8	24	2	(E)								
Total	480	353	391	330	219	589	39									

Capture and color-marking:

A total of 58 loons representing 17 territories were captured, had blood and feather samples taken and were uniquely color-marked for future remote identification (Table 5). Of the 39 adults banded, 25 were present in 1999. The weight of adult loons is a measure of gender. Dimporphism is particular apparent in Lake Umbagog loons (mean difference in body mass is 28%) with males averaging 5,848 +/- 783 g (range is 5,250 to 6,600g) and the smaller females average 4,230 +/- 316 g (range is 4,050 to 5,150g). Gender is also later confirmed while observing the pair (males are generally, visibly larger) and noting which pair member yodels (only males yodel).

Table 5. Summary of loons captured and color-marked at Lake Umbagog, 1993-99.

Marking statistics	#
Number of territories represented	17
Number of adults (males)	22
Number of adults (females)	17
Number of recaptures (males)	8
Number of recaptures (females)	7
Total number of adults	39
Total number of juveniles	19
Total number of loons	58

Demographic

The rate of adults returning to their territory of the previous year (or annual site fidelity) was 84.5% (n=82 actual return-years out of 97 potential return-years) and did not significantly differ between sexes (p>0.05) (Table 6). A total of 9% of the adults switched from their former territory while the remaining outcome of the 6.5% of adults is unknown and is considered the maximum annual adult mortality rate (i.e., annual survivorship is at least 93.5%). Of the 13 adults switching off their former territories, 43% of the males and 83% of the females were found elsewhere on Lake Umbagog. Of these adults, 14% of the males (1 of 7) and 17% of the females (1 of 6) were able to reestablish a breeding territory (Gull Island-98 to Black Island Cove-99 for the male and Lawrence-94 to B Brook-98 and then Sturtevant-99 for the female). The known outcome of adults switching off their territory, but not becoming an established territory holder, was to remain in the general vicinity of their previously held territory (males were 29%, and females were 67%). The outcome of the remaining adults was unknown (57% of the males, 17% of the females).

Table 6. Rate of return to the previous year's territory for color-marked adults on Lake Umbagog, 1994-99

	Potential			Actual			% Site Fidelity		
Year	Male	Female	Both	Male	Female	Both	Male	Female	Both
1994	0	2	2	0	2	2	0	100%	100%
1995	7	7	14	6	6	12	86%	86%	86%
1996	11	8	19	10	7	17	91%	88%	89%
1997	13	8	21	11	6	17	85%	75%	81%
1998	13	7	20	10	5	15	77%	71%	75%
1999	10	11	21	9	10	19	90%	91%	90%
Total	54	43	97	46	36	82	85%	84%	84.5%

Following a mate switch (i.e., divorce), 40% of the males and 83% of the females did not nest. The number of fledged young per year before a divorce was 1.4 and 1.2 for males (n=13) and females (n=16), respectively. The year following the divorce, the number of fledged young per year was 0.2 (n=4) and 0.17 (n=7) for males and females, respectively.

None of the adults banded on Lake Umbagog have been reobserved on neighboring lakes and they have not been recovered elsewhere during migration or winter. Of the 19 loon chicks banded from 1993-99, one has been reobserved during the breeding season. A chick banded on the Harper's Meadow territory in 1995 was found in March of 1997 in Camden Harbor, Maine and was later observed several times in the summer of 1998 at the mouth of the Androscoggin River (as a 3-year old). It was not observed in 1999. Another chick banded in 1995 on nearby Pontook Reservoir (McGill's territory) was found in 1998 and 1999 as a loner throughout each summer on the Androscoggin River.

Methylmercury exposure

Sediment: Sediment samples were taken at 1-10 cm (surface) and 20-30 cm (historical) to provide a rough estimate of changes in Hg inputs over time. Sediment core Hg was also adjusted by percent total organic carbon (TOC). The mean surface sediment total Hg level was 0.20 ppm (dw, 5.7% TOC) and was at the accepted 0.20 ppm benchmark of lowest effect levels (Persaud et al. 1993). Historical total Hg levels were 0.10 (dw, 8.6% TOC). The percent TOC in surface and historical sediment samples was used to create an index that could be used to fairly compare across sites. The adjusted mean Hg level for surface samples (0.09 ppm, dw) was therefore nine times higher than the historical levels (0.01 ppm, dw).

Fish: Mean total Hg levels for each size class of fish are: small (4 species) was 0.21 +/- 0.04; medium (4 species) was 0.25 +/- 0.08; large (5 species) was 0.27 +/- 0.05; and extra large (4 species) was 0.42 +/- 0.19. Even though loons likely forage on white suckers, they were not included in the above large fish summary because small, medium and extra large size classes were not represented and using one size class Hg levels would unfairly bias the comparisons between size classes and Hg levels.

Table 7. Summary of mercury levels in six fish species that are potential prey for loons on Lake Umbagog.

Species	Size class	Sample* Size	Mean Weight(g)	Composite	Mean Total Hg	Risk Rating
Brown Bullhead	medium	4	59	yes	0.29	M
(Ameiurus nebulosus)	large	4	94	yes	0.27	M
	X large	3	176	yes	0.33	H
	>X large	1	226	no	0.41	XH
Chain Pickerel	small	2	14	yes	0.17	M
(Esox niger)	large	1	101	no	0.32	H
	X large	1	209	no	0.30	H
Fallfish	small	4	4	yes	0.22	M
(Semotilus corporalis)	medium	1	32	no	0.34	H
	large	1	98	no	0.30	H
	X large	1	200	no	0.35	H
Golden Shiner	small	3	6	yes	0.25	M
(Notemigonus crysoleucas)	medium	4	31	yes	0.18	M
Yellow Perch	small	3	11	yes	0.18	M
(Perca flavescens)	medium	2	31	yes	0.18	M
	large	5	54	yes	0.20	M
	X large	1	118	no	0.70	XH
	> X large	1	221	no	0.82	XH
White Sucker	large	1	84	no	0.08	L
(Catostomus commersoni)						

* Sample size (n) represents the number of fish in the composite.

Generally small- and medium-sized fish were below the high risk impact threshold (once exception was medium-sized fallfish), while large-sized fish exceeding the 0.30 ppm of total Hg included the Chain Pickerel and Fallfish but not the Brown Bullhead, Yellow Perch, and White Sucker. However, extra large-sized and larger fish all exceeded the high and sometimes extra high risk category. The only species of fish and size class in the low Hg risk category was large White Sucker.

Yellow Perch were also analyzed for percent of MeHg for four size classes. The mean MeHg levels for each size class was: 0.18 +/- 0.03 (n=2) for small; 0.17 +/- 0.05 (n=6); 0.17 +/- 0.07 (n=3), and 0.19 (n=1). Inorganic Hg was less than the detection limit (0.10) for most size classes but was measured at 0.12 (35g) and 0.24 (78g) for the two larger perch. This indicates that although total Hg levels represent at least over 67% of MeHg concentrations, some perch have significantly lower MeHg concentrations of 44-61% of total Hg levels.

