The Squam Lake Loon Initiative

Progress Report

July 2019

The Squam Lake Loon Initiative

Progress Report, July 2019

Executive Summary

Between 2005-2007, Squam Lake experienced an unprecedented decline of close to half of its adult loon population, followed by the near-complete reproductive failure of its remaining loons. The Loon Preservation Committee (LPC) launched its Squam Lake Loon Initiative to understand the causes of the declines in Squam's loon population and to restore a healthy population of loons to the lake.

Squam's loons are facing multiple co-occurring stressors that are common to loons throughout the state, including climate change, increased recreational activities, increased predator populations, and other threats. Contaminant burdens that were higher than on other lakes and elevated rates of lead tackle mortality have, in concert with these other stressors, apparently resulted in disruptions to loon survival, breeding success, and social structure. Productivity improved over the previous several years in 2018, with 6 chicks hatched and three that survived. While this is an improvement, productivity on Squam remains well below historic levels.

The identification of elevated contaminant levels in inviable Squam loon eggs from failed nests has driven LPC's work to identify sources of contaminants in the Squam watershed and to monitor contaminants in loon eggs. Four inviable eggs tested from the 2018 breeding season were lower than the peak levels found in 2005-2007 and followed a stable trend for legacy contaminant levels since 2008. Levels of PBDE (flame retardants) and PFOS contaminants in these eggs followed slightly increasing trends. LPC measured the thickness of eggshells from Squam Lake and other lakes as a first step in LPC's investigation of eggshell thickness in relation to contaminant levels and productivity. LPC will be preparing a paper for submission to a peer-reviewed journal of its egg contaminant results.

Sediment sampling conducted by LPC as part of our efforts to identify sources of contaminants has pinpointed three sites of contaminated sediments. Levels of contaminants at these locations are above levels identified as being possibly or likely harmful to aquatic life. LPC presented these data in a report to New Hampshire Department of Environmental Services (DES) and requested that DES address this issue as soon as possible with options and plans for mitigation. DES, the Squam Lakes Association, and researchers at Plymouth State University have recognized the gravity of this situation, and LPC has been instrumental in forming a coalition of agencies and organizations to expand the investigation into contaminants and options for mitigation.

In bringing this issue to light and leading a collaboration of state and federal agencies, a university, and non-profit organizations, LPC is ensuring that these issues are not minimized but rather tackled head on to safesguard the health of Squam and all its inhabitants. LPC will continue to work to recover Squam Lake's loon population through greatly increased research, monitoring, management, and outreach as part of the Squam Lake Loon Initiative. This work will continue to inform LPC's conservation efforts for loons on Squam and throughout the state.

Background

Between the fall of 2004 and the spring of 2005, Squam Lake lost seven of its loon pairs. The decline from 16 to 9 pairs represented 44% of Squam's loon population, a drop unprecedented on Squam or any other large lake in LPC's 43-year history of monitoring loons throughout New Hampshire. It also brought Squam's loon population to its lowest level since LPC began to survey Squam Lake in 1975**.** This decline was followed by the near-complete reproductive failure of the remaining loon population. In 2007, only three chicks were hatched on Squam, and only one survived to late August and was presumed to have fledged. Loons on Squam had not experienced a reproductive failure of this magnitude since 1978, the year LPC petitioned successfully to have loons added to the Threatened Species list in New Hampshire.

The Squam Lake Loon Initiative is LPC's response to the decline of Squam's loon population. The Initiative began in 2007 and includes an increased monitoring, research, management, and outreach effort to:

1. Determine the overall survival and reproductive success of Squam's remaining loon population

2. Assess causes of nest failures and collect inviable eggs from failed nests for analysis of a wide range of contaminants

3. Rescue sick or injured loons to increase loon survival

4. Find and collect loon carcasses, determine causes of death, and test dead loons for contaminants and pathogens (disease-causing organisms)

5. Band loons to allow us to identify and track individual birds and collect blood and feather samples for analysis of contaminants, pathogens, and indicators of health

6. Determine survival and breeding success of previously banded and sampled loons, and relate survival and breeding success of individuals to their levels of contaminants and pathogens

7. Incorporate results into a systems dynamics model to determine the relative contributions of a wide range of possible stressors on the mortality and reproductive failure of loons on Squam Lake

8. Determine possible sources of contaminants and options for mitigation of these sources

9. Restore and maintain a healthy and stable population of loons on Squam Lake as a component of a healthy statewide population of loons.

Squam's Loon Population and LPC's Management Activities in 2018 and 2019

Squam Lake's loon population in 2019 includes 12 pairs loons, the same number as in 2018. Six chicks hatched on Squam Lake in 2018, a marked improvement over the single chick that hatched in 2017, and three chicks survived (Figure 1). To date in 2019, 4 chicks have hatched on Squam Lake and two nests are still active.

To date in 2019, Squam Lake has had 6 nest failures. Causes of nest failure included: loon intrusions, the death of a pair member, black flies, mammalian predation, and abandonment for unknown causes.

While final rates of productivity for 2019 remain to be seen, the reproductive success of Squam's loon pairs remains far below pre-2005 levels, and productivity has remained low since the period of critical decline in 2005-2007. Loon breeding success from 2008-2018 of 0.19 chicks surviving/territorial pair is less than half the statewide average and far less than the rate of 0.48 chicks surviving/territorial pair needed to maintain a viable population (Figure 2). Translating these rates to actual numbers of loon chicks, from 1995-2004 an average of ten chicks were hatched each year on Squam and an average of seven chicks fledged.

LPC carries out management activities to help increase the chances for successful productivity and chick survival. In 2018 and 2019, LPC floated 8 nesting rafts each year on Squam Lake (Figure 3). In 2018, 5 of the 6 chicks hatched on Squam came from nesting rafts floated by LPC. In 2019, to date 3 rafts have been used, but no chicks have hatched yet from these nest attempts. All nesting attempts (10 in 2018 and 9 to date in 2019) have been protected by ropes and signs around the nesting areas, and chicks have been protected by LPC's orange "Caution: Loon Chick" signs to alert boaters to the presence of loon chicks in an area of the lake.

Loons on Squam are facing multiple stressors, such as increased boating and recreational activities, increasing temperatures and storm events, increased populations of shoreline predators (raccoons, mink, etc.), and fluctuating water levels. All of these factors are common to loons on lakes throughout New Hampshire, yet declines on Squam have been more severe and protracted than those on other lakes. The factors that seem to set Squam Lake apart from other New Hampshire lakes are elevated levels of chemical contaminants and high rates of mortality from lead fishing tackle.

