The Squam Lake Loon Initiative

Progress Report

July 2020

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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 social structure, loon survival, and breeding success. Productivity has improved to an extent each of the past two years; and, in 2020 to date, 9 chicks have hatched and 7 are still thriving on Squam Lake. However, average productivity on Squam remains well below historic levels.

The identification of elevated contaminant levels in unhatched Squam loon eggs collected from failed nests has driven LPC's work to identify sources of contaminants in the Squam watershed and to monitor contaminants in loon eggs. LPC tested three unhatched eggs from the 2019 breeding season. Levels of contaminants in two of the three eggs were higher than mean levels in recent years. Levels of PBDE (flame retardants) and PFOS contaminants in these eggs followed slightly increasing trends. LPC is 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 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), shared the report with the Squam Lakes Association, and recommended additional testing of sediments and fish. As a follow up to LPC's findings, DES tested fish from Squam, issuing a new, more stringent fish consumption guideline in spring 2020 due to elevated PCBs in the fish. 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 identify 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 addressed to safeguard the health of Squam and all its inhabitants. LPC will continue to work to recover Squam Lake's loon population through intensive 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 45-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 intensive 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 provide an independent assessment of the factors influencing 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 2020

Squam Lake's loon population in 2020 includes 13 pairs of loons, one more pair than in 2019. To date in 2020, 9 chicks have hatched on Squam Lake and 7 of them are still thriving. Two nests are still active on the lake. By comparison, 4 chicks hatched in 2019 and all 4 fledged (Figure 1). To date, Squam Lake has had 13 nesting attempts in 2020 between 11 pairs—one more nesting pair and two more nesting attempts than in 2019.

To date in 2020, Loon Preservation Committee has collected one adult loon that died on Squam Lake. The banded Perch Island female, part of a nesting pair, was killed by a boat strike in the boat lane north of Potato Island. The necropsy was conducted by New Hampshire Veterinary Diagnostic Laboratory, which confirmed traumatic injuries to her body associated with impact as well as injuries from a boat propeller. Despite the Perch Island male's efforts to incubate the eggs on the nest following the death of the female, the nest failed after he was finally forced to abandon it.

The failure of the Perch Island nest after the death of the nesting female is one of 5 nests that have failed to date on Squam Lake. In addition, two nests failed due to mammalian predation and two nests failed due to unknown causes.

Squam has seen a welcome increase in the rate of nesting over the past 5 years. While the outcomes for this breeding season are still in flux, the reproductive success of Squam's loon pairs in recent years remains far below pre-2005 levels. From 1995-2004, an average of 10.1 chicks were hatched each year on Squam and an average of 6.6 chicks fledged. From 2008-2019, an average of only 4.7 chicks hatched each year and 2.7 fledged. This is a rate of 0.20 chicks surviving per territorial pair (CS/TP), less than half the statewide average and far less than the rate of 0.48 CS/TP needed to maintain a viable population (Figure 2). Already the improved hatch rate in 2020 is encouraging.

LPC carries out management activities to help increase the chances for successful productivity and chick survival. In 2020, LPC floated 8 nesting rafts on Squam Lake (Figure 3), and 7 of those rafts were used. To date in 2020, all chicks produced on Squam have hatched from LPC's rafts. So far this year, LPC has protected 12 nesting attempts by placing ropes and signs around the nesting areas, and all chicks that hatched 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.

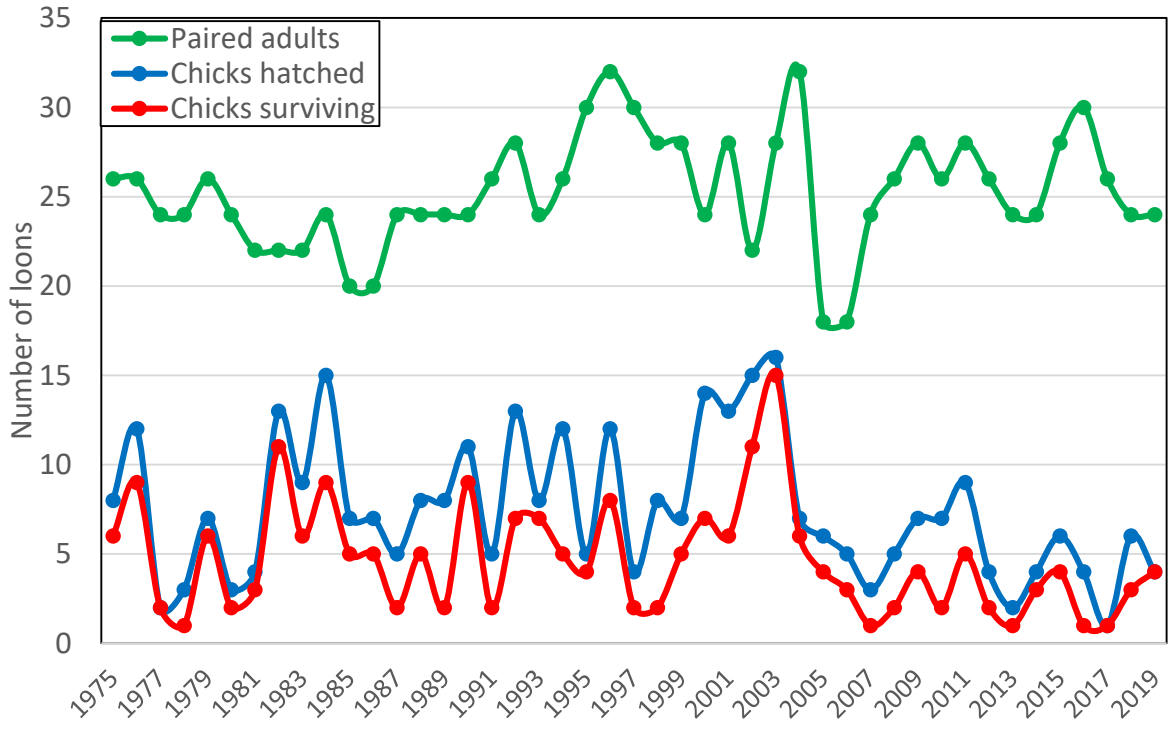


Figure 1: Squam's loon population, 1975-2019.