Table 8. Summary of mean mercury concentrations in tissues collected from loons captured on Lake Umbagog, 1993-99.

Matrix type	Unit	Sample Size	Mean +/- sd	range
Adult Male blood	ww, ppm	28	2.24 +/- 0.56	1.21 to 3.48
Adult Female blood	ww, ppm	22	1.14 +/- 0.47	0.53 to 2.23
Adult Male feather	fw, ppm	28	15.6 +/- 4.4	7.3 to 24.3
Adult Female feather	fw, ppm	24	8.7 +/- 3.3	4.3 to 19.5
Juvenile blood	ww, ppm	17	0.18 +/- 0.15	<DL to 0.48
Whole egg	ww, ppm	32	0.70 +/- 0.34	0.17 to 1.62

Common Loon: The mean blood Hg level for males and females was 2.24 ppm and 1.14 ppm, respectively (n=50) (Table 8). The mean feather total Hg level for males and females was 15.6 ppm and 8.7 ppm, respectively (n=52). Mean blood and feather Hg levels in loons are below risk thresholds set by Evers et al. (1999) although some individuals are over these limits (Table 2). Three adult loons (all males), from Leonard Pond, Magalloway, and Potter Cove territories were found to exceed the high risk category of 3.0 ppm in blood. Individuals (all males) that exceeded the high risk feather category of 20 ppm include individuals at Gull Island, Harper's Meadow, Lower Magalloway, Magalloway River, and Potter Cove.

Table 9. Matrix Hg levels categorized according to set risk thresholds.

Territory	AdMaleBl	AdFemBl	JuvBl	Egg	Risk
Absalom	-	-	-	H	H
Bear Island	-	-	-	M	M
Black Island	M	L	-	2H,3M	M
Chewonki	M	L	L	-	L
Glassby	M	M	M	-	M
Gull Island	M	L	-	M,2L	L
Harper's Meadow	H, 3M	3M	H,2M,L	-	M
Lawrence	M	L	-	-	M
Leonard Marsh	M	L	-	-	M
Leonard Pond	H, M	M, L	-	-	M
Lower Magalloway	M	-	H	2M	M
Magalloway	H, 3M	2M	H,M,3L	H	H
Metallak	M	M	-	-	M
Pine Point	M	2M	H, L	-	M
Potter	H, M	-	H, L	-	H
Rapid River	M	L	-	-	L
Southeast Arm	-	-	-	2H, M	H
Stateline	-	-	-	2M	M
Sturtevant	-	-	-	M	M
Sunday Cove	M	M	-	M, 2L	M
Sweat Meadow	3M	3M	-	-	M
Three Island	2M	L	-	2M, L	M
Thurston	-	-	-	2M,3L	L

* Five territories were not sampled and include: B Brook, Big Island-North, Big Island-South, Sargent, and Thibodeau.

High risk thresholds set for juveniles were above 0.30 ppm for some individuals between 4-6 weeks of age. Lakewide mean Hg levels in juveniles are below this risk limit, although four territories have loons that exceed this limit: Lower Magalloway, Magalloway River, Pine Point, and Potter Cove. Three of the four are the same territories where adult loons also exceeded their high risk category. Mean egg Hg levels from LakeUmbagog loons were above impacts found in other bird species (Thompson 1996) however they were below the 1.0 ppm high risk threshold set by Evers et al. (1999). There are six eggs from four loon territories that exceed the high risk threshold (Absalom, Black Island Cove, Magalloway, and Southeast Arm). When categorizing the blood and egg matrices by Hg risk levels, 23 of the 28 loon territories were represented (Table 9, Appendix 3). Of these, 17.5% were rated low, 65% were moderate, and 17.5% were at high risk to impacts from Hg ingestion. The four territories at high risk to MeHg availability were Absalom, Magalloway, Potter, and Southeast Arm.

Discussion

Lake Umbagog's Common Loon's breeding population has been increasing since annual surveys began in 1976. This increase is apparently related to the reduction of anthropogenic impacts that originally reduced Lake Umbagog's breeding population to levels lower than the carrying capacity. Although the year with the lowest number of territorial pairs on Lake Umbagog is unknown, the nine territorial pairs found in 1976 are used as the benchmark for demographic aspects for the past 24 years (Appendix 4). There are two concerns with today's breeding population of Lake Umbagog's loons. There is a significant decline in fledging success for the current 5-year time period (Table 4) and there is a significant difference in several reproductive measures between the north and south end (Table 3). These concerns may be related to density-dependent pressures, hydrological management, methylmercury toxicity, or their interactions.

Density-dependent Pressures

The spatial (Appendix 4) and temporal (Figure 3) changes of Lake Umbagog's breeding population have been carefully documented and since 1993, individual performance from uniquely marked loons has enhanced the resolution of monitoring capabilities. Two aspects of characterizing loon demographics are emphasized and include (1) describing the impacts of loon densities on social structure and ultimately reproductive success and (2) assessing the habitat quality of established loon territories as measured by their reproductive performance. Although these density dependent reproductive measures are natural (Fowler 1981), impacting them physically through hydrological manipulation or chemically through enhancement of MeHg availability is possible and may be happening on Lake Umbagog.