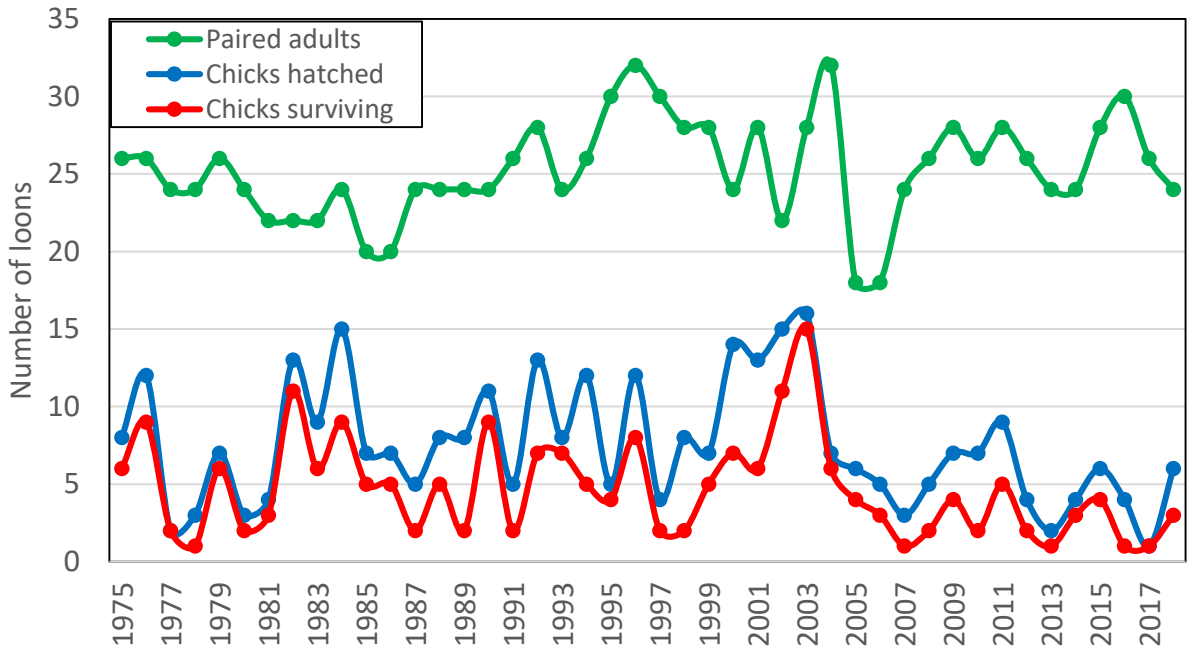

Figure 1: Squam's loon population, 1975-2018.

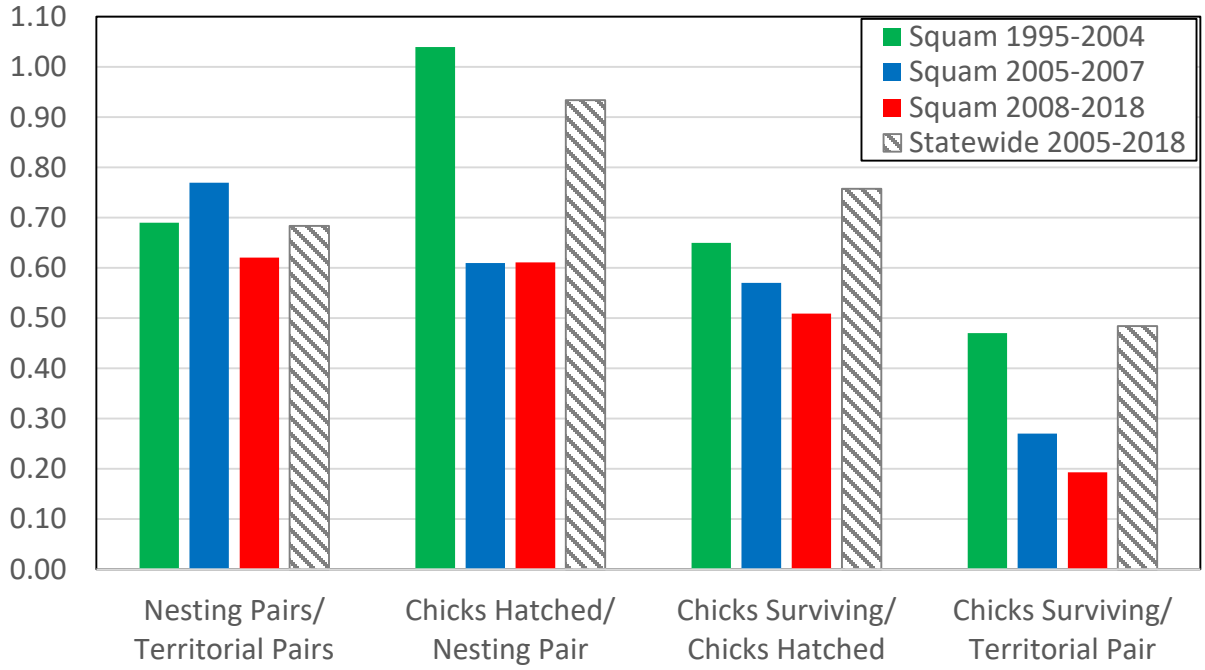

Figure 2: Productivity rates on Squam Lake before, during, and after the 2005-2007 period of decline compared with the statewide productivity rate. The statewide rate of overall productivity (Chicks Surviving/Territorial Pair) is more than twice the rate in recent years on Squam Lake.

Figure 3: LPC's Squam Lake Project Biologist, Tiffany Grade, floats a nesting platform in early spring on Squam Lake.

Contaminants in Squam Lake Loon Eggs

Unhatched eggs collected from failed Squam between 2005 and 2007 revealed high levels of a number of contaminants, including PBDE (flame retardants), PFOS (stain guards, firefighting foam), PCB (industrial insulating/cooling agents), DDT and its breakdown product DDE and chlordane (pesticides), and dioxins and furans (PCDD/F's; byproducts of industrial processes). Levels of contaminants from Squam during 2005-2007 were **up to seven times higher** than levels found in eggs collected from lakes throughout New Hampshire, Maine, and New York, as well as higher than the periods before and after these critical years on Squam. Some of these contaminants were present at levels that have been shown to affect the health and reproductive success of other bird species (Figure 4).

It is important to note that, although average total PCB levels on Squam are below lowest observed effects levels (Figure 4), levels of a particularly toxic subset of PCBs—the dioxin-like PCBs—are elevated. Dioxin-like PCBs impact organisms in a similar way to dioxins and furans, and toxic equivalency factors allow these groups to be added together to measure toxicity. When added together, levels of dioxins, furans, and dioxin-like PCBs exceed lowest observed effects levels by over 4 times during the 2005-2007 and over 2 times in more recent years (Figure 4).

All of the contaminant classes tested by LPC in Squam's loon eggs may interact with each other within an organism, and some may interact synergistically, i.e., the combinations of two or more contaminants may far exceed the impacts of either contaminant in isolation. However, the combined effects of these contaminants in wildlife are not well understood.

