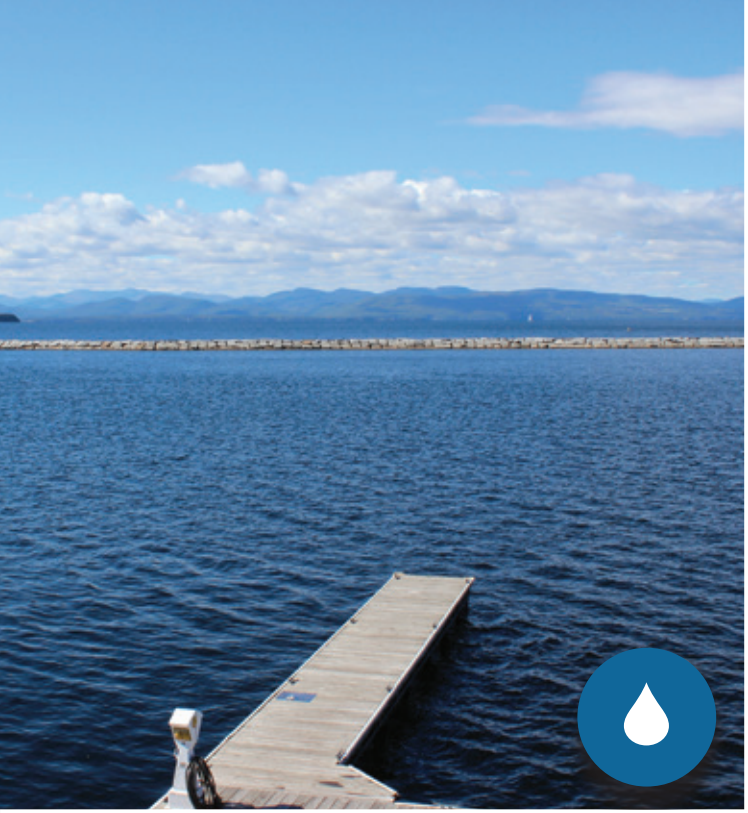
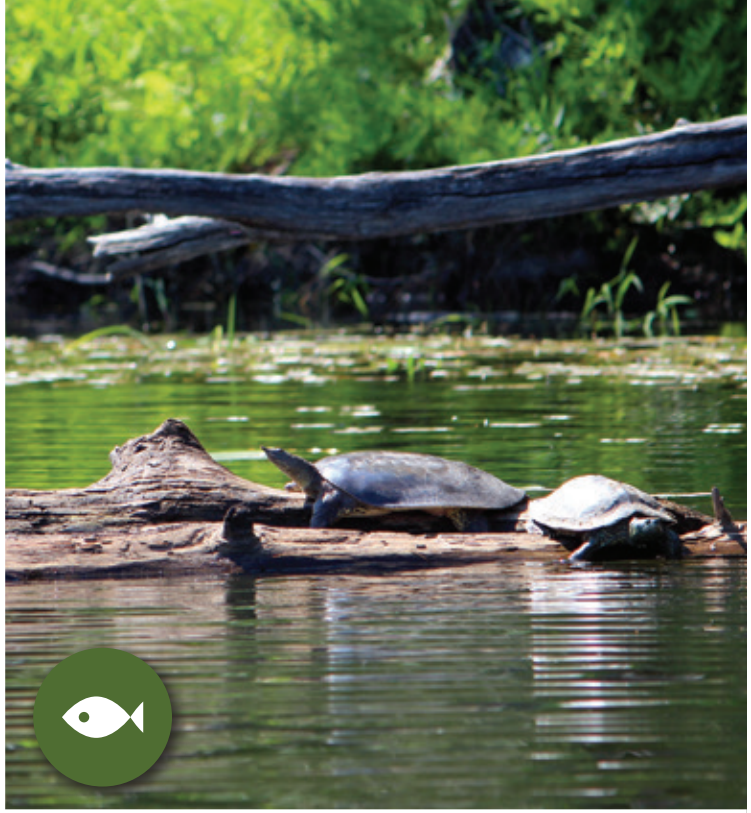




2021 Lake Champlain STATE of the LAKE and Ecosystem Indicators Report

Lake Champlain Basin Program

ABOUT THE LAKE CHAMPLAIN BASIN PROGRAM

The Lake Champlain Basin Program (LCBP) coordinates and funds efforts that benefit the Lake Champlain Basin's water quality, fisheries, wetlands, wildlife, recreation, and cultural resources. The program works in partnership with federal agencies; state and provincial agencies from New York, Québec, and Vermont; local communities; businesses; and citizen groups. These partners lead collaborative actions to address water quality and environmental challenges that cross political boundaries in a multinational watershed.