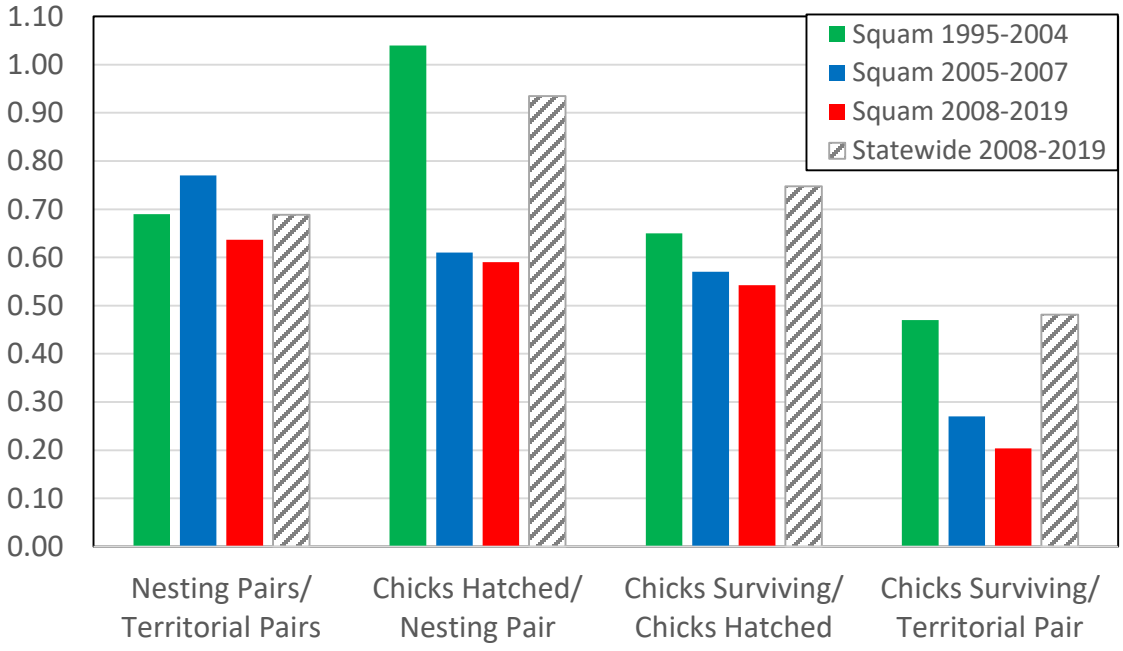


Figure 2: Productivity rates on Squam Lake before, during, and after the 2005-2007 period of decline compared with the statewide productivity rate. The statewide rate of overall productivity (chicks surviving/territorial pair) is more than twice the rate in recent years on Squam Lake.

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

Contaminant Research on Squam Lake

The history of contaminants research on Squam Lake is complex. Below is a brief timeline of how it unfolded.

- 2005-2007: Critical years of the decline of loons on Squam Lake
- 2007: LPC launches Squam Lake Loon Initiative. While researching the many factors contributing to this decline, we began testing unhatched loon eggs from failed nests for a variety of contaminants, including PCBs, dioxins/furans, DDT, chlordane, flame retardants (PBDEs), and PFAS.
- 2012-2013: By 2012, LPC had gathered enough data to try to track down potential sources of these contaminants. We partnered with Plymouth State University to sample crayfish from Squam and its tributaries to try to identify a source.
- 2015-2016: LPC sampled sediments in key tributaries indicated by the crayfish and other tributaries around the lake to narrow in on specific contaminated locations.
- 2017:
    - LPC submitted a report to NH Department of Environmental Services (DES) detailing our sediment results and reporting on two areas of DDT contamination and one area of PCB, dioxin, and furan contamination.
    - Squam Contaminants Group is formed as a result of LPC's discussions with DES. This Group brings together agencies and organizations to coordinate activities and information about contaminants in the watershed, further investigate the contaminant issue, and work together on solutions. The Group includes

representatives of LPC, DES, NH Fish and Game, Plymouth State University (PSU), and Squam Lakes Association (SLA).

- 2018:
  - DES collected fish samples from Squam in September to investigate potential human health risks associated with the contaminants LPC had found in loon eggs, crayfish, and sediments.
  - PSU graduate student, Amanda May, started a follow-up investigation of the elevated levels of DDT LPC discovered in Bennett Brook.
  - SLA conducted follow-up sediment sampling at key contaminated sites identified by LPC and additional sites.
- 2019: Report on SLA's sediment sampling confirmed elevated contaminant levels at sites identified by LPC.
- 2020:
  - DES received results of fish testing conducted in 2018 and issued new fish consumption guidelines for Squam Lake due to elevated PCBs.
  - Amanda May completed her thesis on DDT in Bennett Brook.
  - Squam Lake Contaminant Forum held, including presentations by representatives of LPC, PSU, DES, and SLA. To watch the Forum, please visit https://loon.org/lpc-work/squam-lake-study/.
  - LPC is preparing a report on contaminants in unhatched loon eggs statewide and a paper for a peer-reviewed journal.

Contaminants in Squam Lake Loon Eggs

Unhatched eggs collected from failed Squam nests 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 six 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. Although it is not known how these contaminants impact loons, some of the contaminants were present at levels that have been shown to affect the health and reproductive success of other bird species (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.