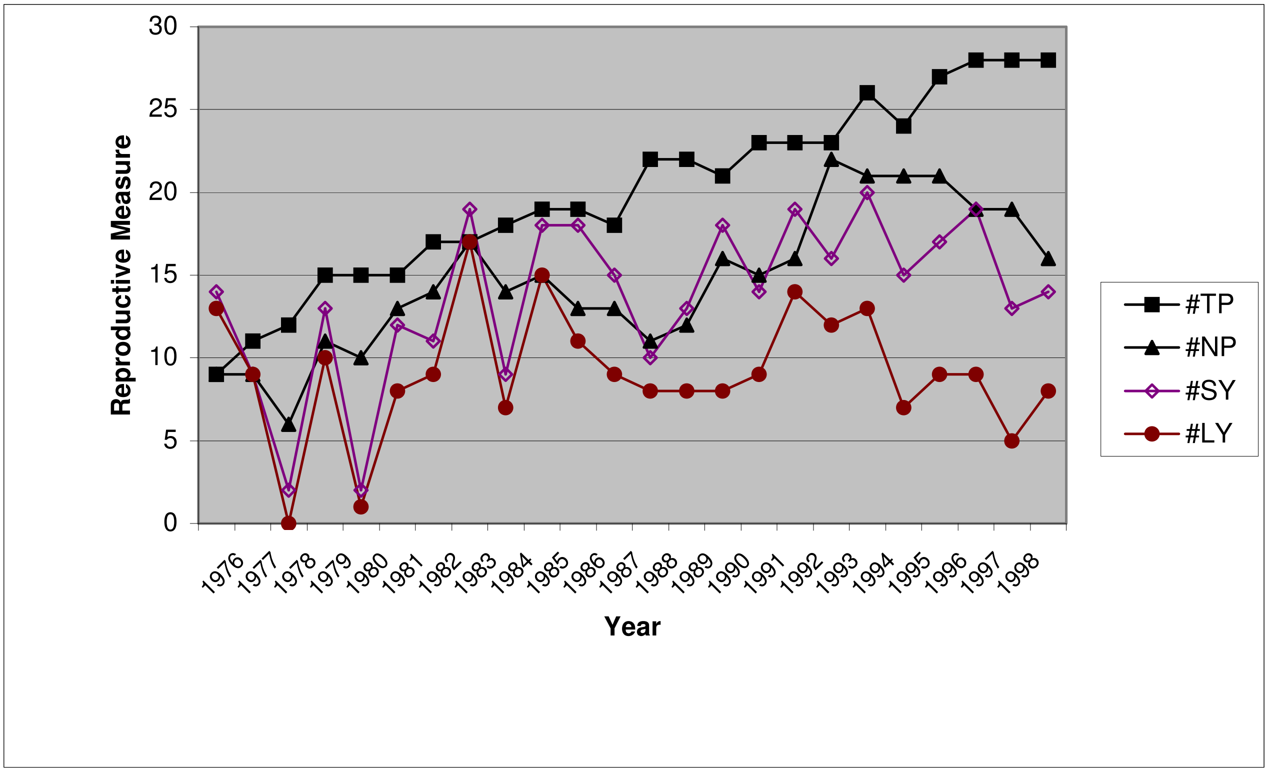
Loon Population Dynamics: The Common Loon is a classic example of a K-selected species. Adults are on of the largest bird species in the northern temperate zone and have a lifespan that likely ranges up to 30 years with an annual survival rate of 95% for established territory holders. Although a maximum of two chicks may be produced each year, on average 0.52 +/- 0.10 young annually fledge per territory (LPC Unpubl. Data). Should an average adult loon breed for 20 years, approximately 10 young would be produced. Of these, an average of 20% would return (Evers et al. In Press) and even fewer would survive to breeding age. Large pelagic birds, such as shearwaters (*Puffinus* spp.) and fulmars (*Fulmarus* spp.), have similar life expentancies and life history strategies (Botkin and Miller 1962, Bradley et al. 1989). These and long-lived species like the Common Loon, exhibit age-dependent mortality.

The loon's life history strategy indicates its evolution in stable habitats and populations that hover at carrying capacity. Competition for high quality breeding territories is therefore intense in most situations where breeding habitat is limiting and non-breeding populations exist. The 24-year mean statewide New Hampshire non-breeding population or individuals not holding a territory is 19% (LPC Unpubl. Data).

The non-breeding individuals spend their summers in common-use areas of Lake Umbagog and frequently test the fitness of established territory holders. Evaluation occurs during "circle dances" and should an intruder determine a confrontation is energetically worthwhile, physical conflict may ensue. The same-sex conflicts happen throughout the breeding season, although usurpations primarily occur within 1-3 weeks after ice-off and again following a nest failure.

The impacts of high intrusion rates can be measured through site fidelity and rates of divorce. In the Great Lakes,Evers et al. (In Press) defined three loon territory types including whole, multiple, and partial. Whole lake territories were those territories that occupied one lake that did not contain other territorial pairs. Loon pairs with multiple lake territories typically have a nest on a lake <60 acres (Piper et al. 1997) and use at least one other lake during the breeding season. Territories found on large water bodies where breeding pairs are adjacent to each other without physical boundaries are partial lake territories. Adult annual site fidelity in the Great Lakes was 72% on partial lake territories and was significantly lower than the 84.5% found on Lake Umbagog ($p<0.05$). This difference may be related density-dependent pressures that are higher in the Great Lakes. If this is valid, then the breeding loon density (both established territory holders and non-breeders) will likely continue to increase on Lake Umbagog (Figure 3). This is understandable since the areas with partial lake territories measured in the Great Lakes have not experienced the chronological population depression that loons on Lake Umbagog have undergone.

Figure 3 Chronological summary of Common Loon territorial pairs (TP), nesting pairs (NP), small young (SY), and large young (LY) on Lake Umbagog, 1976-99.



The switching of territories by loons does impact annual reproductive success. When there is a territorial switch the pair member that remains on territory typically establishes a pair bond with another adult. The pair member that is usurped by an intruding loon either establishes another territory or wanders without a mate for the remainder of the breeding season. On Lake Umbagog, 11 loons (5 males and 6 females) switched mates, generally within 3 weeks of ice-off. When a switch occurred 40% of the males did not attempt to nest that year while 83% of the females failed to make a nesting attempt. Therefore, the production of young hatched dropped following a switch in mates. Prior to a recorded mate switch loons hatched an average of 1.4 and 1.2 chicks, respectively for males and females. While the year following a mate switch males hatched 0.20 young and females 0.17 young.

As loon densities (i.e., number of territorial pairs) continue to increase, site fidelity will decline, divorce rates will increase, and long-term reproductive success (i.e., fledged young per territorial pair) of the breeding population will decline. This is currently evident as the 24-year chronological summary shows a relatively consistent rate of increasing territorial pairs whereas the crowding of loon territories has reduced nesting success (i.e., nesting pairs divided by territorial pairs), chick survival, and overall reproductive success in the last 5-year time period (Table 4, Figure 3). The expansion of loon pairs into the river territories contributed to a temporary increase in lakewide reproductive performance. When removing the productivity measures of these river territories during time period D, a stronger decline in reproductive measures is evident.

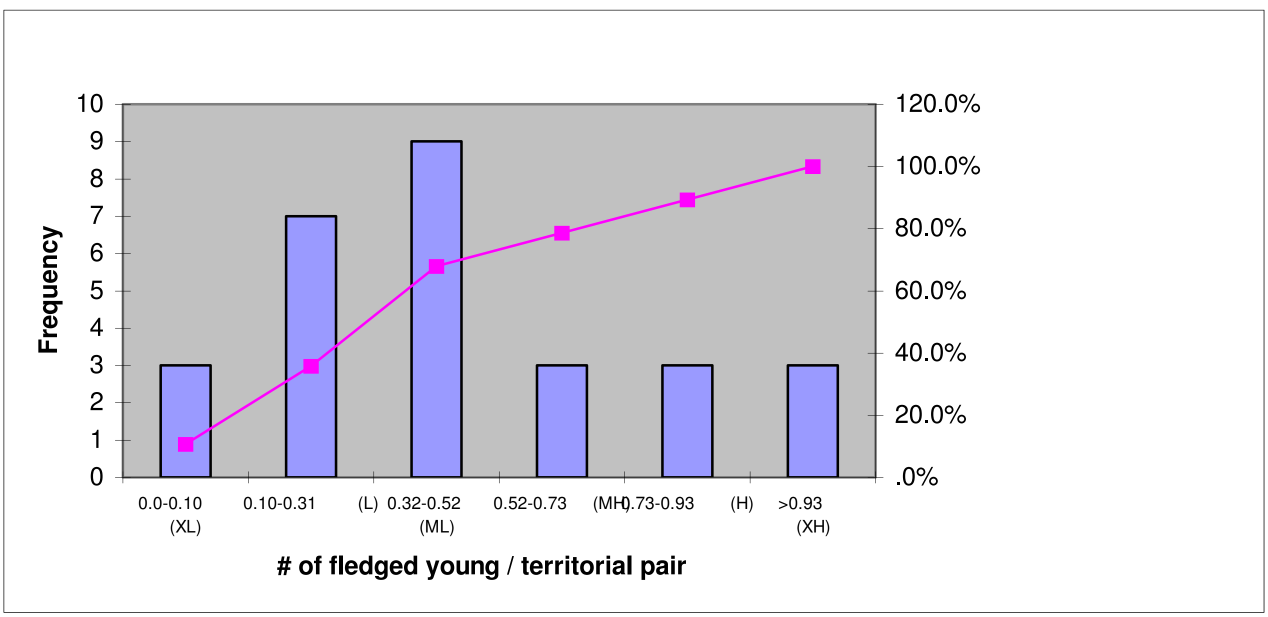
Comparison of the north and south ends of Lake Umbagog also provide evidence of density dependent pressures, although other factors are probably more responsible for the dichotomy of reproductive measures. Chick survival and the success of nesting, hatching, and fledging are lower in the south end vs. the north end (Table 3). However, the greatest discrepancies are with hatching and fledging success. Territories on the north end are much more likely to hatch their eggs and those chicks are more likely to survive to fledging age. Although higher densities of breeding and non-breeding adults are likely conflicting with parental activities the uneven habitat quality is a potentially confounding factor.