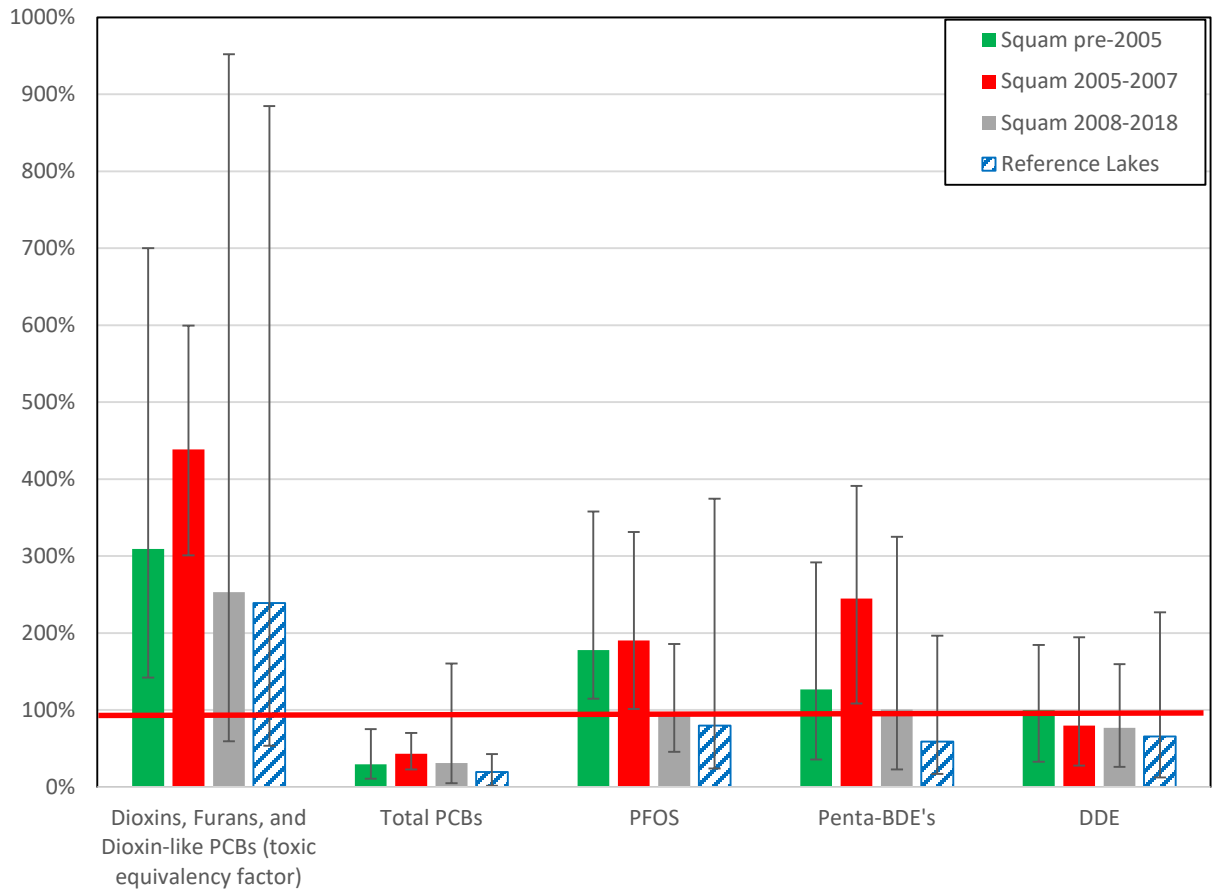

Figure 4: Contaminant levels in Squam eggs as a percentage of lowest levels causing health or reproductive effects in other bird species, as indicated by the red line.

Levels of legacy contaminants (DDT/DDE, PCBs, dioxins/furans) in Squam loon eggs from failed nests collected between 2008-2018 have been following a stable but not, in general, decreasing trend. Levels from flame retardants (PBDEs) and PFOS have showed a slight increasing trend. LPC tested four inviable Squam loon eggs from the 2018 nesting season. Contaminant levels in these eggs were similar to the average of levels in other eggs from this period, with the exception of two eggs that had higher than average flame retardant levels.

In an effort to better understand the potential impact of these contaminants, LPC has begun an investigation of loon eggshell thickness in relation to contaminant levels and productivity. Some of these contaminants, such as DDT and possibly PBDEs as well, may cause eggshell thinning. In spring 2019, LPC hired former staff biologist, Chris Conrod, to measure eggshells from Squam and reference lakes as a first step in this investigation (Figure 5). Analyses of these data will begin in fall 2019.

The discovery of these contaminants in Squam's loon eggs raised two important questions for LPC: 1) What are the sources of the high levels of contaminants found in Squam's loon eggs? and 2) What impacts are these contaminants having on Squam's loon population?

Figure 5: Former LPC staff biologist Chris Conrod measures thickness of eggshells from Squam and reference lakes as a first step in LPC's investigation of eggshell thickness in relation to contaminant levels and productivity.

Hypotheses as to the Sources of Contaminants

LPC has investigated five hypotheses to explain the high levels of contaminants present in Squam's loon eggs. These hypotheses and the evidence for or against them are listed below:

1) *There was a change in the food web in Squam Lake, which forced loons to feed at a higher level of the food web, thus exposing them to higher levels of contaminants.* Isotope testing did not reveal any change in the levels of the food web at which Squam's loons are feeding. Isotope testing also revealed that the nutrients (and, consequently, the contaminants) in the loon eggs came from a freshwater source, not from the ocean.

2) *The age structure of Squam's loon population (i.e., old loons that had accumulated contaminants over their lifetimes) contributed to elevated contaminant levels in the loons.* Banding evidence does not suggest the existence of a cohort of old loons on Squam.

3) *Squam has a unique hydrology, holding water longer than other lakes, which allows for the retention and build-up of contaminants.* Data on flushing rates of lakes collected by Jeff Schloss and Bob Craycraft of University of New Hampshire Cooperative Extension does not support the hypothesis that overall lake hydrology accounts for contaminant levels found in Squam's loon eggs.

4) *Pollution from a diffuse source accounts for the elevated contaminant levels found in Squam loon eggs.* Data collected by LPC working collaboratively with Jeff Schloss and

Bob Craycraft of University of New Hampshire Cooperative Extension does not support the hypothesis that the contaminants found in Squam's loon eggs came from a diffuse source.

5) *Pollution from one or more isolated sources accounts for the elevated contaminant levels found in Squam loon eggs*. An isolated source posits a single large input of contaminants into a system. Illegal dumping, accidental, spill, or a leaking container of chemicals are examples of possible isolated sources. The evidence suggests that at least some of the contaminants in Squam loon eggs came from multiple isolated sources in the Squam watershed.