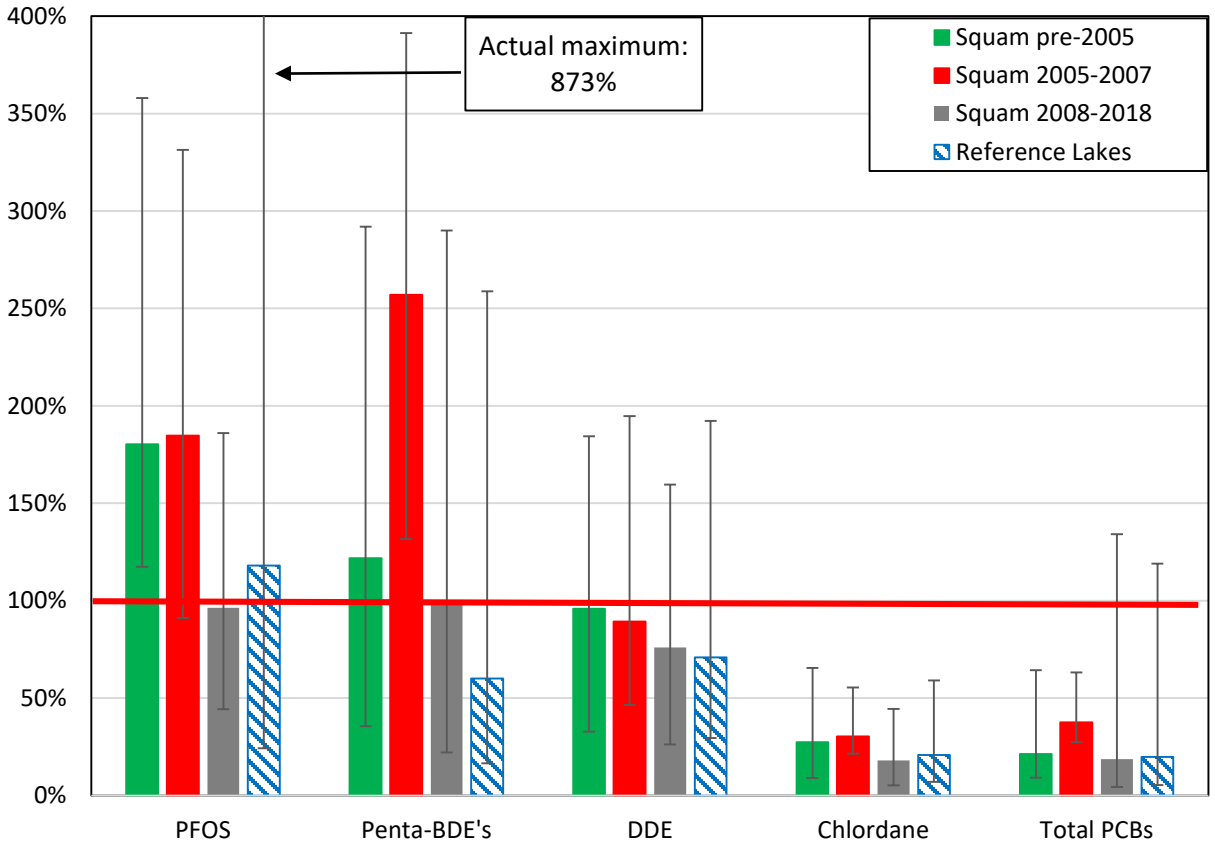
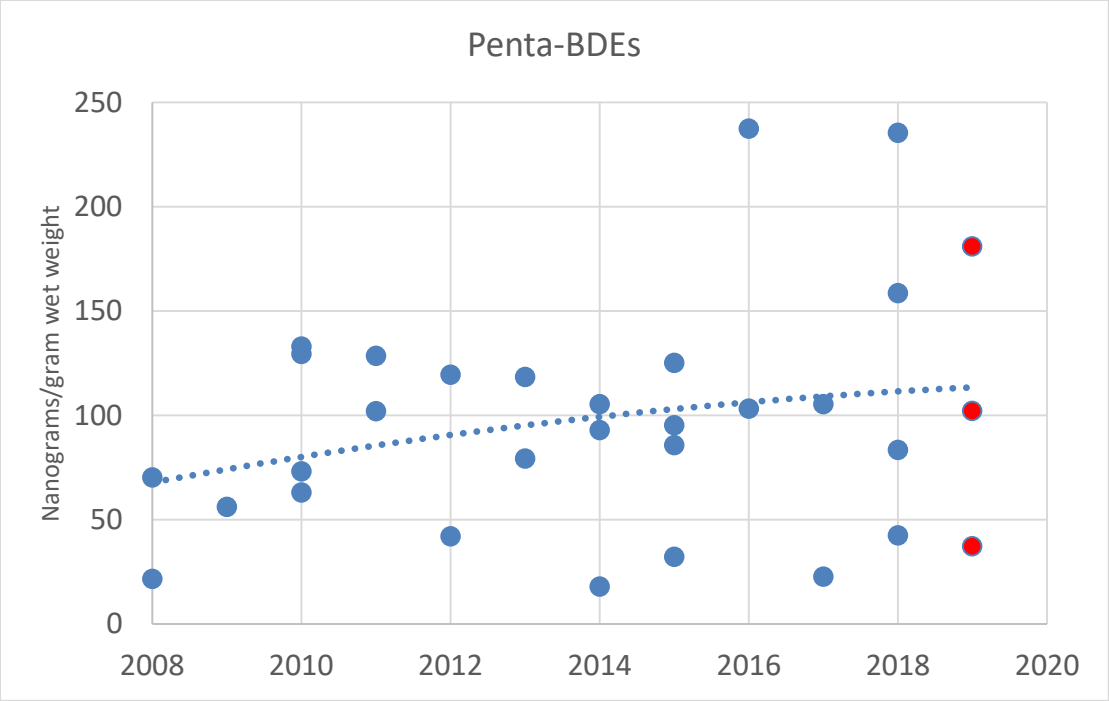
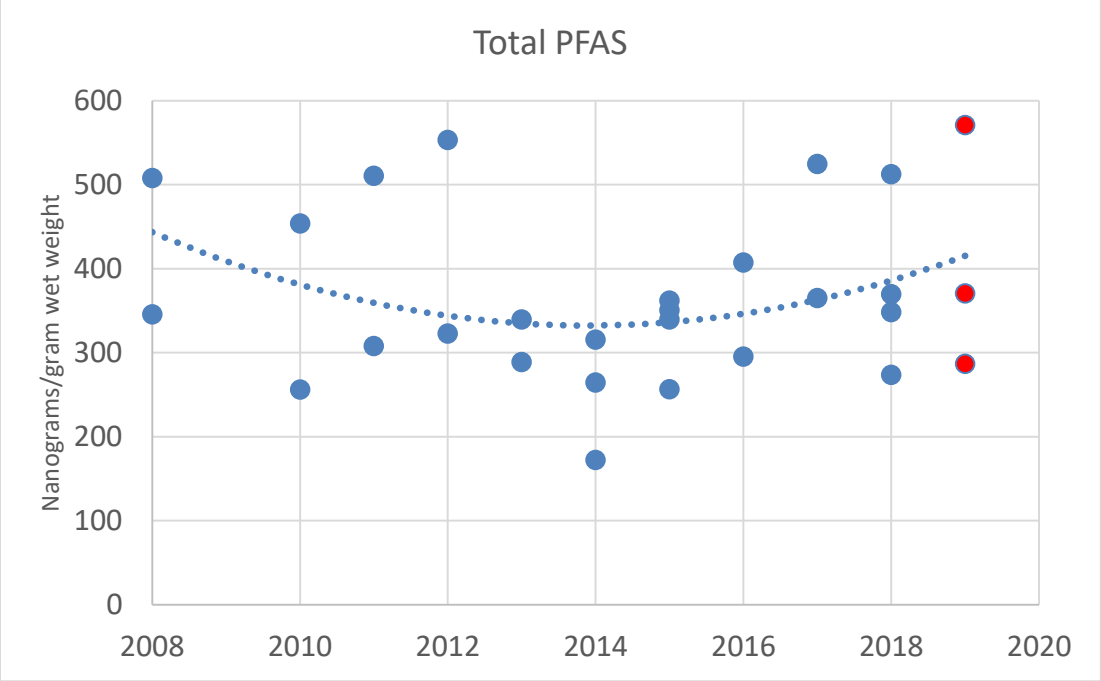