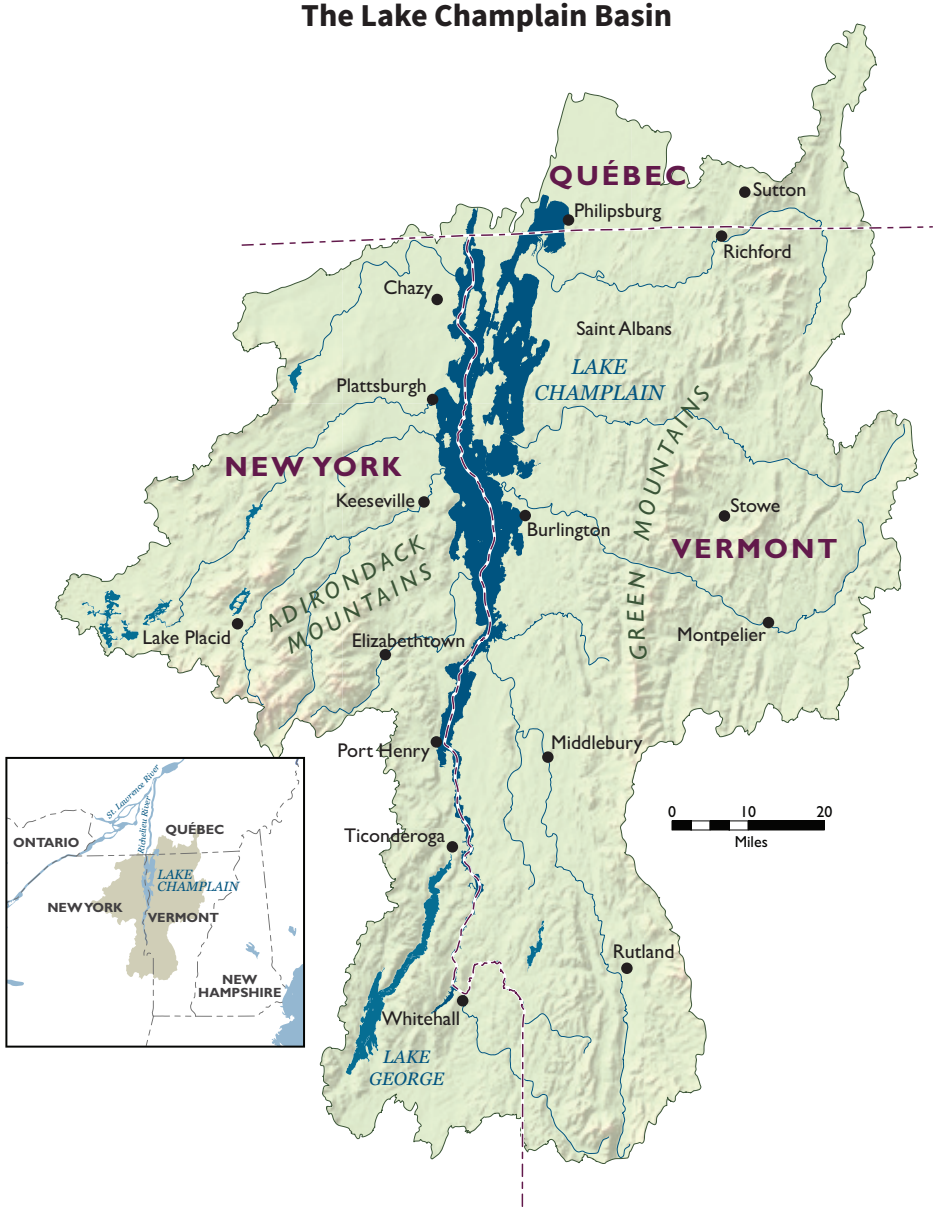
The LCBP was created by the Lake Champlain Special Designation Act of 1990, which named Lake Champlain as a resource of national significance. The LCBP was charged with developing and implementing a comprehensive and coordinated plan for protecting the Lake Champlain Basin. The LCBP works closely with program partners to implement management goals outlined in *Opportunities for Action: An Evolving Plan for the Future of the Lake Champlain Basin.*

The Lake Champlain Steering Committee guides the LCBP's work. Its members include staff from the U.S. Environmental Protection Agency and several other U.S. federal agencies, state and provincial governments in New York, Québec, and Vermont; local governments; and Lake Champlain Sea Grant. The chairpersons of the LCBP's Technical Advisory Committee, Heritage Area Program Advisory Committee, Education and Outreach Advisory Committee, and Citizen Advisory Committees also serve on the Steering Committee.

The LCBP receives funding from the U.S. Environmental Protection Agency, the Great Lakes Fishery Commission, and the U.S. National Park Service. NEIWPCC manages the LCBP's financial, contractual, and human resources business operations on behalf of the Lake Champlain Steering Committee. LCBP staff are employees of NEIWPCC. NEIWPCC is a regional commission that helps the states of the Northeast preserve and advance water quality.

Visit lcbp.org to learn more.

The Lake Champlain Basin

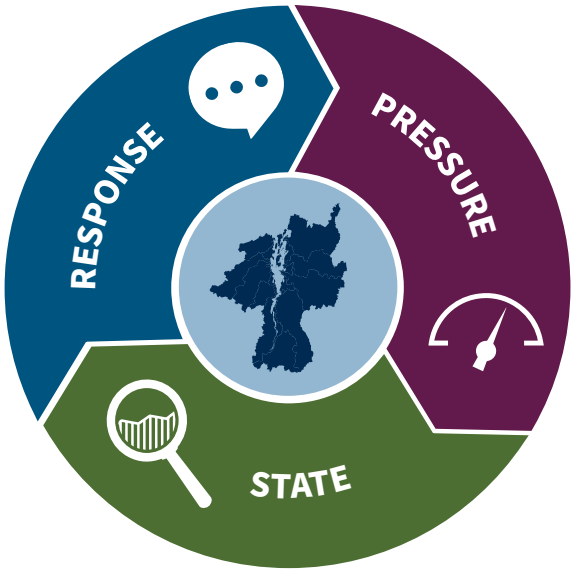


Cover photos: LCBP

Table of Contents

Lake Champlain is a unique and invaluable resource for residents and visitors to our region. Thousands of people rely on the Lake for sustenance, inspiration, and rejuvenation. The Lake's tributaries are the lifeblood of the ecosystem, connecting communities and habitats in the farthest reaches of the watershed to the Lake itself. The Lake Champlain Basin Program (LCBP) is committed to protecting, restoring, and preserving Lake Champlain and its watershed through collaborative partnerships and through leveraging the strength of its communities.

LCBP and its partners manage the Lake Champlain Basin with a "Pressure-State-Response" approach. In this model, "pressures" represent challenges introduced by human activities, the "state" is science-based evidence for the condition of the ecosystem, and the "response" is LCBP's plan to protect and restore Lake Champlain and its watershed. Every three years, the *State of the Lake and Ecosystem Indicators Report* documents the state of the Lake's ecosystem and provides context on how pressures from human activities have led us to this point. LCBP strives to do this through graphs of scientific measurements with clear scientific interpretation and through an Ecosystem Indicator scorecard, which provides the status and long-term trends for several important issues at a glance.



LCBP is pleased to include a new Ecosystem Indicator in this report—the first in nearly two decades—to help readers understand changes in how often the Lake freezes over and potential impacts of these warming trends on the Lake's ecosystem. The report also includes several new figures to illustrate changing chloride levels, the relationship between phosphorus and nitrogen and possible impacts on cyanobacteria (formerly called "blue-green algae") blooms, and access for landlocked Atlantic salmon to their historical ranges in major rivers of the Basin. A new map in the report highlights conserved lands around the Basin and public beach locations on the Lake. Public access is now more important than ever, since the COVID-19 pandemic drove people to find recreation opportunities on conserved lands, lakes, and public trail systems in new ways.

Many stories shared in this report are encouraging. Fisheries managers are reducing the number of lake trout stocked by 33%, a decision informed by the documented success of wild lake trout reproduction over several years. Surveys have shown that 60% of boaters take precautions to prevent the spread of invasive species, signaling awareness of individual responsibility in preventing invasive species introduction and spread. New programs are connecting students and adults to the history and heritage of the region and are bringing kids outside to experience and learn about their watershed.

This report also describes several ongoing challenges. The amount of nutrients delivered to the Lake from the Basin each year must be reduced to meet water quality goals, and warm weather cyanobacteria blooms continue to impact recreation in many parts of the Lake. Despite several invasive species interceptions and prevention measures, the fishhook waterflea was discovered in the Lake in 2018.