Identifying Point Sources of Contaminants

During the initial loss of adult loons in 2005, loon pairs disappeared from the northeastern section of the lake. LPC hypothesizes that high levels of contaminants could have contributed to the deaths of these loons. This evidence, in conjunction with higher than background levels of contaminants in crayfish sampled from the northeastern coves and tributaries flowing into Squam, supported the hypothesis of one or more sources for emerging contaminants in the northeast corner of the lake. After further efforts to sample crayfish higher in the tributaries were unsuccessful, LPC staff sampled sediments from key tributaries in the fall of 2015 and 2016, collecting 25 sediment samples from different areas of the Squam watershed (Figure 6), which were submitted for contaminant testing.

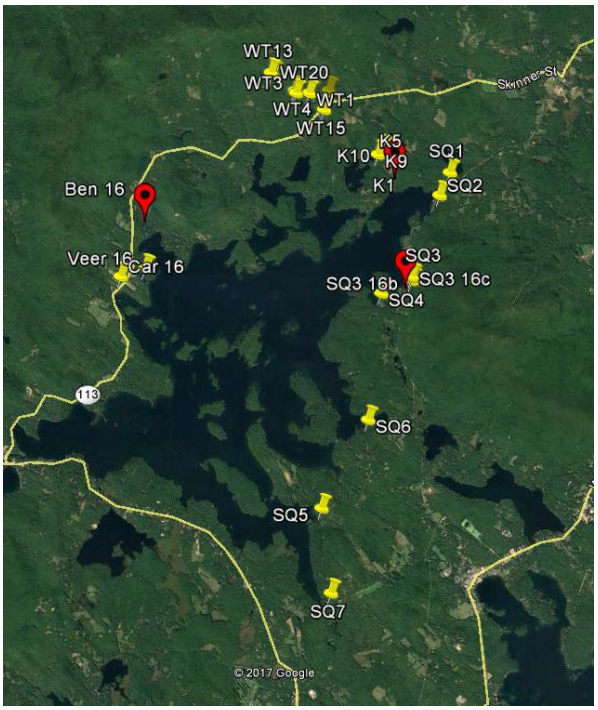

Figure 6: Locations of sediment samples collected by LPC in 2015-2016 and submitted for contaminant testing. Red markers indicate sites with elevated contaminant levels.

Results of Sediment Sampling

LPC's sediment sampling revealed 3 key locations of elevated contaminant levels in sediments. Contaminants at these sites exceeded levels identified by various agencies and researchers as being possibly or likely harmful to aquatic life.

The "K1" site is located on the outflow from Kusumpe Pond into Squam Lake, downstream of a gravel road. This was a site of concern following LPC's 2015 sediment sampling. Subsequent to sampling in the fall of 2015, there was a reported beaver dam blowout and culvert repair work on the road upstream of the site. LPC re-sampled the site, and testing revealed a substantial increase in PCB levels at this site, which far exceeded Canada's probable effects levels at which "adverse biological effects [to aquatic life] frequently occur" (Canadian Council of Ministers of the Environment 2001) and exceeded MacDonald et al.'s conservative probable effects level, "above which harmful effects [to aquatic life] are likely to be observed" (MacDonald et al. 2000; Figure 7). There was also a substantial increase in levels of dioxins and dioxin-like PCB's, which reached 90% of the Canadian probable effects levels (Figure 8).

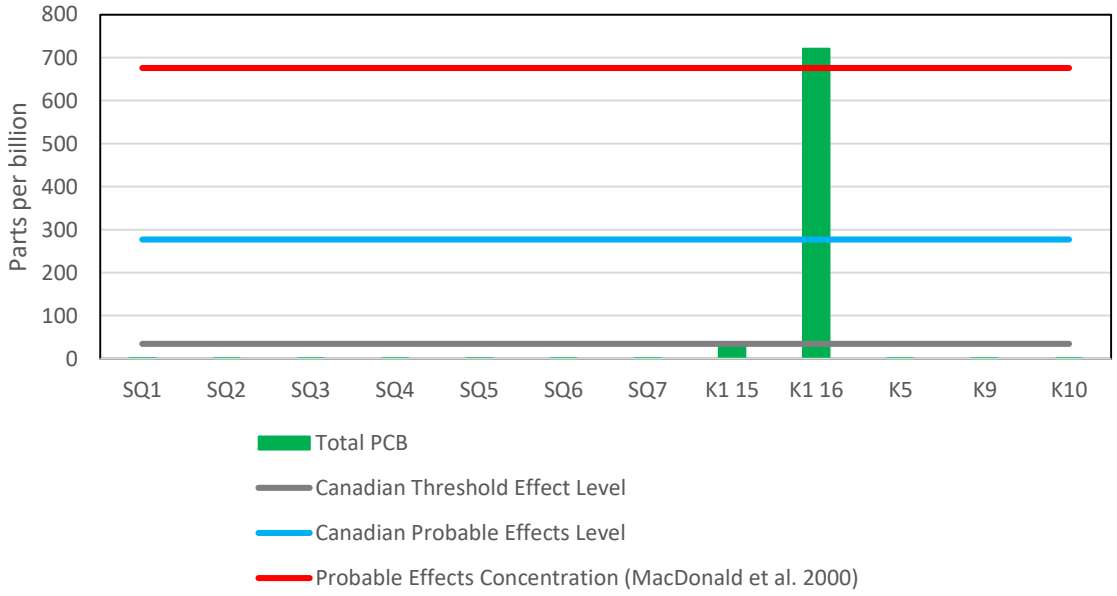

Figure 7: Total PCB levels in sediments collected in the Squam watershed. Levels of total PCB's at the K1 site in 2016 exceeded probable effects levels established by the Canadian Ministry of the Environment and by MacDonald et al. (2000).

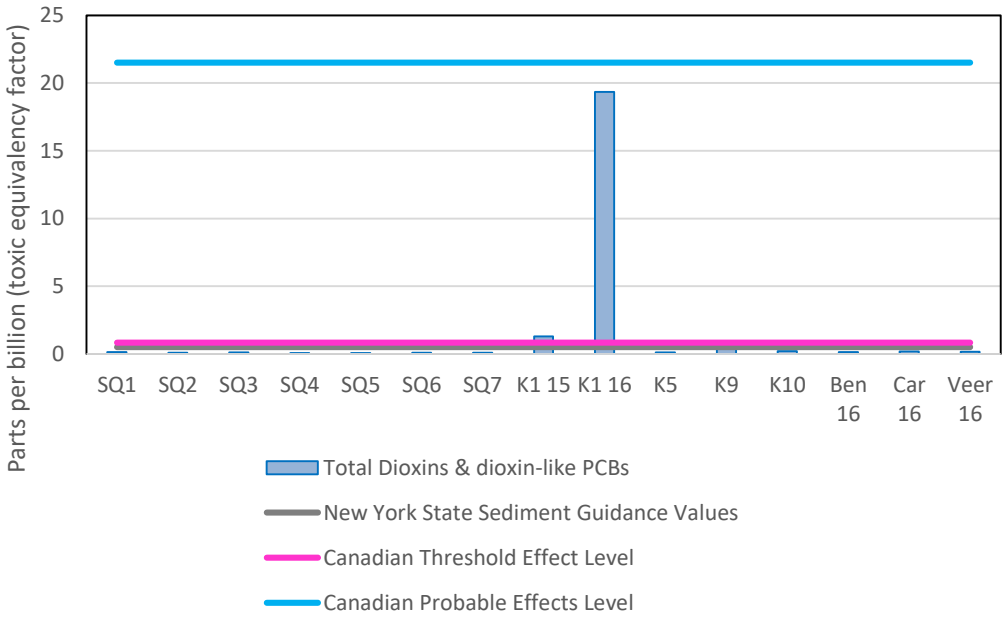

Figure 8: Levels of dioxins and dioxin-like PCB's in sediments collected in the Squam watershed. Levels of these contaminants at the K1 site in 2016 were 90% of the probable effects level for likely harm to aquatic life established by the Canadian Ministry of the Environment.