Figure 4: Contaminant levels in Squam eggs as a percentage of lowest levels causing health or reproductive effects in other bird species, as indicated by the red line. The error bars indicate the range of contaminant levels.

LPC tested three inviable Squam loon eggs from the 2019 nesting season. Two of these three eggs tested higher than the 2008-2019 mean for all major classes of contaminants tested. Levels of BDEs (flame retardants) and PFAS contaminants in Squam loon eggs from failed nests collected between 2008-2019 are showing slightly increasing trends, while legacy contaminants (DDE, chlordane, PCBs) have been following a generally stable but not decreasing trend (Figure 5).


Penta-BDEs
Nanograms/gram wet weight
250
200
150
100
50
0
2008
2010
2012
2014
2016
2018
2020


Total PFAS
Nanograms/gram wet weight
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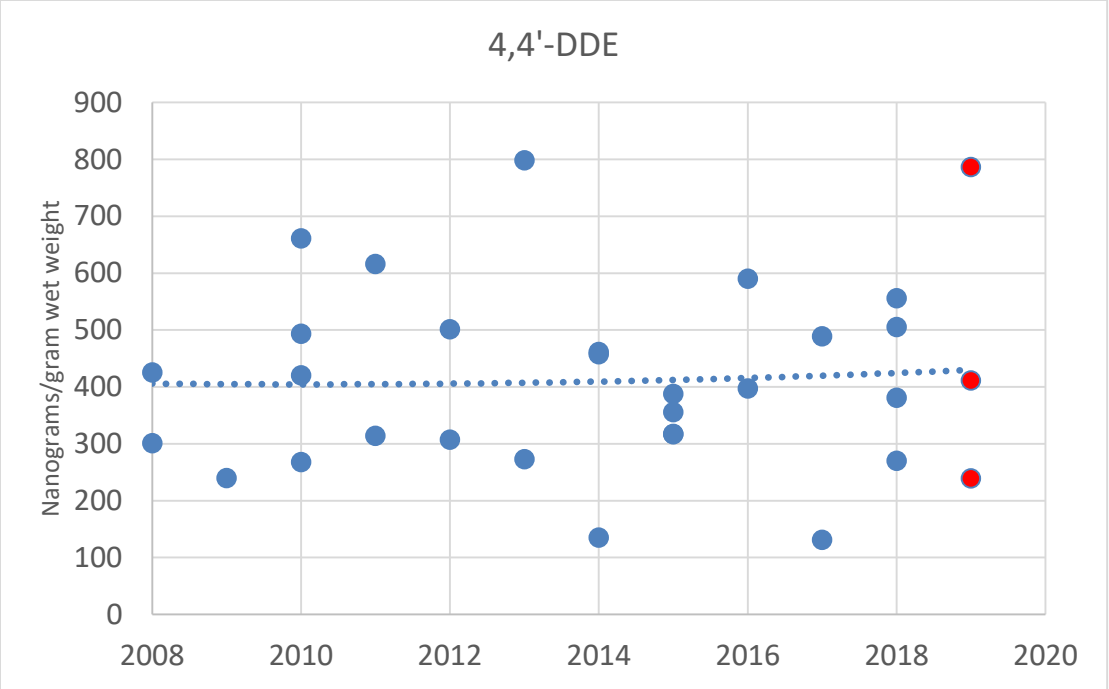
500
400
300
200
100
0
2008
2010
2012
2014
2016
2018
2020