Evaluating Habitat Quality: The quality of nesting habitat was measured and rated according to reproductive performance. Nest and territory habitat features were not characterized. The six categories of nesting habitat quality were statistically developed and based on the 24-year mean for Lake Umbagog (0.46 +/- 0.31). The statewide mean for New Hampshire of 0.52 surviving chicks per territorial pair tended to be higher (LPC unpubl. data). The quality of nesting habitat was broken down as the mean number of chicks survived per territorial pair: they are extra low (0-0.10), low (0.11-0.31), moderate-low (0.32-0.52), moderate-high (0.54-0.73), high (0.74-0.93), and extra high (>0.93). Loon territory quality is likely not constant and over the past 24 years changed according to vegetative features, human activity, changes in water levels, and changes in loon social dynamics.

Loon pairs in 1976 likely occupied some of the highest quality nesting habitat on Lake Umbagog (Appendix 2). Except for the four river territories, territory initiation over time increasingly occurred in areas in view of other loon territories, and these higher densities subsequently reduced reproductive performance and likely compromised habitat quality. Expansion of loon pairs into the river territories midway during the breeding population increase may represent phenotypic plasticity, where individuals programmed for breeding in lake scenarios simply adapted to river scenarios (Caswell 1983). This adaptation is likely density dependent.

A total of 19 territories were rated as below average. Using this reproductive measure as an indicator of the nesting habitat quality shows 32% are above average and are carrying the reproductive load for Lake Umbagog (Figure 4). The three river territories are particularly highly productive, even though these are relatively new territories on Lake Umbagog (territory initiation was 1986 for Harper's Meadow, 1989 for Magalloway, and 1992 for Sweat Meadow). Unlike loon territories on the lake, the river territories are likely less prone to intruding non-breeding adults vying for an established territory. The Sunday Cove territory is also an area that can be effectively protected by a breeding pair. Five other territories also produced an above-average number of fledged young and although they do not share the optimal territory configurations for minimizing the frequency of intrusions like the river territories, high quality nesting habitat likely contributed to improved fledging success (Table 3). The below average reproductive success for many of the other established territories is likely related to territory boundaries that have a high water to shoreline ratio, therefore providing increased access from non-breeding adults. However, until physical measurements can be made for each loon territory, it is difficult to factor out other influences.

Figure 4. Frequency of territories designated in six categories for the number of fledged young per territorial pair on Lake Umbagog, 1976-99.



Hydrological Management

The reproductive success for all territories before 1985 was compromised by the unmanaged water level fluctuations (Table 10). Impact from floodings and drawdowns after 1985 were likely closer to natural rates, although the past seven years have exhibited a tripling of the percent failure since the previous time period. The water level management scheme has been in place since 1985. It apparently, dramatically improved the percent of nest failures related to nest floodings and particularly strandings. Predicting the impact of storm evens on the three watersheds flowing into Lake Umbagog with models would potentially reduce above-natural flooding and starnding of loon nests.

Nest failures are significantly greater on the south end (n=34) vs. the north end (n=13) ($p<0.05$), and expectedly, renesting attempts are double the rate on the southern end (Table 3). Lower nesting success (i.e., hatched young per nesting pair) on the southern end reflects the higher rate of nest failures that are at least partly due to changing water levels. A comparison with reservoirs in Voyageurs National Park, Minnesota shows an average of 60-70% of loon nests failing due to water level changes (Reiser 1988). Although Lake Umbagog's nest failure is significantly lower, loon populations in Minnesota are at carrying capacity while northern New Hampshire's is still increasing and recolonizing vacant breeding habitat.

Table 10. Summary of nest failures related to water level fluctuations on Lake Umbagog, 1976-99.

Time Span	Years	Nesting Attempts	Nests Flooded	Nests Stranded	Percent Failure
1976,78-84	8	94	13	11	26%
1985-92	8	118	4	1	4%
1993-99	7	139	15	3	13%

Assessment of the risk of methylmercury exposure

The overall impact on reproductive success from MeHg availability is unknown and was not analyzed, however the availability of MeHg in four biotic matrices was examined and a certain degree of hazard to Lake Umbagog loons does exist. The availability of MeHg was measured in sediments, fish and various loon matrices for Lake Umbagog and other lakes in its watershed from 1993-99. A comparison of Lake Umbagog loon Hg levels with neighboring reservoirs within the watershed provided relevant context.

Lakewide mean Hg levels in sediments and loon eggs exceeded accepted threshold levels of impact, while overall Hg levels in fish and adult or juvenile blood were elevated but did not exceed established thresholds (Table 10). Although mean Hg levels in the biota indicate less lakewide risk compared to neighboring lakes, certain size classes and species of fish, age and sex classes of loons, and geographic areas of the lake are more at risk than others.

Although sediment Hg levels can provide a chronological benchmark for the amount of Hg entering an aquatic system, it is not a good predictor for MeHg productivity and availability because of unrelated hydrology and biogeochemical processes. Sediment Hg levels on Lake Umbagog are similar to other lake systems, including extremely high risk ones like Flagstaff Lake (Evers and Reaman 1998).