LPC also identified two locations (SQ3 and Ben 16) at which the levels of DDT in the sediments exceeded various effects levels. Levels of DDT at the Ben 16 site exceeded multiple sediment guideline values (Figure 9), including those used by the U.S. Department of the Interior (Effects Range Median) at which "adverse effects [to aquatic life] are likely to occur" (U.S. Department of the Interior 1998). Chemical profiles of total DDT at both of these locations revealed that the DDT was largely undegraded, suggesting either recent mobilization of sediments or recent applications of DDT.

LPC presented its sediment data in a report to New Hampshire Department of Environmental Services (DES) and requested that DES address this issue as soon as possible with options and plans for mitigation. DES, the Squam Lakes Association, and Plymouth State University have recognized the gravity of this situation, and LPC has been instrumental in forming a coalition of organizations to expand the investigation into contaminants and options for mitigation. For further details of LPC's sediment testing and results, please see LPC's report to NH DES at http://www.loon.org/squam-lake-study.php.

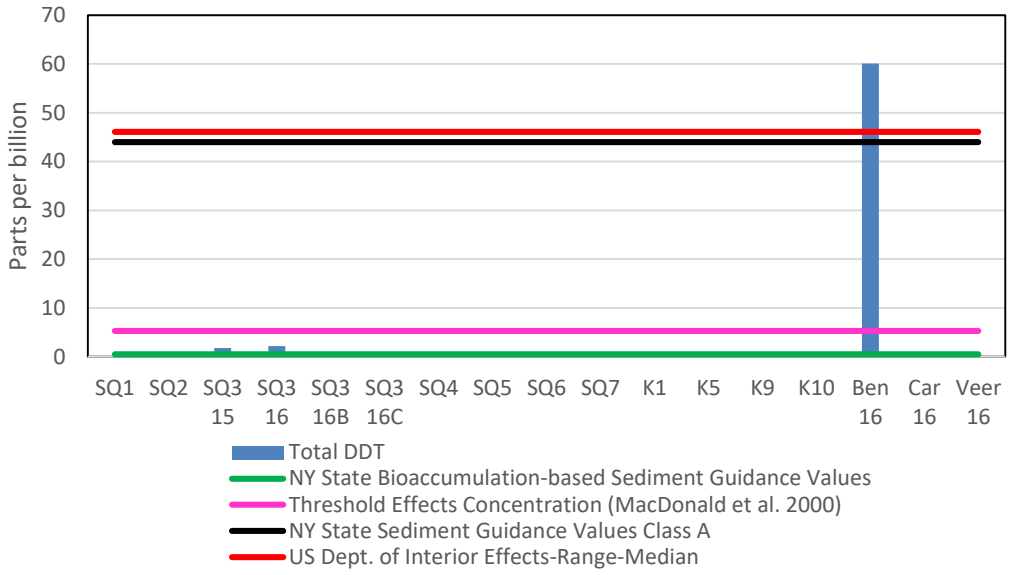

Figure 9: Levels of total DDT in sediments collected in the Squam watershed. Total DDT levels at the Ben 16 site exceed multiple sediment guideline values.

Mortality of Squam Lake's Adult Loons

Two adults from Squam Lake have died in the past year. The Moon Island female of 2018 died from lead poisoning from an ingested lead fishing jig in November 2018 in Cape May, New Jersey. It is unclear whether she acquired the jig on Squam Lake or while she was on the ocean. The 2019 Yard Islands female was collected in early July, and the necropsy showed that she died of avian malaria. This was only the second loon documented in North America to have died from avian malaria and suggests the influence of climate change in exposing loons to new pathogens that previously were not extant within their range. Sadly, the nest failed at the Yard Islands failed as a result of this loon's death.

Staff from Tufts University School of Veterinary Medicine and the University of New Hampshire Veterinary Diagnostic Laboratory performed necropsies on 17 adult loons from Squam Lake that were found dead between 2004 and 2019. The majority of these loons died as a result of human causes: 8 loons died as a result of ingested lead fishing tackle; 3 loons were killed by boat strikes; and 1 died as a result of a gunshot wound. Many more Squam Lake loons missing during this time period remain unaccounted for and are presumed to have died on their ocean wintering grounds, possibly as a result of poor body condition resulting from exposure to multiple stressors on Squam.

Since the opening of the reconstructed public boat launch in 2001, the rate of mortality from lead fishing tackle on Squam Lake has increased by 85% (Figure 10) and is twice the overall statewide rate of lead mortality during the same period. Loon populations may be negatively impacted by the loss of even 0.4% of their population annually from human causes; and, between 2001 and 2018, Squam lost on average 1.7% of its adult loon population annually due to lead fishing tackle alone. Although it is not possible to demonstrate causation, it is worth noting that,

since 2001, the number of boats counted in the annual Squam Lakes Association boat census, the number of fishing tournaments, and the number of boats participating in fishing tournaments have all increased.