4,4'-DDE
Nanograms/gram wet weight
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800
700
600
500
400
300
200
100
0
2008
2010
2012
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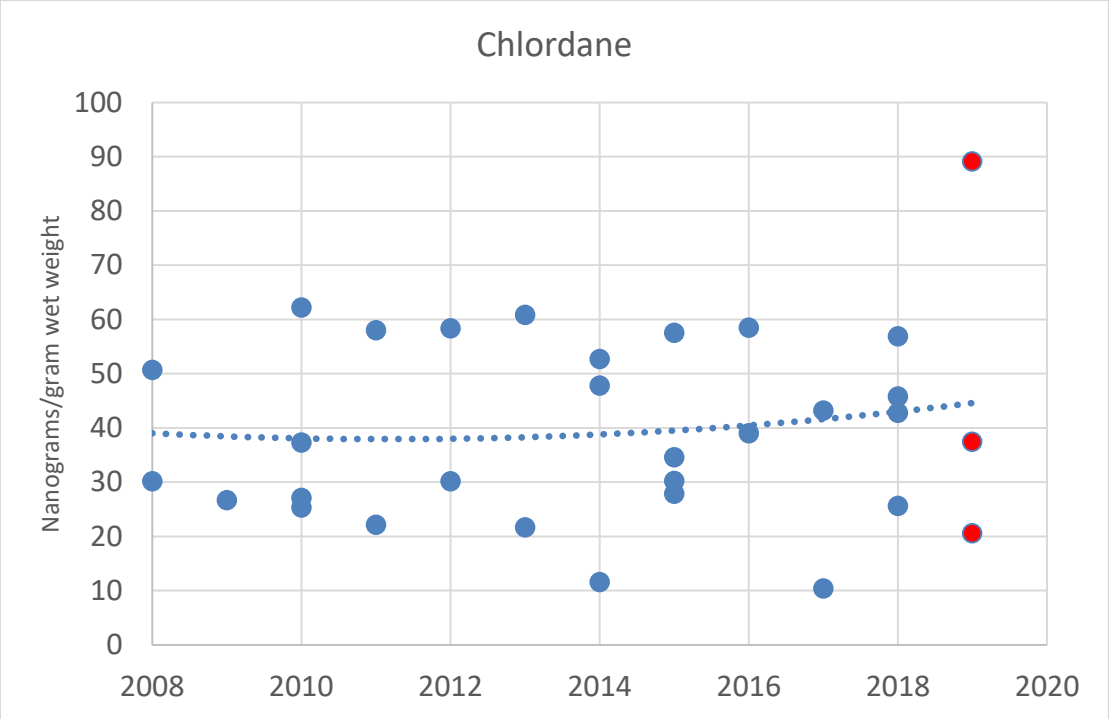
2020


Chlordane
Nanograms/gram wet weight
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90
80
70
60
50
40
30
20
10
0
2008
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2012
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2016
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2020

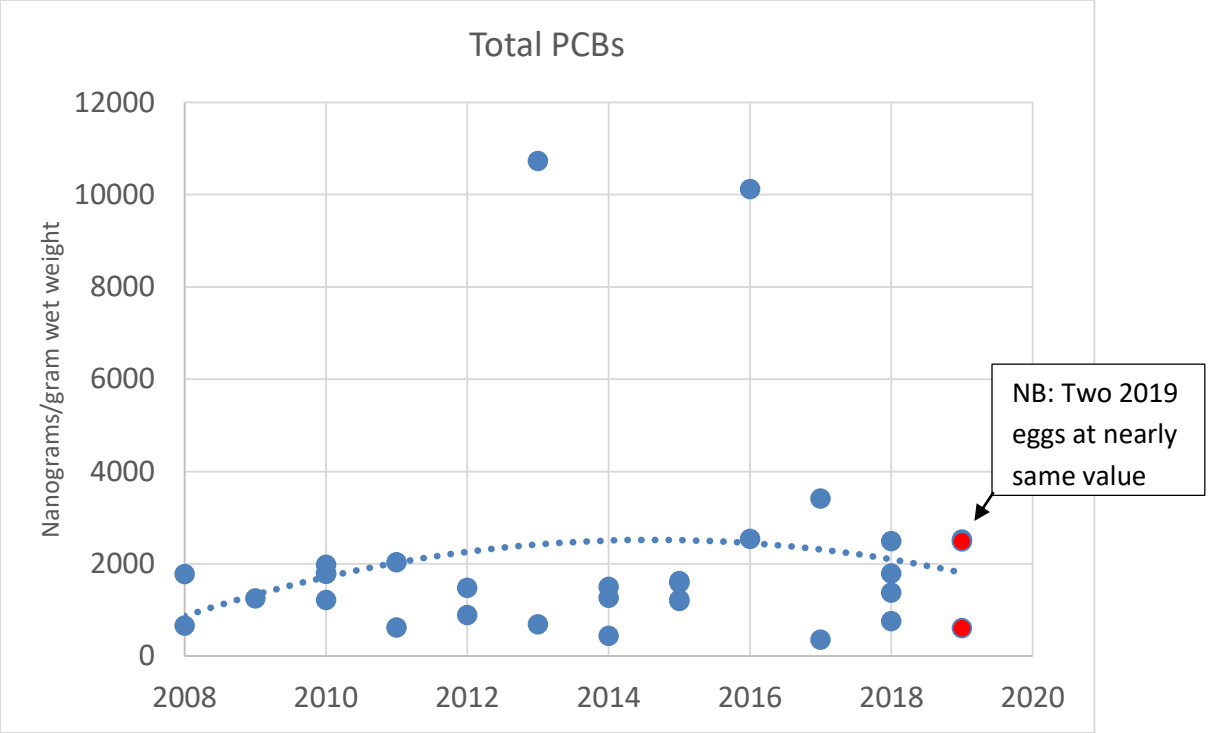

Figure 5: Trends of contaminant levels in unhatched Squam loon eggs from failed nests, 2008-2019. Three 2019 eggs tested in the past year marked in red.