As the COVID-19 pandemic changed the world in countless ways and severely limited public engagement in 2020, many outreach and interpretation programs were postponed or transitioned to virtual platforms. Many of these new approaches to informing and involving the public will be lasting and will shape our future work to protect and restore the health of the Basin.

LCBP is working with new and existing partners to include, amplify, and translate messaging to more communities in the Lake Champlain Basin; to encourage projects and programs that look beyond traditional outreach; and to develop new approaches that will be more inclusive. This collaborative approach by all users of the Lake will help the community to achieve its shared goals for clean water, healthy ecosystems, thriving communities, and an informed and involved public.

This document is complemented by the *State of the Lake* website, which contains additional content, a full French translation, and citations for the scientific literature and technical reports that inform the report. Learn more at sol.lcbp.org.

ECOSYSTEM INDICATORS
by LAKE SEGMENT

			MISSISQUOI BAY		NORTHEAST ARM*		MALLETTS BAY		MAIN LAKE		SOUTH LAKE	
		Trend Start	STATUS	TREND	STATUS	TREND	STATUS	TREND	STATUS	TREND	STATUS	TREND
CLEAN WATER	Phosphorus in Lake (p. 13)	1990	Poor	No trend	Poor	Deteriorating	Fair	No trend	Poor	No trend	Fair	No trend
	Phosphorus from rivers (p. 14)	1991	Poor	Deteriorating	No status data	No trend data	Poor	No trend	Poor	No trend	No status data	No trend
	Phosphorus from WWTFs† § (p. 15)	1995	Good	Improving	Good	Improving	Good	Improving	Good	Improving	Good	Improving
	Cyanobacteria blooms (p. 11)	2013	Poor	No trend	Fair	Deteriorating	Fair	No trend	Fair	No trend	Fair	No trend
	Fish consumption advisories† (p. 7)	2018	Fair	No trend	Fair	No trend	Fair	No trend	Fair	No trend	Fair	No trend
HEALTHY ECOSYSTEMS	Sea lamprey wounding† (p. 24)	2003	Fair	Improving	Fair	Improving	Fair	Improving	Fair	Improving	Fair	Improving
	New aquatic invasive species (p. 22)	2018	Fair	Deteriorating	Fair	Deteriorating	Fair	Deteriorating	Fair	Deteriorating	Fair	Deteriorating
	Invasive water chestnut coverage (p. 26)	2018	Fair	Improving	Fair	Deteriorating	Good	No trend	Fair	No trend	Poor	Improving
CLIMATE IMPACTS	Lake Champlain freeze-over (p. 21)	1906	Trend: Lake surface freezing over less frequently.									

** Northeast Arm indicator statuses and trends for in-lake phosphorus concentrations, tributary phosphorus loading to the Lake, and cyanobacteria blooms do not include data from St. Albans Bay.*

† These lake-wide indicators are the same for all segments.

§ Wastewater treatment facilities

Some trends may be impacted by year-to-year differences in data collection and reporting. This is especially true for cyanobacteria bloom data, which is collected by a network of volunteer community scientists.

Using the most current data available, the 2021 Ecosystem Indicators Scorecard describes the status and trends of Lake Champlain's five major segments: Missisquoi Bay, Northeast Arm, Malletts Bay, Main Lake, and South Lake. Nine indicators have traditionally been used to characterize the current condition of Lake Champlain. Many pressures influence the indicators for each segment and affect the five segments differently, depending on their distinct physical and biological characteristics. Responses from and management actions of LCBP and its partners have improved some of these indicators in many ways; others will continue to improve as LCBP works toward its mission. A new indicator was added for this report: Lake Champlain freeze-over. Management activities likely will have little impact on this trend, but changes in ice cover may impact the Lake's ecosystem and are worth reporting.

Indicators were chosen with the guidance of dozens of scientists and state, provincial, and federal technical experts as the best means of characterizing progress, or the lack of it, in areas where adequate data exist. Detailed explanations of each indicator and the criteria used to determine the scores are available on the LCBP State of the Lake website (sol.lcbp.org).

The *State of the Lake* Summary on pages 4 and 5 of this document highlights key issues for each of these five major Lake segments.

STATUS

- GOOD
- FAIR
- POOR
- NO STATUS DATA AVAILABLE

TREND

- IMPROVING
- NO TREND
- DETERIORATING
- NO TREND DATA AVAILABLE

STATE OF THE LAKE SUMMARY

Missisquoi Bay

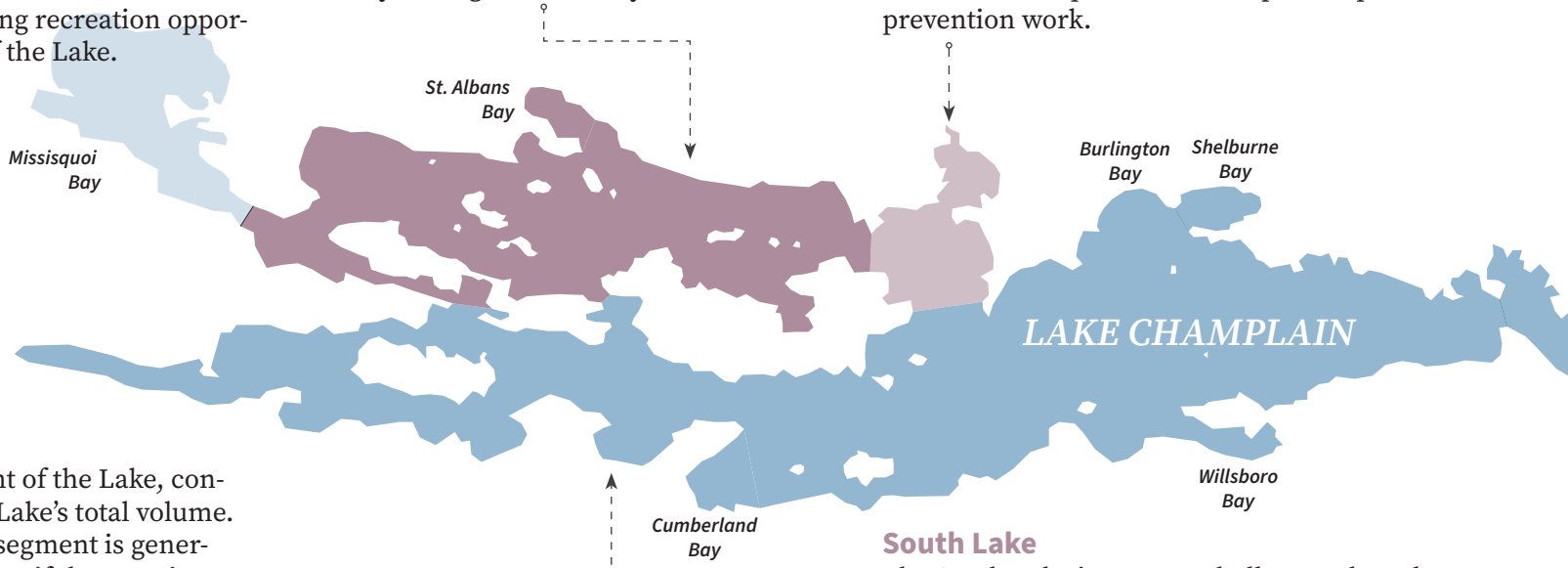
This shallow bay spans Québec and Vermont and is fed by the Missisquoi, Pike, and Rock Rivers. The bay contains less than 1% of the Lake's total volume but 7% of the Lake's surface area. Venise-en-Québec and other towns on the bay rely heavily on the health of Missisquoi Bay for their tourism industry. Elevated nutrient concentrations and seasonal release of legacy phosphorus from lake sediments contribute to frequent cyanobacteria blooms in warm months, inhibiting recreation opportunities and other uses of the Lake.