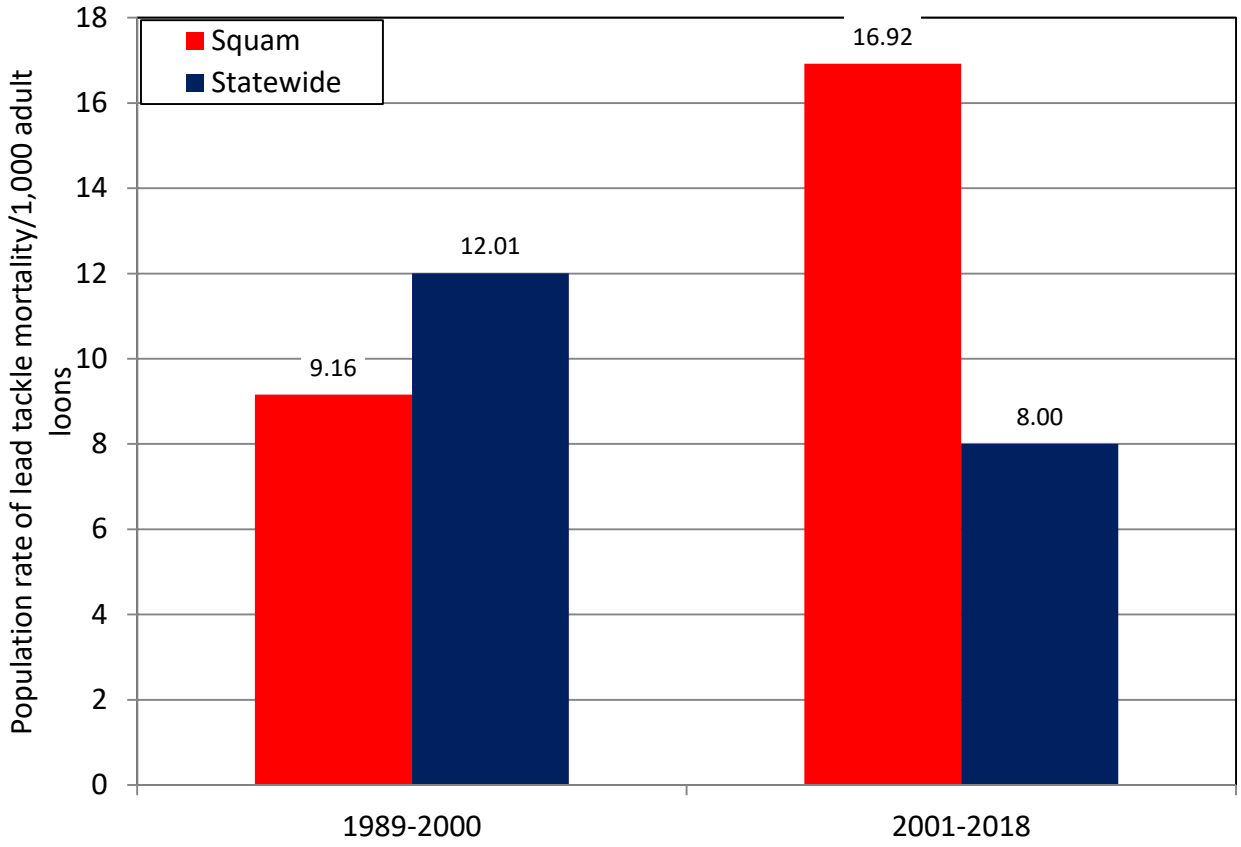

Figure 10: Population rates of lead mortality on Squam Lake vs. statewide population rates of lead mortality.

Working Hypothesis to Explain the Impacts of Stressors on Squam's Loon Population

The discovery of high levels of contaminants in Squam's loon eggs raised the question of what impact these contaminants had on the loon population in concert with the many other stressors facing Squam's loon population. LPC has a working hypothesis to understand the impacts of combined stressors on Squam's loon population. ***This is a hypothesis only and subject to change as new evidence become available.***

Like loons throughout New Hampshire, Squam's loons have been experiencing increasing stressors over time, from increased recreational pressure to increasingly hot summers and more intense precipitation events. On Squam, recreational and fishing pressure became more intense

in the years following 2001, coincident with the reconstruction of the public boat launch in the same year, and mortality from lead fishing tackle increased in the same period (Figure 7). In approximately 2002, evidence suggests that there may have been an influx of contaminants into the lake from sources on tributaries flowing into Sandwich Bay and perhaps Bennett Cove, likely as a result of increased runoff. By 2004, these contaminants had worked their way up the food chain to loons. These contaminants concentrate in fat reserves and may have contributed, in combination with other stressors, to poor body condition and the deaths of many of Squam's loons during the winter of 2004/2005 as their fat reserves were metabolized for the fall molt and migration. The loon pairs that survived to reproduce in subsequent years deposited high levels of contaminants into their eggs, possibly contributing to poor productivity.

By 2008, some of the contaminants released from the point sources seem to have flushed though the Squam system, as evidenced by a decline in contaminant levels in Squam's loon eggs from 2008-2010. However, evidence suggests that factors including ongoing high levels of adult mortality from lead fishing tackle and other anthropogenic causes continue to undermine the recovery of Squam's loon population. The loss of so many established, experienced adult loons has led to the immigration of new loons to fill vacant territories. These loons are intruding into territories, driving remaining established loons out of their territories, disrupting nesting, and, in some cases, killing chicks. While these behaviors are typical for territorial disputes, the effects on Squam are amplified due to ***high human-caused adult mortality*** and the resultant large number of vacant territories. Loons have evolved to thrive in a stable environment and stable social structure, and Squam's loons have had neither since 2001. These disruptions seem to be evident in the ongoing decline in nesting propensity and chick survival in recent years.

Continued monitoring of contaminant levels in loon eggs is warranted, given recent discoveries of contaminated sediments. High rainfall in the spring of 2017—the fourth wettest spring in New Hampshire in 100 years—may have flushed contaminants into Squam. This flushing could cause contaminants in sediments to re-mobilize, which could then work their way into the Squam food web and into Squam's loons. LPC will continue to monitor contaminant levels in unhatched loon eggs from Squam to examine runoff as a mechanism for contaminant transport into Squam's food web.

The critical factor to restore a healthy population of loons to Squam Lake seems to be ***keeping the adult loons alive*** to stabilize the social structure. Increasing the use of non-lead fishing tackle and educating lake users about the dangers of lead and the need to boat carefully around loons will help reduce the threat of human-caused mortalities to loons. As the social structure stabilizes, there is reason to hope that productivity on the lake will improve, as the disruptions Squam loons are currently facing during nesting and chick-rearing may abate. The evidence from the decline of loons on Squam Lake and an earlier decline on Lake Umbagog suggests this will take time. LPC has learned from both of these events that perturbations to the system cast a long shadow over a loon population, which could be expected in a long-lived bird like a loon. While the causes of the declines of the loon population on Umbagog are unknown and the adult population there has not recovered, in the last two years, productivity of the remaining pairs of loons on Umbagog has finally begun to recover. As would be expected in a complex biological system, the experience of loons on Umbagog and Squam are not directly comparable, but the example of Umbagog suggests that, with time and supportive management, Squam's loons can

recover. And on Squam, we understand much better the impacts of human activities on the decline of the loon population and ***how we can work together to help the population recover***.

The Squam Lake Ecosystem Model

LPC is working with Lori Siegel of Siegel Environmental Dynamics (SED) to integrate results of its research into a systems dynamics model to better understand recent changes in Squam's loon population. This model seeks to gain insight into whether any given stressor is enough to drive the population decline or, as might be expected in such a complex system, is enough to compromise the integrity of loons such that, in concert with other stressors, it threatens the population. The model differentiates between impacts to loon survival, chick hatching, and chick survival and allows us to isolate impacts at each lifecycle focal point. Table 1 outlines the factors identified by the model to date as impacting loons at each stage of their life history while on Squam Lake. In supporting LPC's evidence and research on these stressors, the model will help LPC and others protect Squam's loons and the ecological integrity of Squam Lake.

Table 1: Factors influencing loon survival and breeding success on Squam Lake identified by the systems dynamics model.