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. Former LPC staff biologist, Chris Conrod, measured eggshells from Squam and reference lakes as a first step in this investigation (Figure 6) and these results will be analyzed in relationship with productivity data.

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 6: 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 confirmed 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 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, in conjunction with other stressors, 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 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 7), which were submitted for contaminant testing.

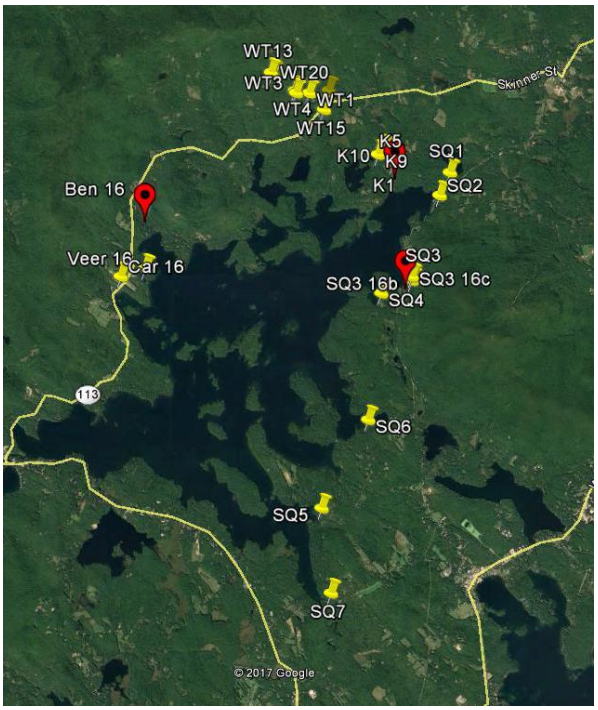

Figure 7: Locations of sediment samples collected by LPC in 2015-2016 and submitted for contaminant testing. Red markers indicate sites with elevated contaminant levels.

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.

LPC identified a site of elevated levels of PCBs and dioxins/furans in the sediment 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, and testing in 2016 revealed a substantial increase in contaminant levels at this site following a reported beaver dam blowout and culvert repair work on the road upstream of the site. Levels in 2016 exceeded Canada's probable effects levels at which "adverse biological effects [to aquatic life] frequently occur" (Canadian Council of Ministers of the Environment 2001) by 2.6 times, the New York State Bioaccumulation-based Sediment Guidance Values ("NY Guidelines") by 176 times, and also 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). Levels of dioxins and dioxin-like PCB's reached 90% of the Canadian probable effects levels and exceeded NY Guidelines by 38 times.

LPC also identified two locations (at Bennett Brook and opposite Kent Island) at which the levels of DDT in the sediments exceeded various effects levels. At Bennett Brook, DDT levels exceeded the U.S. Department of the Interior's Effects Range Median at which "adverse effects [to aquatic life] are likely to occur" (U.S. Department of the Interior 1998) by 1.3 times and the NY Guidelines by 125 times. DDT levels at the site opposite Kent Island were lower than at Bennett Brook but exceeded NY Guidelines by 4.6 times. Chemical profiles of total DDT at both of these locations revealed that the DDT was largely undegraded, suggesting recent mobilization of DDT in the sediments.

LPC presented its sediment data in a report to New Hampshire Department of Environmental Services (DES) and shared it with the Squam Lakes Association. LPC requested that DES address this issue as soon as possible and conduct fish and further sediment testing to establish the extent of the contamination at these sites. Establishing the extent of contamination would allow for the determination of the most appropriate mitigation options for each site. 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.

DES' PCB Fish Consumption Advisory

As a follow-up to LPC's data on PCB levels in loon eggs, crayfish, and sediments in the Squam watershed, New Hampshire Department of Environmental Services (NH DES) launched a study of PCB levels in fish from Squam Lake. The goals were to investigate another level on the food web between the contaminated sediments LPC found and the loons and to explore potential human health risks to people eating fish from Squam Lake. Loons are a key indicator species, being primarily fish eaters, and PCBs are known to biomagnify through the food web, so loons

are accumulating the contaminants from the fish they eat. It is known that the nutrients (and, thus, contaminants) deposited in eggs come from what the loon has been eating in the few weeks immediately prior to egg-laying. Loons are on territory for 4-6 weeks prior to egg-laying, so the contaminants in the eggs came from what they were eating on Squam. Isotope tests conducted by LPC confirmed that the material in loon eggs was clearly from freshwater sources rather than the ocean. Thus, there was a potential risk to humans eating fish from Squam as well.

NH DES sampled yellow perch and smallmouth bass on Squam in the fall of 2018 and received and analyzed the results this past spring, which indicated elevated levels of PCBs in fish on Squam. NH DES issued a fish consumption guideline for the Squam Lakes that is considerably more restrictive than the standard mercury guidelines in place throughout the state. The new guidelines for the Squam Lakes recommend limiting consumption to: for adults and children >7 years old, 1 meal per month of yellow perch and 1 meal every 4 months of smallmouth bass and other fish; for women of child-bearing age, 1 meal every 2 months of yellow perch and 1 meal every 6 months of smallmouth bass and other fish; and for children <7 years old, 1 meal every 3 months of yellow perch and 1 meal per year of smallmouth bass and other fish. Details of the new guidelines can be found at: https://www.des.nh.gov/media/pr/2020/20200330-squam-lake-fish.htm.