Northeast Arm

Located entirely within the state of Vermont, the Northeast Arm holds about 13% of the Lake's volume. This relatively deep Lake segment is dotted with many islands, bays, and shallower areas, creating a favorite area for many boaters and anglers. St. Albans Bay, a large and productive bay, has frequent challenges with cyanobacteria blooms. A small population of invasive water chestnut is successfully managed in this bay.

Malletts Bay

A large, deep bay, Malletts Bay offers a mix of cold- and cool-water fishing and serves as a recreation hub for sailing and other boating activities. Over the past 10 years, phosphorus concentrations in this Lake segment have been just above the phosphorus limit, and cyanobacteria blooms are infrequent. The bay is home to one of the busiest public launches on Lake Champlain, creating a need for increased aquatic invasive species spread prevention work.



Main Lake

This is the largest segment of the Lake, containing about 85% of the Lake's total volume. The water quality in this segment is generally excellent, offering plentiful recreation opportunities, angling for cold-, cool-, and warm-water fish, and a high quality drinking water supply for many Lake Champlain Basin residents. Cyanobacteria blooms appear here only occasionally. This segment also offers many historic interpretation opportunities, from shipwrecks in the Lake to historic forts on the hillsides.

South Lake

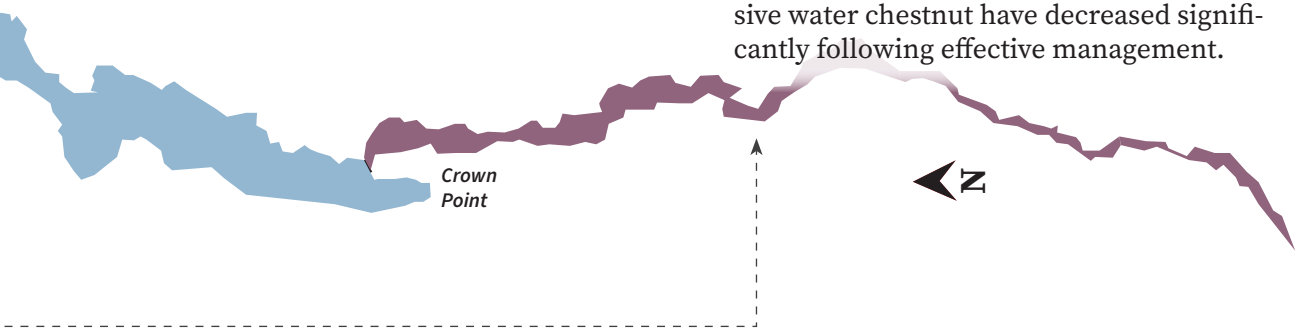
The South Lake is narrow, shallow, and markedly different from the rest of Lake Champlain. This area is known for scenic views and biological diversity. A number of native mussel species are found here, and the Poultney River system provides crucial habitat and large wetland complexes along the river. Consistent support for invasive water chestnut management in the South Lake continues to yield gains in reducing stress on the aquatic plant community and local recreation.

Clean Water

In most parts of Lake Champlain water quality remains good, however the Lake does not meet Clean Water Act goals for all uses. Fortunately, despite current water challenges the Lake continues to provide quality drinking water, and water-based recreation remains available to residents most of the time. Still, cyanobacteria blooms impact recreation during the summer months, especially where phosphorus levels remain too high and in other areas when warm weather persists. Some beaches are occasionally closed due to too much bacteria, typically following large storm events. Lake-wide, fish consumption advisories remain in place due to mercury, a problem in lakes across the Northeast, and chloride levels are increasing but remain well below the point of impacting drinking water quality. Municipalities are upgrading combined sewer systems to reduce the occurrence of overflows, which can send pathogens from untreated waste into the Lake.

Healthy Ecosystems

The Lake Champlain Basin provides habitat for thousands of native species, including more than 70 species of threatened and endangered fish and wildlife. However, climate change, invasive species, and pressures from human activities all threaten the health of the Basin's ecosystem. Successful wild lake trout reproduction has allowed for the reduction of stocking of this species to maintain a balance of predators and prey in the Lake. Aquatic passage restoration has provided gains for Atlantic salmon habitat, but many systems remain fragmented. Wounding of lake trout by sea lamprey remains above targets, but Atlantic salmon are near target rates. Lake Champlain freezes over much less often than it did in the recent past, causing ecosystem effects that are not fully understood. Efforts to reduce the introduction of new invasive species have been successful, but established populations continue to do harm, and new threats require vigilance. Impacts from invasive water chestnut have decreased significantly following effective management.



Thriving Communities

Nearly 40% of the land area in the Lake Champlain Basin is conserved to some extent, providing ample recreational opportunities. The COVID-19 pandemic reinforced the need for conserved lands and public spaces—public trail systems, boat launches, and other outdoor recreation spaces saw a significant increase in use, to the point where New York State has enacted a system to address overcrowding. LCBP and partners have been working to ensure inclusion of traditionally underserved and Indigenous communities in Lake-related programs across the Basin. The LCBP acknowledges the history and culture of Indigenous people of the Basin and recognizes that we are all stewards of our natural and cultural resources.