Fish provide a more accurate accounting of the processes impacting MeHg availability than abiotic measurements. Six species of fish were separated into four size classes (based on Barr 1996) and analyzed for total Hg levels. A fifth category (>extra large) was opportunistically measured. Differences in fish Hg levels between size classes tended to increase. Fish were collected from only one site (Three Island Cove), which is not representative of all Lake Umbagog areas. Adult female and larger juvenile loons likely targeted small- and medium-sized fish. Although Yellow Perch are a preferred species (Barr 1996, Evers and Reaman 1998) and their Hg levels were below the 0.30 ppm high risk impact threshold, other species such as medium-sized bullhead and fallfish did exceed high risk thresholds and could potentially put loon individuals at risk to toxic amounts of Hg. Larger male loons would tend to eat more large-sized fish that generally were at or exceeded impact thresholds (i.e., bullhead, pickerel, and fallfish). Individual fish in the extra large category or larger may provide a potential Hg spike to adult male loons that may on average have one meal per day of this size class (Barr 1996). Large Yellow Perch were exceptionally high and conceivably one meal could impact an individual loon (most likely a male).

Lakewide mean blood Hg levels for adult and juvenile loons were relatively moderate and did not exceed high risk thresholds (Table 10). Blood levels indicate acute dietary Hg uptake and do generally reflect potential fish prey Hg levels found on Lake Umbagog (Evers and Reaman 1998), while feather Hg levels provide an indication of chronic bioaccumulation (Evers et al. 1999). Since most of the annual MeHg burden in loons is acquired during the breeding season (BRI, unpubl. Data) the amount of MeHg entering a loon during the breeding season is mostly reflected in the flight feathers molted in during the winter. These flight feathers are cut during the breeding season to better understand chronic body burdens and appear to also readily indicate age of the loon (i.e., older loons have the opportunity to bioaccumulate more MeHg than younger loons). Since the mean annual increase in MeHg body burdens is 10.6% (for males) and 7.4% (for females) (Evers et al. 1999) they will eventually reach toxic levels of MeHg.

Male loons had significantly higher body burdens of MeHg than females due to (1) females ability to dump mercury into their eggs and (2) because of the sexual dimorphism, the larger males also tend to eat larger, older fish that have higher Hg levels than smaller, younger fish (Evers et al. 1998). Juvenile loons do increase their blood mercury levels as they age in high risk situations, while in lower risk situations (prey fish are <0.30 ppm) they are able to depurate their mercury body burdens through one of their three feather molts (Evers and Reaman 1998). On Lake Umbagog, some areas likely have the capacity to support fish Hg levels that would overwhelm the ability of juvenile loons to depurate all the Hg through their feathers and therefore would create an increase in blood Hg levels through the juvenile growth period.

One pattern that has developed is the tendency for blood MeHg levels to be highest in the loon territories in southern Lake Umbagog and on the Magalloway River versus those on the Androscoggin River and northern Lake Umbagog (Table 11). The distinction between Hg levels on the lake with the northern end having significantly less MeHg available vs. the southern end is a new finding and implies differing biogeochemistries and known hydrological impacts as well as potential point sources problems from the Dead Cambridge River. Conversely, the basis for high Hg levels in the Magalloway River are relatively well known. The headwaters of the Magalloway River are several miles north at Aziscohos Lake which has loons with some of the highest MeHg body burdens in the United States (Evers and Reaman 1998, Evers et al. 1998). Apparently some of the waterborne mercury from Aziscohos Lake flows into the Magalloway and is related to the MeHg body burdens in adult and juvenile loons foraging in the river.

Table 11. Mean (+/- sd) blood and egg Hg concentrations in four locations, 1993-99.

Location	Adult Male	Adult Female	Juvenile	Egg
Southern L. Umbagog	3.20 (n=1)	None	0.21 +/- 0.27 (n=2)	0.76 +/- 0.32 (n=12)
Magalloway River[1]	2.48 +/- 0.62 (n=7)	1.35 +/- 0.47 (n=4)	0.17 +/- 0.14 (n=7)	0.75 +/- 0.31 (n=3)
Androscoggin River[2]	2.24 +/- 0.66 (n=8)	1.29 +/- 0.13 (n=6)	0.14 +/- 0.08 (n=3)	-
Northern L. Umbagog	1.96 +/- 0.30 (n=12)	0.89 +/- 0.42 (n=11)	0.12 +/- 0.14 (n=4)	0.67 +/- 0.38 (n=16)

[1] Territories include Magalloway, Lower Magalloway, and Leonard Pond
2 Territories include Harper's Meadow and Sweat Meadow

Relationship of water level fluctuations and MeHg availability

To determine if water level fluctuations affect MeHg productivity and availability, sediments, forage fish, and loon tissues were sampled from Lake Umbagog and several lakes in the Rangeley Lakes study area (Table 12). Patterns predicting Hg concentrations in abiotic and biotic matrices were undetected for the waterbodies except for extent of annual drawdown (the greater the drawdown the higher the Hg concentrations) (Evers and Reaman 1998). Therefore, each target reservoir was treated separately and the factors that contributed most toward MeHg productivity and availability and their relationship with measured biotic matrices. Because annual and summer water level fluctuations were significantly correlated with adult female and juvenile loon blood Hg concentrations ($p<0.05$) this parameter was emphasized for each lake characterization.

There are several benchmarks used for the lake characterizations. Top layer sediment Hg concentrations (unadjusted by %TOC) exceeding 0.20 ppm (dw) are considered elevated by Maine DEP standards (Persaud et al. 1993). Game fish (i.e., of a size likely to be eaten by people) Hg levels of 0.2 ppm is the level set for human fish consumption in Maine. Barr (1986) documented lowered productivity by adult loons eating fish with 0.30 ppm Hg and no productivity when foraging on fish with over 0.40 ppm Hg. Adult blood Hg levels exceeding 3.0 ppm are considered elevated. Unadjusted juvenile blood Hg levels over 0.30 ppm are considered elevated (Meyer et al. 1998). Feather Hg levels over 20 ppm indicate impact thresholds (Scheuhammer 1991).

Sampled matrices were compared with our designated threshold levels to determine their capacity to produce enough MeHg to threaten wildlife. When summarizing the various abiotic and biotic matrices by reservoir (Table 11) a more comprehensive and quantifiable evaluation was made. A reservoir by reservoir analysis indicates tremendous differences in Hg risk to wildlife. Some reservoirs such as Rangeley Lake indicate low overall lake and individual loon risks. While Lake Umbagog Hg risk rates are moderate, a closer look does show differing Hg availability (Table 11). The Magalloway River and southern Lake Umbagog loon pairs tend to have higher Hg exposure than those on the Androscoggin River and the northern part of the lake. Although flooded river valleys (e.g., Aziscohos and Flagstaff Lakes) with water level fluctuations over 1.5 m have higher Hg exposure than other reservoir types, watershed point sources for Lake Umbagog (i.e., Magalloway River and Dead Cambridge) appear to play a major role for impacting certain loon territories (Appendix 5).

Table 12. Mean Hg levels in Common Loon matrices sampled in 8 reservoirs and their summarized risk rating.