Life history parameter	Factors influencing outcome
Adult loon survival	• Lead fishing tackle mortality • Increased angler tournament activity • Contaminants
Chick hatching rate	• Immigration of new loons • Excessive precipitation • High temperatures • Human disturbance • Contaminants
Chick survival	• Human disturbance • Adult mortality from lead fishing tackle • Contaminants

Remediation

LPC is working to address the challenges loons are facing on Squam and restore a healthy population of loons to the lake in the following ways:

1) *Limiting mortality from lead fishing tackle:* LPC's data was the impetus for legislation to increase protections of loons from lead fishing tackle. Mortality from lead fishing tackle has likely contributed to the current social chaos and resultant low productivity on the lake. LPC has published a paper detailing our lead tackle mortality data and the population-level effects of lead tackle mortality on New Hampshire's loon population in the peer-reviewed *Journal of Wildlife Management*,

an important step to buttress New Hampshire's lead legislation against efforts to repeal the bill, as well as to communicate our findings to the scientific community.

Educating the public about the dangers of lead to loons forms a major part of all of LPC's outreach activities on and around Squam Lake. The evidence suggests that the most important thing we can do right now to restore a healthy population of loons on Squam is to ***keep adult loons alive***. Protecting loons from lead fishing tackle is a critical component of that effort. LPC has convened several meetings of the Fish Lead Free Working Group to address this issue and reduce mortalities from lead fishing tackle ingestion on Squam and throughout New Hampshire.

In 2018. LPC piloted a lead tackle buyback program in partnership with the New Hampshire Department of Fish and Game at two tackle shops in the state. The program was very successful, collecting over 4700 individual pieces of lead tackle—any one of which could have killed a loon. In 2019, we have expanded the program to 8 tackle shops, including Squam Boat Livery. For more information on the program, please visit www.loonsafe.org.

2) *Increasing reproductive success:*

- **Management:** LPC is continuing intensive management on Squam Lake to increase the reproductive success of loons, including the provision of artificial nesting rafts where appropriate, roping and signing loon nesting areas, and the placement of "Caution: Loon Chick" signs to alert boaters to the presence of loon chicks.
- **Investigating causes of nest failures:** Cameras placed at loon nests help us understand the causes of nest failures. Evidence from nest cameras has resulted in enhanced management activities to protect loons from human disturbance in the pre-nesting stage.
- **Outreach:** Educating the public about the needs of loons and the importance of maintaining a respectful distance forms an important part of LPC's outreach activities. LPC has dramatically increased its outreach to the Squam Lake community and visitors through weekly presentations at the Rockywold-Deephaven Camps (RDC) on Squam Lake and twice-weekly loon cruises on the lake in partnership with the Squam Lakes Natural Science Center. In addition to these regular talks, LPC gives other presentations in the Squam area, including annual presentations at the Holderness Central School's environmental education week and programs at the Squam Lakes Association. These outreach opportunities resulted in 38 presentations in and around the Squam Lake area in 2018. Additionally, LPC's Squam Lake Project Biologist, Tiffany Grade, was invited to speak at the Linnaean Society of New York in April 2019 on the work of the Squam Lake Loon Initiative (Figure 11).
- **Loon Chick Watch:** LPC collaborated with the Squam Lakes Association on the sixth year of the Loon Chick Watch program on Squam to protect loon chicks from boat disturbances and collisions.

- **Mitigating effects of climate change:** Covers on loon nesting rafts help protect loons from avian predators and provide shade for incubating loons, which can easily overheat. In addition, LPC deployed experimental covers on two rafts on Squam in 2018 to test whether these new covers provide more shade for nesting loons to help loons cope with a warmer climate. LPC's nest cameras also help us understand the impacts of climate change on nesting loons by allowing LPC to assess nest attendance during heat waves and observe behavioral signs of heat stress in incubating loons.

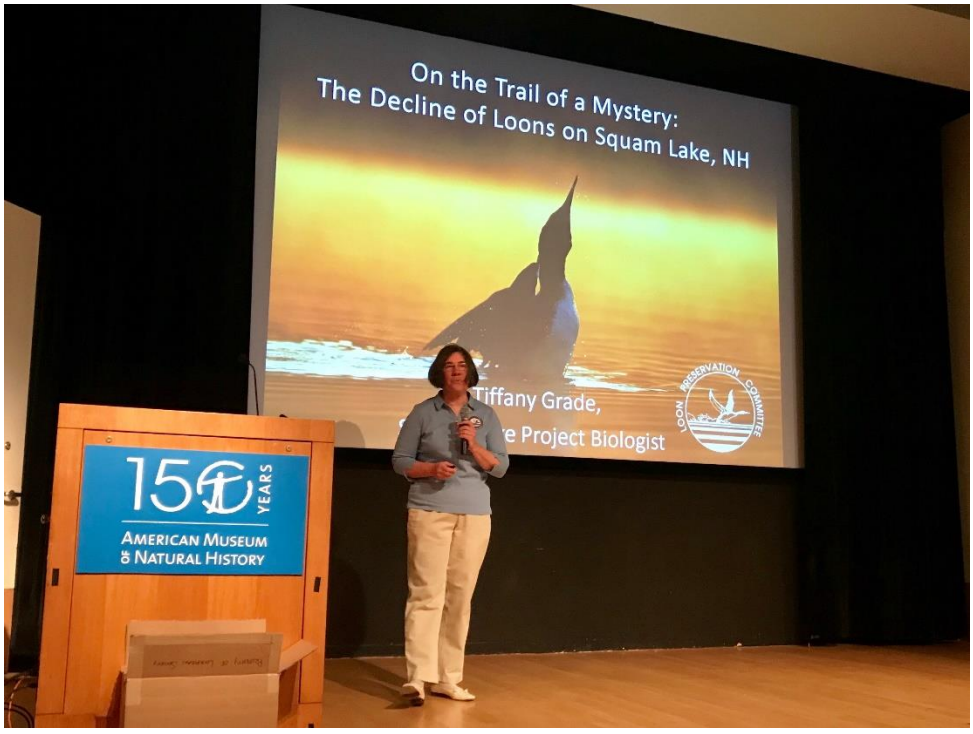

Figure 11: LPC's Squam Lake Project Biologist, Tiffany Grade, speaking to the Linnaean Society of New York at the American Museum of Natural History in New York City, April 2019.

3) *Identifying levels and sources of contaminants:* LPC continues to investigate contaminants as one of many possible contributors to both reduced survival and reduced breeding success of Squam's loons. In spring 2017, LPC submitted a report on the results of our sediment sampling to New Hampshire Department of Environmental Services (DES) and requested that DES address this issue as soon as possible with options and plans for mitigation. Since the submission of this report to DES, staff from LPC, DES, the Squam Lakes Association (SLA), and Plymouth State University (PSU) have met on several occasions to review LPC's findings and plan our next steps to address this issue. This has been an education for LPC in the limits of what falls under the purview of DES: contamination in a lake ecosystem in a top-level predator but which is not clearly from a distinct point source falls through the established programs of DES. Consequently, there is little if any state funding to address the issue.