Informed and Involved Public

Watershed education efforts have reached many learners of all ages throughout the Lake Champlain Basin, developing future stewards of our water resources. During the 2018–2020 time period, boat launch stewards reached more than 192,000 boaters at public boat launches with messaging related to invasive species and other water quality issues. The LCBP Resource Room connected in person with more than 70,000 visitors during this same period. New programs target specific focus areas, such as residential lawn care for water quality or field trip opportunities for students. The COVID-19 pandemic created new opportunities to develop virtual programs, which allowed for broader reach to wider audiences and which will likely continue.

GOAL: Water in the Lake Champlain Basin's lakes, ponds, rivers, and streams will sustain diverse ecosystems, support vibrant communities and working landscapes, and provide safe recreation opportunities.

The rain and snow that fall on the Lake Champlain watershed feed 14,700 miles of streams and rivers that deliver more than 2 trillion gallons of water to the Lake each year. Streams and rivers also carry vital nutrients, organic material, and pollutants that each play a role in the quality of Lake Champlain's water for drinking, recreation, and a functioning ecosystem with native wildlife. Water quality in many regions of the Lake is excellent, though human activities in the past and present create challenges for Lake Champlain's future.

DRINKABLE, FISHABLE, AND SWIMMABLE WATER

Lake Champlain provides high-quality drinking water to more than 145,000 people.

Lake Champlain is a safe and reliable source of drinking water to approximately 24% of the Basin's population. There are 100 public water suppliers in the Lake Champlain Basin that pump, treat, and distribute water for use and consumption. As is true throughout much of the world, consuming untreated water is considered unsafe and is not recommended.

All public water utilities are required to monitor for 86 potential contaminants in drinking water, including several microorganisms, disinfectants, disinfection by-products, inorganic and organic contaminants, and radionuclides. Drinking water from Lake Champlain rarely exceeds limits for any of these contaminants.

Lake Champlain fish can be safely enjoyed as part of a healthy diet when consumption advisories are followed.

Fishing is an important way that communities in the Basin connect with the Lake Champlain ecosystem. New York, Vermont, and Québec

have each determined safe fish consumption levels for their jurisdictions to provide guidance to anglers.

Mercury biomagnifies through the food chain, which means that older, larger predatory fish typically contain more mercury than smaller fish. Therefore, a small species such as yellow perch will generally contain lower levels of mercury than lake trout, a larger predatory fish. Because children and women of childbearing age may be more susceptible to negative effects of mercury consumption, advisories are sometimes more restrictive for these groups.

Local and national efforts have resulted in decreases in mercury concentration in several Lake Champlain fish species. This was particularly true from the 1990s until 2011, when mercury decreased in nearly all fish species sampled (Figure 1). Between 2011 and 2017, however, the trend reversed, and mercury was found to have increased in all species sampled. The reason for this reversal is unclear, and research is underway to investigate potential causes for the change.

The Lake Champlain Basin's rivers and lakes are safe for swimming at most times.

The Lake Champlain Basin provides countless opportunities for swimming with its 587 miles of shoreline, 54 public beaches on the Lake, and hundreds of river swimming holes. For most of the swimming season, beaches in most places on Lake Champlain are safe and open to the public. When considered together, the 17 public beaches included in Figure 2 were open for swimming about 97% of the time from Memorial Day to Labor Day during the 2018–2020 timeframe. When a public beach is closed for health concerns, it is usually a result of a cyanobacteria bloom, which caused closures about 2% of the days during this time frame, or elevated levels of coliform bacteria, which caused closures less than 1% of the days. Although several of these beaches had very few or no closures in 2018–2020, St. Albans Bay Park was affected the most and was open 87.5% of the time.

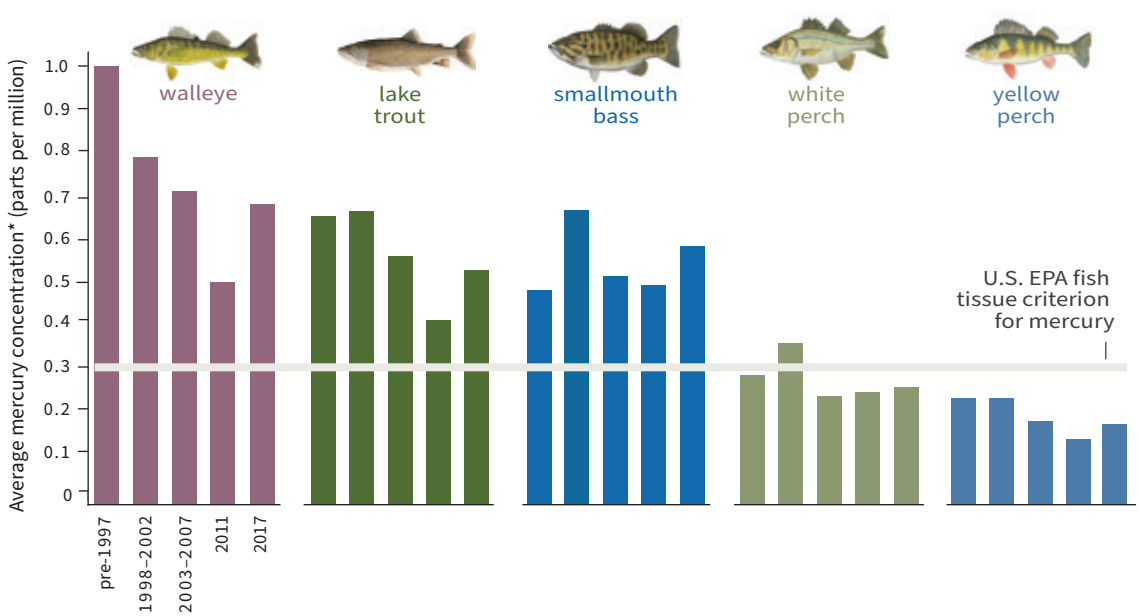
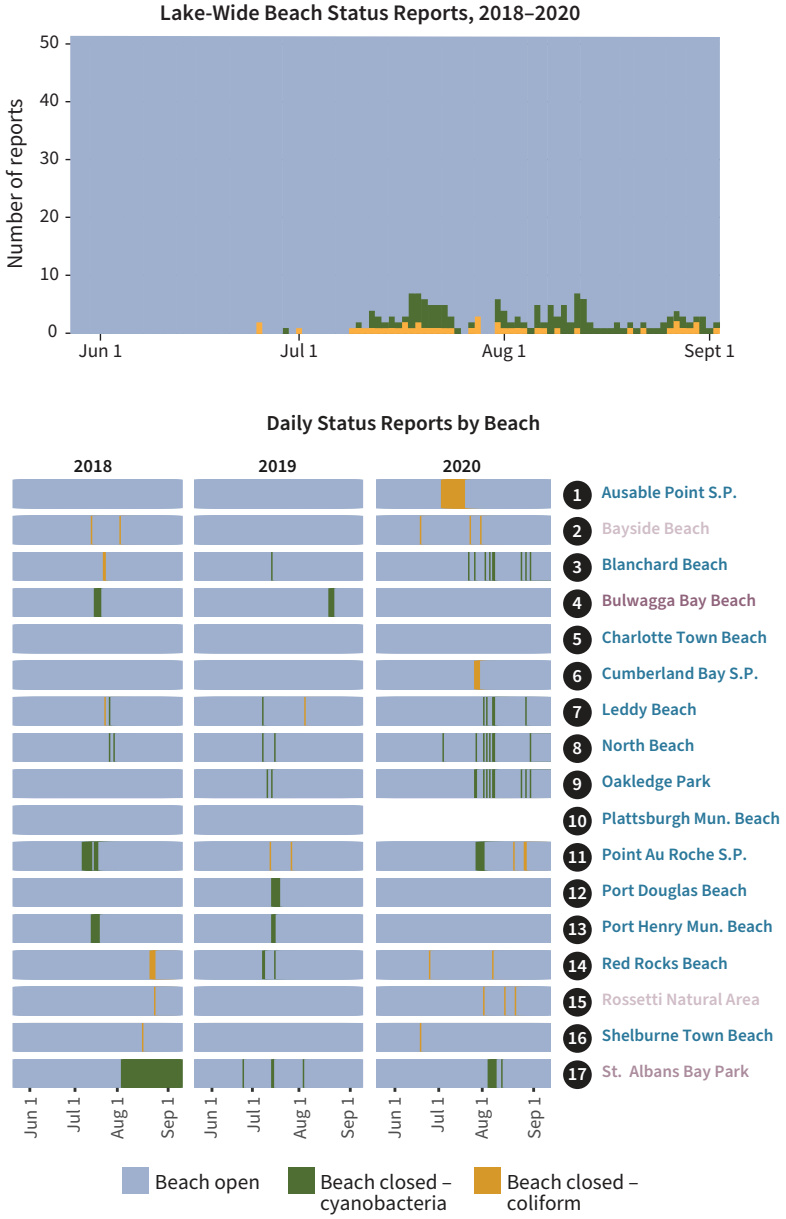