	Sediment	Game Fish	Forage Fish	Yellow Perch	Loon Egg	Male Blood	Female Blood	Male Feather	Female Feather	Juvenile Blood	Juvenile Blood Index	Matrix % Risk
(thresholds)	0.20	0.2	0.3	0.3	0.5	3.0	3.0	20	20	0.3	-	-
Wyman	-	-	-	-	2.49*	2.9	-	25.2*	-	-	-	75%
Flagstaff	0.22*	0.71*	0.63*	0.42*	0.27	4.5*	3.6*	21.7*	15.3	0.51*	2.27	71%
Aziscohos	0.25*	-	0.28	-	1.27*	3.3*	2.3	21.8*	15.6	0.39*	2.06	70%
Umbagog	0.20*	0.49*	0.26	0.19	0.70*	2.2	1.1	15.6	8.7	0.18	0.85	30%
Mooselook	0.20*	0.92*	0.29	0.23	0.85*	1.8	1.3	14.0	8.5	0.07	0.23	30%
Richardson	0.24*	0.43*	0.26	0.16	-	1.6	1.6	18.9	20.6	0.02	0.12	25%
Indian	0.24*	0.28*	0.29	0.25	-	1.8	1.4	12.6	11.4	0.19	0.76	17%
Rangeley	-	-	-	-	-	1.4	1.0	10.3	9.3	0.16	0.51	0%

* Exceeds designated threshold level

Summary of impacts on loon reproductive performance

To better understand and manage Lake Umbagog's breeding loon population, more information is needed on density dependent pressures. One of the betters approaches is to increase the number of uniquely color-marked loons, particularly young-of-the-year and paired adults on the southern end. Marked loons will continue to provide valuable insight on site fidelity, divorce rates, and individual reproductive performance, which all contribute, to assessing the lake's breeding population carrying capacity. Once the carrying capacity is better understood, aspects of loon conservation on Lake Umbagog, including raft placement, water level management, and human disturbance can be appropriately followed to balance the needs of loons as well as our hydrological, economic, and recreational interests.

The factors that contribute to MeHg production and bioavailability in Lake Umbagog include the large watershed, extensive shoreline and photic zone acreage, warm water temperature, and high amount of organic material (Evers et al. 1998). Reservoir age and flushing rates have minimal impact on MeHg bioavailability. Annual water level fluctuations are moderate (2 m) and summer changes are now less prior to 1985 due to regulation restrictions. Upstream inputs of Hg are substantial to the Magalloway and southern Lake Umbagog loon territories. The combination of all these factors create an overall moderately-contaminated system for Hg with some areas quite low in risk while others do exceed high risk thresholds. Further sampling of fish to better represent Lake Umbagog and its tributaries alongside increased effort of collecting loon matrices from the southern end are necessary to better understand geographic sources and extent of exposure. The impacts of MeHg on the molecular, organism, and population level is currently being studied throughout the watershed and will eventually be applied to Lake Umbagog's loon population.