It was the decline of loons on Squam that led LPC to test unhatched loon eggs from failed nests. From there, it was a straight line to contaminants in crayfish, sediments, and now fish, with implications for human health. LPC will continue to test unhatched loon eggs from failed nests on Squam and around the state to monitor contaminant levels. LPC's continued work to monitor contaminants in loons will provide the ultimate measure of the success of any efforts to mitigate the contaminant problem on Squam.

Mortality of Squam Lake's Adult Loons

To date in 2020, one adult loon has been collected dead on Squam Lake. The Perch Island female died as a result of a boat collision in late June 2020 (see pg. 3).

In 2019, the Yard Islands female was collected dead, 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, although two other New Hampshire loons in 2019 subsequently died of avian malaria as well. These deaths suggest the influence of climate change in exposing loons to new pathogens that previously were not extant within their range. Also in 2019, an unbanded loon was collected in mid-October, which died of lead poisoning from lead tackle ingestion.

Staff from Tufts University School of Veterinary Medicine and the University of New Hampshire Veterinary Diagnostic Laboratory performed necropsies on 20 adult loons from Squam Lake that were found dead between 2004 and 2020 (to date). The majority of these loons died as a result of human causes: 9 loons died as a result of ingested lead fishing tackle; 4 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 contaminants and other 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 99% (Figure 8) and is more than 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 2019, Squam lost on average 1.8% 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.

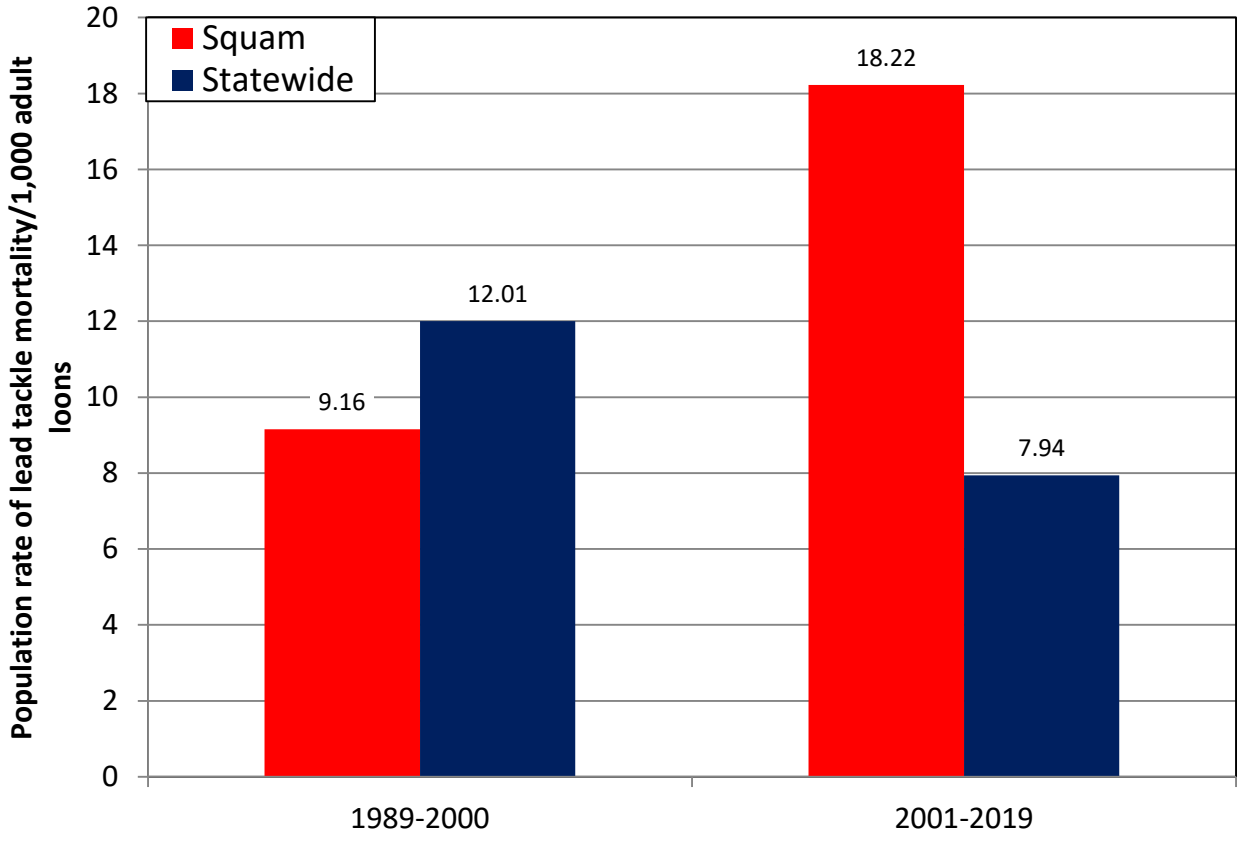

Figure 8: Population rates of lead mortality on Squam Lake vs. statewide population rates of lead mortality.

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 8). 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. The classes of contaminants found in Squam loons concentrate in fat reserves and may become mobilized as fat reserves are used. These contaminants, in combination with other stressors, may have contributed 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 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 territorial vacancies. Loons have evolved to thrive in a stable environment and stable social structure, and Squam's loons have had neither since 2001.

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 early nesting and hatching success evident to date in 2020 may be a result of fewer loon intrusions and a decline in the "social chaos" among Squam's loon population.