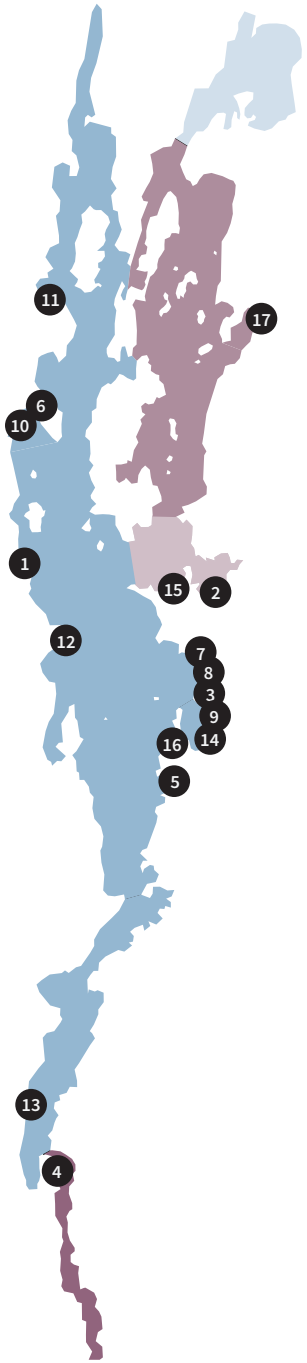
Figure 1 | Mercury concentration in Lake Champlain fish tissue

Photo: Rachel Hamm Vaughan



NOTE: Non-water quality closures are not represented. Québec beaches are not officially monitored for cyanobacteria.
DATA SOURCES: Town Offices, VT ANR, UVM, NYS DOH, MELCC

Figure 2 | Reported public beach closures on Lake Champlain



PATHOGENS

Concerns for pathogens can impact recreation on Lake Champlain.

Harmful disease-causing organisms or viruses known as pathogens can be transported from the digestive tracts of animals to any lake or river, including those in the Lake Champlain Basin. These pathogens can be transported in water that comes in contact with pet, wildlife, or livestock waste as it moves through the landscape or in untreated sewage water. Because it is impractical to test lake or drinking water for every waterborne pathogen, drinking water providers and public beach managers instead test for cell counts of coliform bacteria—a group of mostly harmless bacteria that are present in the digestive tract of all animals, including humans. Elevated levels of coliform bacteria may indicate fecal contamination and the possible presence of waterborne pathogens. Elevated coliform bacteria levels in localized areas of Lake Champlain typically only occur following rainstorms that wash bacteria, sediment, and pollutants into the Lake.

Combined sewer overflow events are potential sources of pathogens and are a challenge to eliminate.

To minimize the threat of waterborne pathogens and other pollutants, it is usually best for cities and towns to maintain separate pipe networks to transport stormwater and sanitary sewage independently. However, several municipalities in the Lake Champlain Basin

have "combined" systems, where stormwater and sanitary sewage flows are combined in places into one piping network and conveyed to a wastewater treatment facility. When heavy rainfall creates more stormwater runoff than can be accommodated by a combined system, a combined sewer overflow (CSO) allows some of this water to be discharged to a nearby waterway through overflow pipes (Figure 3). During a CSO, untreated or partially treated sewage may then enter a stream or river and eventually the Lake. Although CSOs can be a primary cause of temporary localized elevated coliform bacteria levels, their contribution to Lake Champlain nutrient pollution is insignificant compared to other sources.

Efforts are underway to better understand and address the sources of coliform bacteria in the Lake Champlain Basin's waterways. The City of Plattsburgh, for example, used DNA tracking technology to determine the source of coliform bacteria that led to public beach closures along the city's Lake Champlain shoreline. The study found that gulls and cows were the most common sources of coliform bacteria during dry weather conditions and after rainstorms that did not result in CSOs. After storms that resulted in CSOs, the most common sources were gulls, humans, and dogs.

Substantial efforts have been made to reduce the number of CSO events in the Lake Champlain Basin. Since 1990, the number of CSO discharge points in the New York and Vermont portions of the Basin has decreased from 87 to 31. Municipalities throughout the Basin are working to reduce pressure on their stormwater systems by separating their systems, eliminating discharge points, upgrading their treatment facilities, and implementing green stormwater infrastructure projects to reduce stormwater inputs.