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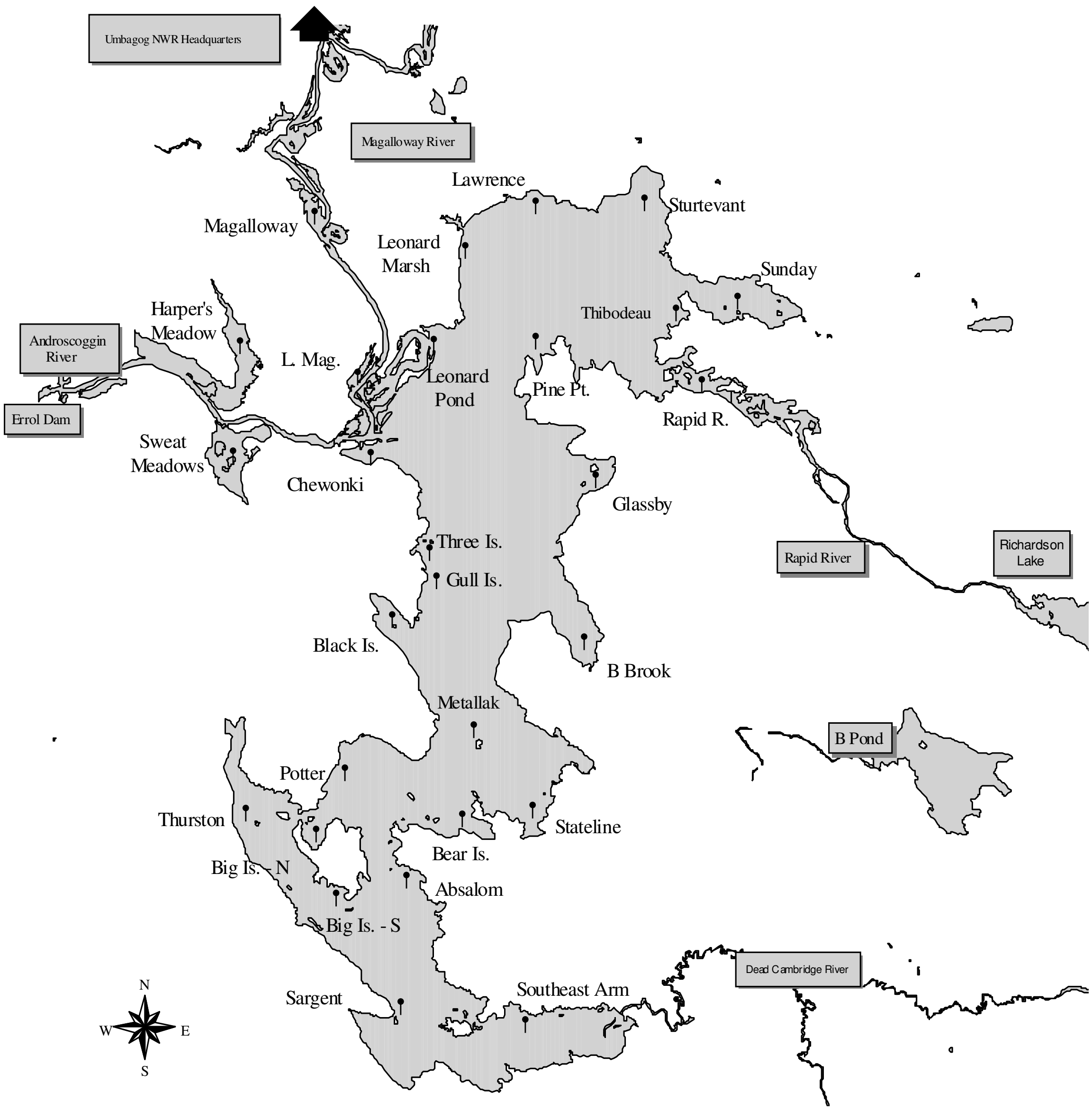
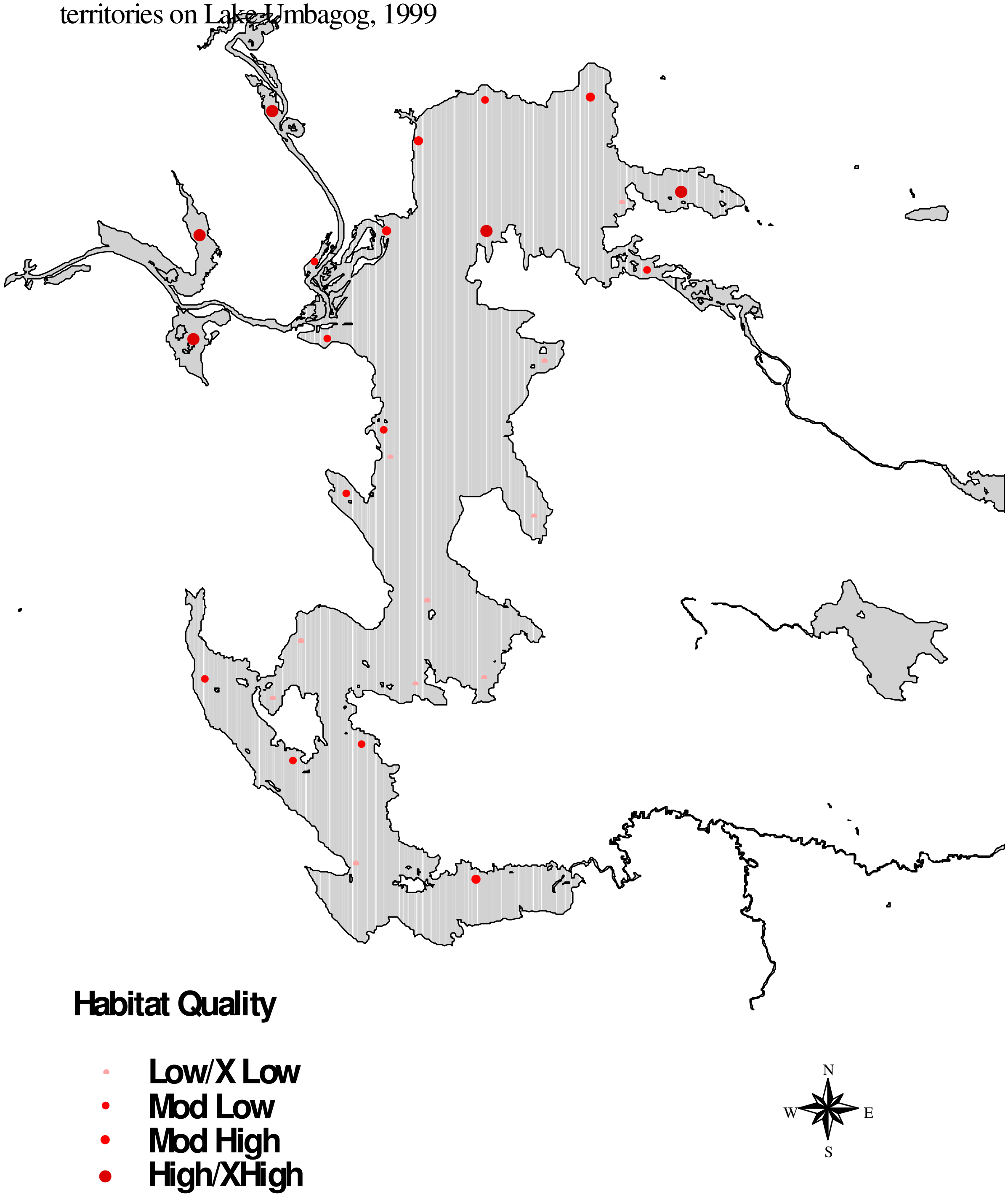
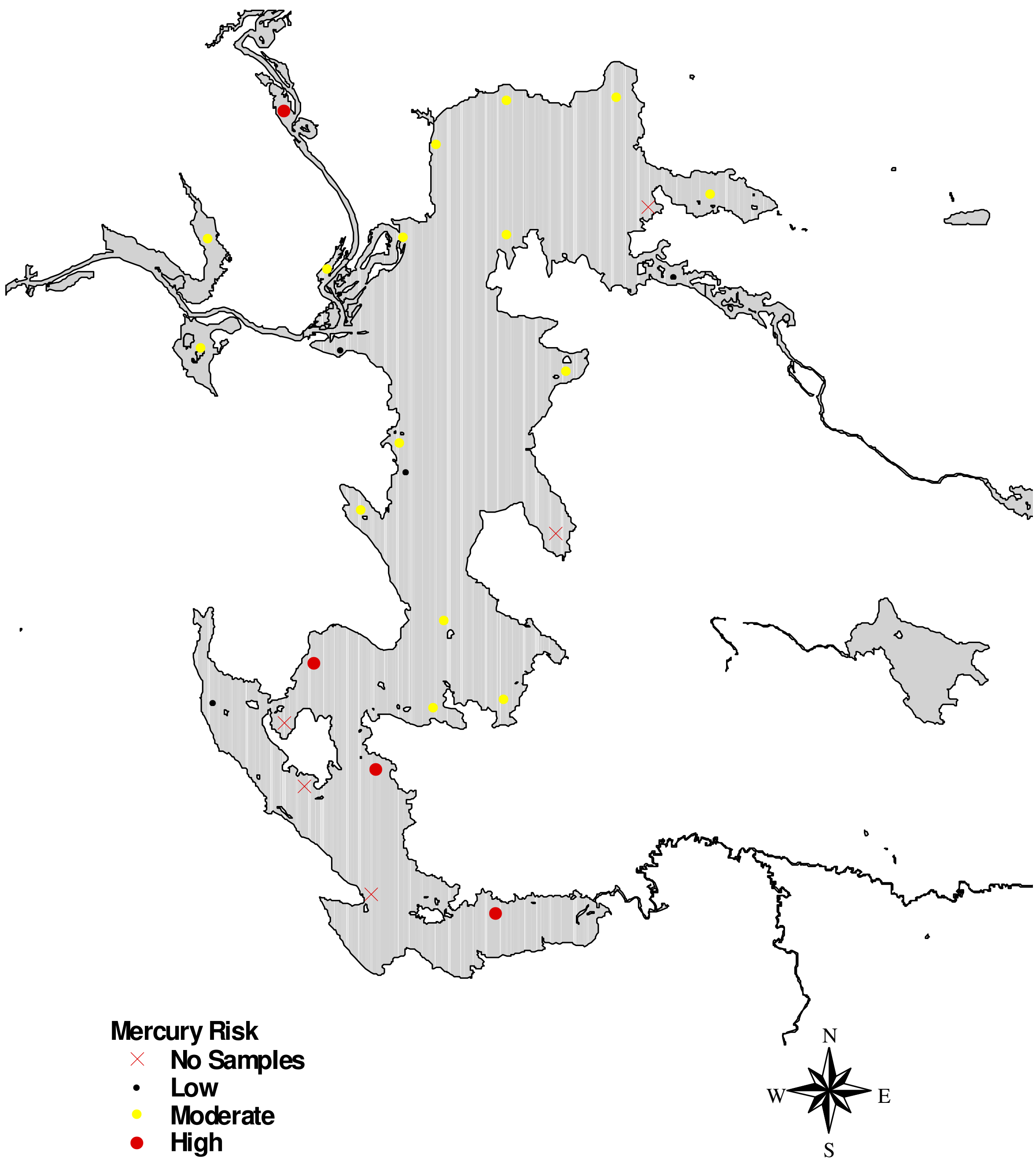
Appendix I. Distribution of Common Loon territories on Lake Umbagog, 1999