LPC is working with DES to organize tasks among collaborators and move research to investigate and resolve contamination issues forward. In the autumn of 2017, staff from New Hampshire Geological Survey completed an assessment of the culverts near the sites of contaminated sediments identified by LPC. In consultation with LPC, DES collected fish from Squam in fall of 2018 to assess contaminants in the food web and potential human health effects from these contaminants, with funding from US Environmental Protection Agency to perform contaminant testing. Although testing was delayed as a result of the government shutdown in early 2019, DES expects results in fall 2019.

Early in 2018, LPC sent its collaborators detailed recommendations for future sediment sampling. A graduate student at PSU is following up on the sites LPC identified as elevated for DDT to investigate contaminant pathways in hopes of discovering the exact source of the DDT. SLA collected sediment samples in fall 2018 and is in the process of having a hired consulting firm, Geosyntec, analyze and report on the samples. SLA is also planning on collecting local history information from Squam residents to learn about potential historic sources of contamination in the watershed. It is hoped that these efforts will continue to help us track sources and extent of contamination in the watershed and identify steps that may be taken towards remediation or containment of contaminated sites.

In bringing this issue to light and leading this collaboration of state and federal agencies, a university, and non-profit organizations, ***LPC is working to ensure that these issues are not minimized but rather tackled head on to safeguard the health of Squam and all its inhabitants.*** The loons ultimately will tell us about the success of any work or remediation done on Squam. As indicators of the health of the aquatic environment, Squam's loons originally alerted us to the problem of contamination on Squam Lake, and they will continue to serve as sensitive barometers of contamination in the watershed. LPC will continue to test inviable loon eggs from failed nests on Squam for these contaminants and take a leadership role in contaminants work on Squam. We are determined to see that the work continues to be done in a way that is best for the loons, for the health of the Squam ecosystem, and the wildlife and people that call Squam home.

Next Steps

The Squam Lake Loon Initiative has already provided critical baseline data on contaminants and other environmental stressors on loons which will be invaluable to assess changes in, and effects of, contaminants and pathogens in the future. The collaboration of researchers formed as a result of the decline of loons on Squam Lake is unprecedented, and the testing being done on loon samples is the most comprehensive undertaken anywhere to date. Based on LPC's testing of inviable Squam Lake loon eggs, Squam's loons are carrying a contaminant body burden that includes not just DDT and PCB's but dioxins, furans, flame retardants (PBDE's), and stain repellants (PFC's), among other chemicals (Figure 4). LPC remains concerned about the overall contaminant body burden of Squam's loons. LPC's sediment testing identified potential sources for DDT, PCB's, and dioxins/furans (Figure 7-9); but, to date, we have not identified locations for these other contaminants. LPC continues to advocate for testing that covers the full scope of contaminants of concern revealed by our efforts, including dioxins/furans, dioxin-like PCB's, PBDE's, and PFC's, and will work to retain portions of samples for future testing.

The SLLI has resulted in an accurate record of loon populations and productivity on Squam Lake, including causes of nest failures; the quick response to sick or injured loons to increase chances of survival of these loons; an increased number of banded and sampled loons on Squam to increase our knowledge of the survival and breeding success of known individuals, and the relationship of survival and breeding success with contaminant burdens; a model to elucidate the effects of multiple co-occurring stressors on the survival and breeding success of loons; and protection and outreach to recover and maintain the Squam Lake loon population. We anticipate that this initiative will help avoid future declines of loons on Squam and on other lakes; bring to light what could be a much larger, more systemic problem on Squam indicated by the decline of loons; inform other initiatives such as LPC's New Hampshire Loon Recovery Plan and SLA's Squam watershed plan; and help LPC and others make more informed decisions to protect Squam's loons, other wildlife, and the ecological integrity of Squam Lake, as well as lakes throughout New Hampshire.

Objectives for the Squam Lake Loon Initiative in 2019-2020 include:

1. Continue to advocate for comprehensive testing of samples while working with New Hampshire Department of Environmental Services, US Environmental Protection Agency, Squam Lakes Association, and Plymouth State University to determine the extent of contaminated sediments and facilitate remediation of potential point sources
2. Testing inviable loon eggs from failed Squam nests in 2019 to monitor current contaminant levels and trends
3. Analysis of eggshell thickness measurements for eggs with known contaminant levels to determine the effect of contaminants on eggshell thinning and nest failures
4. Banding loons on Squam Lake to measure adult survival, productivity, and contaminant levels of known individuals
5. Testing loon blood samples to identify pathogens and other health concerns, including cyanotoxins
6. Inspecting data from nest cameras to investigate disturbances at nests and explore the influence of climate on incubating loons
7. Analyzing egg contaminant results in preparation for submission of a paper to a peer-reviewed journal
8. Analyzing retention of water within the basins of Squam Lake to investigate whether basin retention relates to contaminant concentrations
9. Continuing intensive monitoring, management, and outreach to support Squam's loons

Squam Lake will continue to play a leading role in advancing our understanding of loons and their challenges in New Hampshire, and the groundbreaking research being conducted on Squam Lake will continue to inform LPC's efforts to preserve loons throughout New Hampshire.

Acknowledgements

LPC would like to thank our many collaborators and partners who have contributed technical expertise or opportunities for outreach to the Squam Lake Loon Initiative over the past year:

- LPC's Technical Committee: Kristen Begor (LPC Board), Sean Flint (US Fish and Wildlife Service), Sandi Houghton (NH Fish and Game), Anne Kuhn (US Environmental Protection Agency), Chris Martin (NH Audubon), Brian Reilly (LPC Board), Sara Steiner (NH Department of Environmental Services)
- New Hampshire Department of Environmental Services: Ted Diers, David Neils, Tracie Sales
- New Hampshire Geological Survey of NH DES: Cheryl Bondi, Shane Csiki
- New Hampshire Veterinary Diagnostic Laboratory: Inga Sidor
- Rockywold-Deephaven Camps
- Victoria Schmidt, Wildlife Rehabilitator, Barnsboro, New Jersey
- Squam Lakes Association: E.B. James, Rebecca Hanson, Melissa Leszek
- Squam Lakes Natural Science Center
- Tufts University Cummings School of Veterinary Medicine: Mark Pokras

LPC would also like to thank the many people, foundations, and efforts that have made our work to understand and reverse the declines of loons on Squam Lake possible.

Literature cited

Canadian Council of Ministers of the Environment (CCME). 2001. Canadian sediment quality guidelines for the protection of aquatic life. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

MacDonald, D. D., C. G. Ingersoll, T. A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Archives of Environmental Contamination and Toxicology 39:20-31.

U.S. Department of the Interior. 1998. Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment: DDT. National Irrigation Water Quality Program Information Report No. 3.