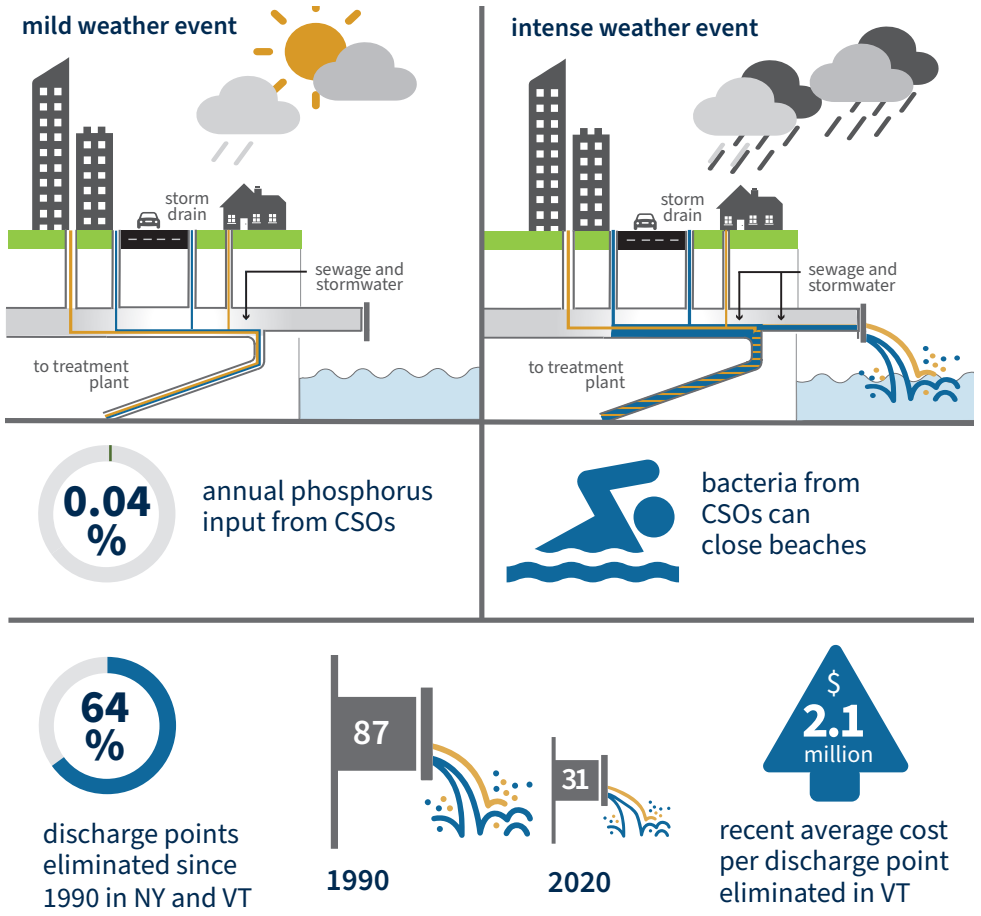


Figure 3 | Combined sewer overflows in the Lake Champlain Basin

CYANOBACTERIA

Since 2013, 95% of routine visual assessments on Lake Champlain during the recreational season reported conditions free of cyanobacteria blooms. Cyanobacteria conditions vary significantly among lake segments, and warm weather blooms continue to present a challenge to recreation and public health.

Cyanobacteria are a group of primitive bacteria that are native to nearly every ecosystem on Earth. Several species of cyanobacteria are found in Lake Champlain, and most of the time they do not cause harm. Cyanobacteria can become harmful and impact recreation when their growth is accelerated by calm, warm weather and excessive levels of nutrients such as nitrogen and phosphorus.

A cyanobacteria bloom occurs when colonies of cyanobacteria become large enough to see with the naked eye and form a surface scum. These colonies often look like green pinhead-sized balls and can form a layer on the surface of the water that may resemble thick pea soup or a paint spill. Cyanobacteria blooms can sometimes produce toxins (known as cyanotoxins) that can be harmful if ingested by humans, pets, or wildlife. Cyanobacteria blooms also can have other adverse effects on Lake Champlain, such as reduced oxygen levels in the water and noxious odors.

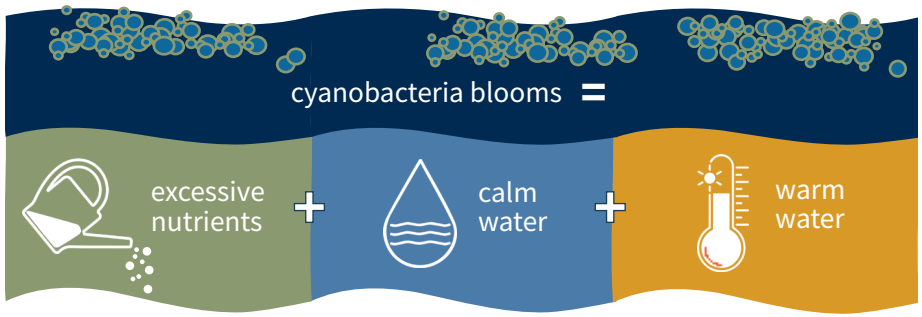
The LCBP works with the Lake Champlain Committee and Vermont and New York state partners to support the Lake Champlain Cyanobacteria Monitoring Program. During the warm months, more than 100 community scientist volunteers report each week on water conditions along the shoreline. If a cyanobacteria bloom is visible, an alert is posted online to the Lake Champlain CyanoTracker Map hosted by the Vermont Department of Health. If the bloom is at a public beach, it is recommended that the beach is closed to swimming as a precautionary measure, even if cyanotoxin concentrations are not known. In many cases, water samples are tested for cyanotoxins to determine whether the beach is safe for swimming, and local authorities are notified if test results merit closure of the beach.