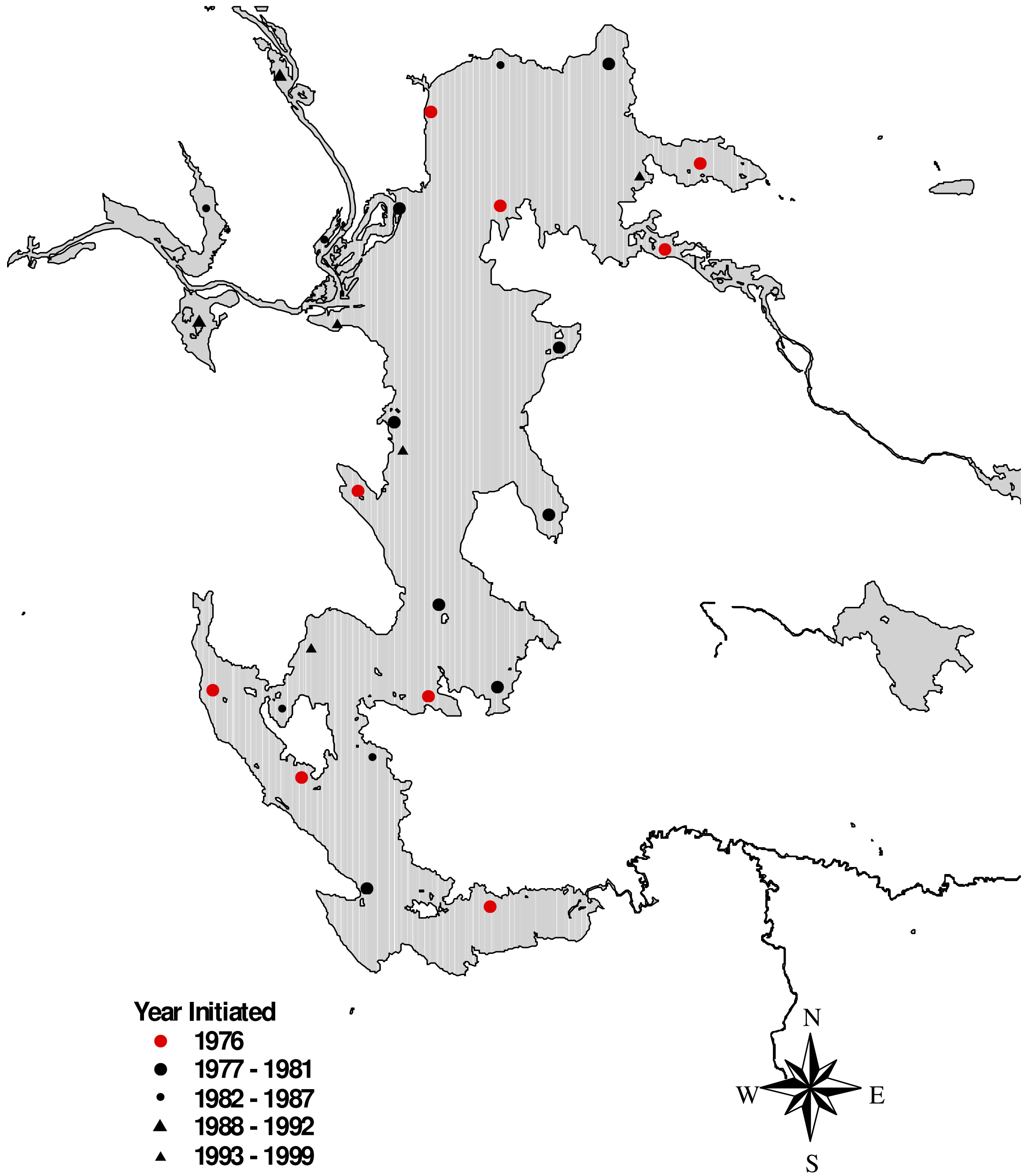
Appendix 2 Distribution of the habitat quality ratings for Common Loon territories on Lake Umbagog, 1999



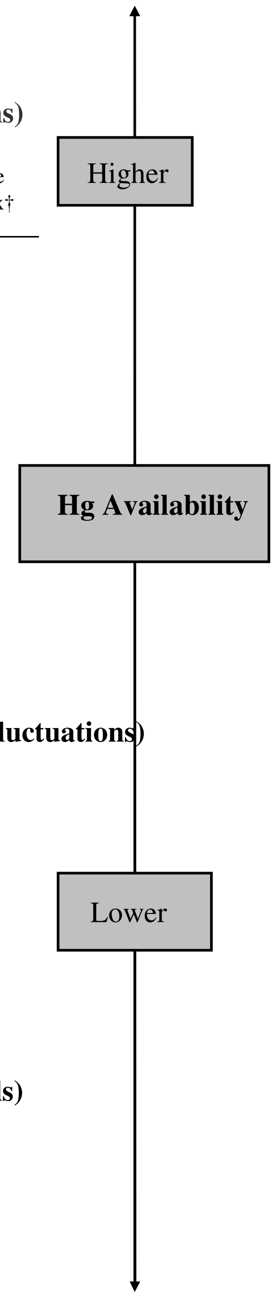
Appendix 3 Distribution of the risk of methylmercury availability to the Common Loon on Lake Umbagog, 1993-99.



Appendix 4. Distribution of territory initiation for Common Loon pairs on Lake Umbagog, 1976-99.



Appendix 5. A comparison of Hg levels and 4 reservoir types in Maine & New Hampshire, 1994-99.



	Mean annual fluctuation (ft.)	Age (years)	Total Watershed Area (sq. miles)	Mean adult blood Hg (µg/g)	Mean juvenile blood Hg index†
Group 1 (Flooded river valleys with low flushing rate and wide water fluctuations)					
Flagstaff	17	46	516	4.00	2.27
Aziscohos	20	85	214	2.76	2.06
Group 2 (Reservoirs with high flushing rate and narrow water fluctuations)					
Indian Pond	3	45	1360	1.55	0.76
Wyman Pond	3	70	2619	2.49	-
Group 3 (Previously natural lakes now with augmented water levels and moderate water fluctuations)					
Umbagog	6	143	1,045	1.82	0.85
Mooselookmeguntic	10	143	382	1.58	0.26
Richardson	10	143	472	1.58	0.11
Group 4 (Previously natural lakes now with regulated stable summer water levels)					
Pontook	2	-	n/a	1.37	0.72
Rangeley	2	162	99	1.23	0.51

† Juvenile blood Hg index calculated as follows: [blood Hg (µg/g) / weight (g)] x 10,000 = ppmHg/g x 10^4