The evidence from the decline of loons on Squam Lake and an earlier decline on Lake Umbagog suggests that recovery 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 would 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 worked with consultant Lori Siegel 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 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
Nesting propensity	• Immigration of new loons • Excessive precipitation • High temperatures • Human disturbance
Chick hatching rate	• Loon intrusions • 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. In 2019, we expanded the program to 8 tackle shops, including Squam Boat Livery. Rockywold-Deephaven Camps and Squam Lakes Association also served as lead tackle collection points. To date, the lead tackle buyback program has removed over 15,000 pieces of lead tackle as a potential threat to loons and other wildlife. 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. The Squam Lake Loon Initiative has resulted in a dramatically increased 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 43 presentations in and around the Squam Lake area in 2019. Additionally, LPC's Squam Lakes 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 9).

  Outreach has proved to be a challenge in 2020 due to the coronavirus pandemic, but a more limited number of loon cruises with the Squam Lakes Natural Science Center resumed in July, and Tiffany's e-newsletters continue to provide updates on Squam's loons to over 400 people.

- **Loon Chick Watch:** In 2019, LPC collaborated with the Squam Lakes Association (SLA) on the sixth year of the Loon Chick Watch program on Squam to protect loon chicks from boat disturbances and collisions. Due to constraints of the pandemic, SLA was not able to partner on the program in 2020, but a more limited and informal program has continued, including assistance from the Lakes Region Conservation Corps.

- **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 and 2019 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.

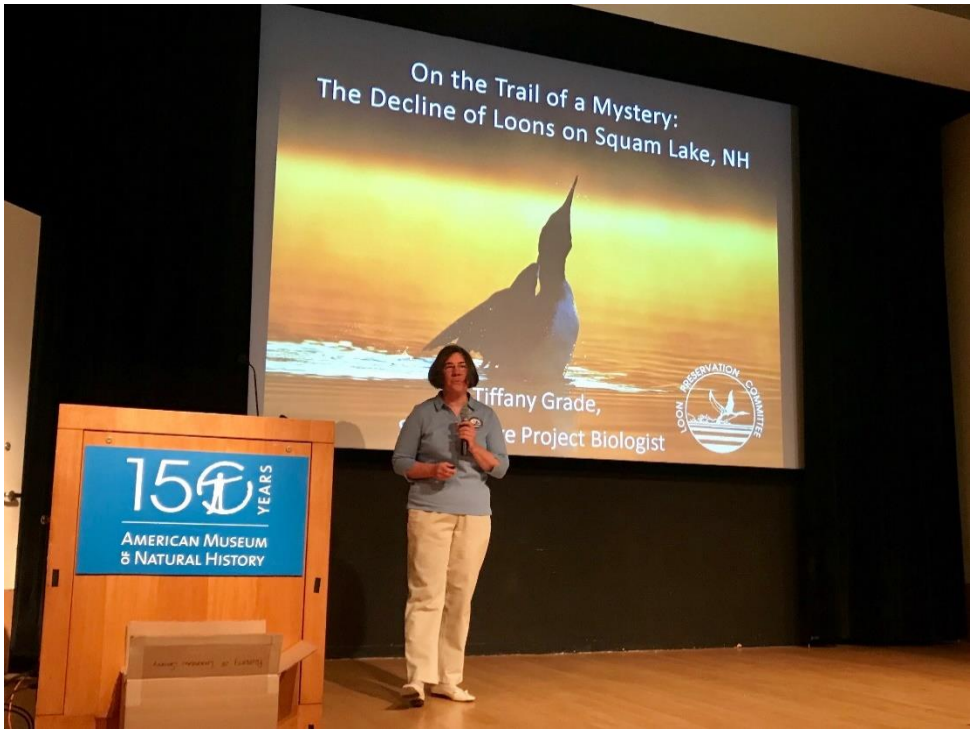

Figure 9: LPC's Squam Lakes Biologist, Tiffany Grade, speaking to the Linnaean Society of New York at the American Museum of Natural History in New York City, April 2019.

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 (see pg. 13). 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. As a result of this work, DES issued a more stringent fish consumption advisory for Squam in spring of 2020 (see pg. 13).

Early in 2018, LPC sent its collaborators detailed recommendations for future sediment sampling. A graduate student at PSU followed up on the DDT identified by LPC in Bennett Brook and completed her thesis work in spring 2020, detailing results of sediment tests elsewhere in the Bennett Brook area. SLA collected sediment samples in fall 2018, and a hired consulting firm, Geosyntec, analyzed and reported on the results of the samples. Contaminant levels in SLA's testing corroborated and, in some cases, exceeded the levels found by LPC.

A public forum was held in the spring of 2020 focusing on research into contaminants in the Squam watershed. Presenters included LPC, DES, PSU, and SLA. A recording of the forum can be found at https://loon.org/lpc-work/squam-lake-study/.

In bringing the issue of contamination in the Squam watershed 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 addressed 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. LPC's research is the only systematic testing in the state for contaminants in a species high up on the food web, like loons. 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 PCBs but flame retardants (PBDEs), and stain repellants (PFAS), 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; 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 PCBs, PBDEs, and PFAS.

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 2020-2021 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 2020 to monitor current contaminant levels and trends
3. Submit a report on Squam and statewide egg contaminant levels to state and federal agencies
4. Submit a paper to a peer-reviewed journal on egg contaminant results
5. Analysis of eggshell thickness measurements for eggs with known contaminant levels to determine the effect of contaminants on eggshell thinning and nest failures
6. Banding loons on Squam Lake to measure adult survival, productivity, and contaminant levels of known individuals
7. Testing loon blood samples to identify pathogens and other health concerns, including cyanotoxins
8. Inspecting data from nest cameras to investigate disturbances at nests and explore the influence of climate on incubating loons
9. Analyzing retention of water within the basins of Squam Lake to investigate whether basin retention relates to contaminant concentrations
10. 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.

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- Squam Lakes Association
- Squam Lakes Natural Science Center
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