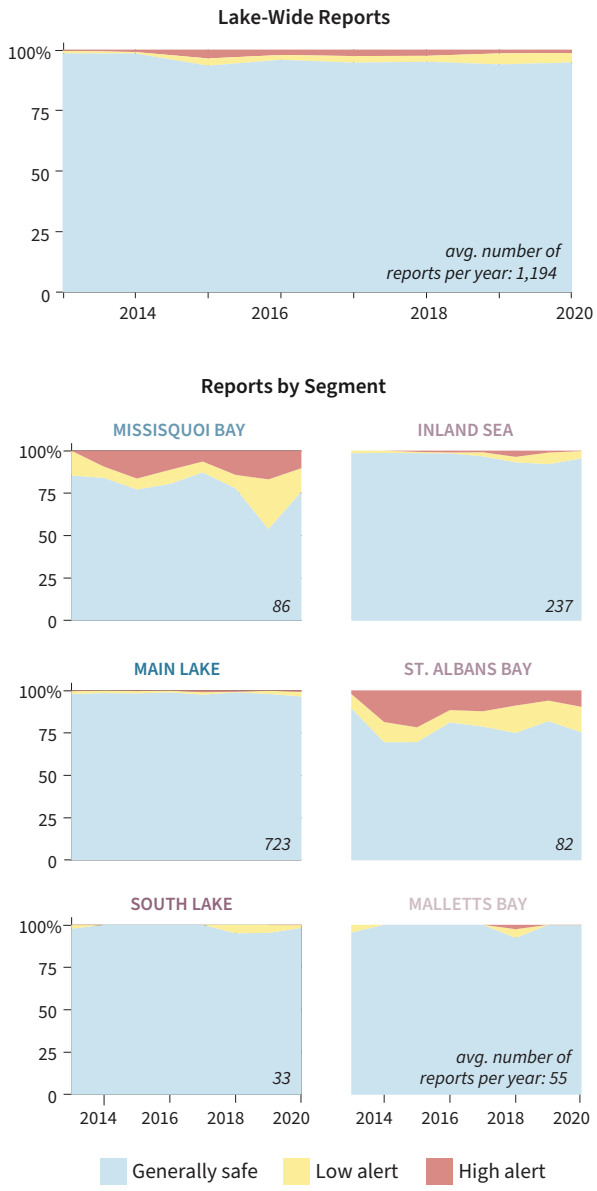
Cyanobacteria blooms are not present most days in Lake Champlain, and over 95% of the approximately 9,500 routine visual assessment reports submitted since 2013 have reported "generally safe" conditions during the recreational season (Figure 4). Bloom frequency and intensity varies drastically among Lake regions; 98% of reports from Main Lake locations since 2013 indicated "generally safe" conditions while that figure is 77% and 79% for St. Albans and Missisquoi Bays, respectively.

Recent cyanobacteria blooms have impacted recreation opportunities for residents and visitors. In the summer and fall of 2020, extended periods of warm and calm conditions caused cyanobacteria blooms and beach closures in many regions of Lake Champlain, including the Burlington area. Unfortunately, climate change may increase these periods of warm and calm conditions to make increasingly favorable conditions for blooms in the future.

Cyanotoxins are rarely detected in Lake Champlain, though it is best to avoid areas with active cyanobacteria blooms.

Laboratory results from Lake Champlain water samples have shown that when there is no cyanobacteria bloom visible, cyanotoxins are very rarely detected and have never been measured above recreational thresholds for public safety. In addition, cyanotoxins are often not detected in water when cyanobacteria blooms are visible. During the 2018–2020 time period, cyanotoxins were detected in 12 of the 262 water samples tested, and all samples were well below public safety recreational threshold levels.





DATA SOURCE: Lake Champlain Cyanobacteria Monitoring Program (LCBP, LCC, VT ANR, NYSDEC, VTDOH)

Figure 4 | Cyanobacteria monitoring reports on Lake Champlain

Since 2015, the 22 Lake Champlain-sourced public water supply systems in Vermont each have voluntarily tested raw and finished (treated) water for cyanotoxins during the warm months. Among over 1,300 samples from these facilities in the summers of 2018–2020, there were no detections of cyanotoxins in finished drinking water samples and two low-level detections of cyanotoxins in raw water samples, which were not confirmed upon repeated sampling.

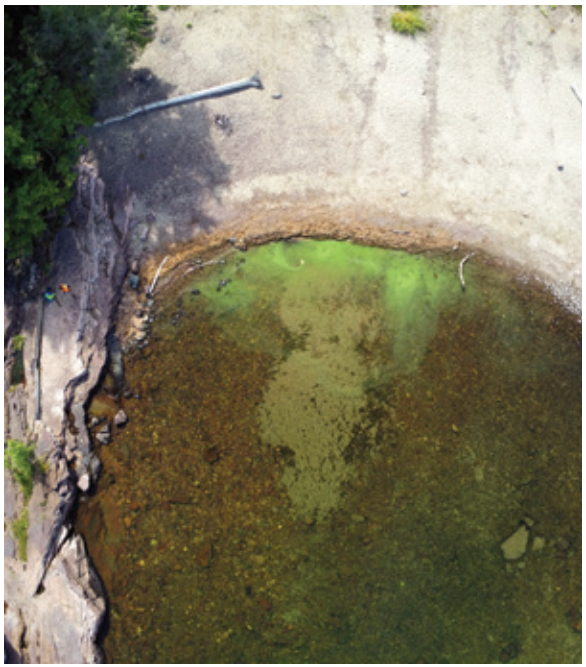
A recent study found no cyanotoxins in Lake Champlain fish tissue.

The RPI Darrin Fresh Water Institute recently collected Lake Champlain fish during low- and high-severity cyanobacteria blooms and analyzed fish tissues for three types of cyanotoxins: microcystin, anatoxin-a, and cylindrospermopsin. None of these cyanotoxins were detected among the 5 species and 153 specimens sampled, suggesting that these cyanotoxins did not accumulate in fish tissue in Lake Champlain.

There is ongoing work to determine the potential impact of cyanobacteria blooms and associated cyanotoxins on water quality and public health.

In addition to the Lake Champlain Cyanobacteria Monitoring Program, partners in the Basin are pushing the envelope to inform our understanding and management of cyanobacteria blooms. The University of Vermont is at the forefront of this research, with projects that will use drones to determine the extent of cyanobacteria blooms and satellite images to study the distribution and severity of cyanobacteria blooms across Lake Champlain. There are also studies that will continue to measure cyanotoxins in fish tissue, determine whether cyanotoxins might aerosolize and impact shoreline air quality, and determine public perception of cyanobacteria blooms in their communities.

The LCBP and its partners are addressing the root cause of cyanobacteria blooms in Lake Champlain by working to limit the levels of nutrients available for their growth.



An aerial photo of a cyanobacteria bloom in progress. Photo: University of Vermont Spatial Analysis Lab

NUTRIENTS

Nutrients are essential for life but create problems for lakes when in excess.

Nutrients, including nitrogen and phosphorus, are a natural part of all ecosystems, are essential for all forms of life, and have been delivered to Lake Champlain by natural processes for millennia. In the post-industrial era, however, human activities have rapidly increased the rate of nitrogen and phosphorus delivery to Lake Champlain and to thousands of waterbodies around the world, with profound effects on freshwater systems.

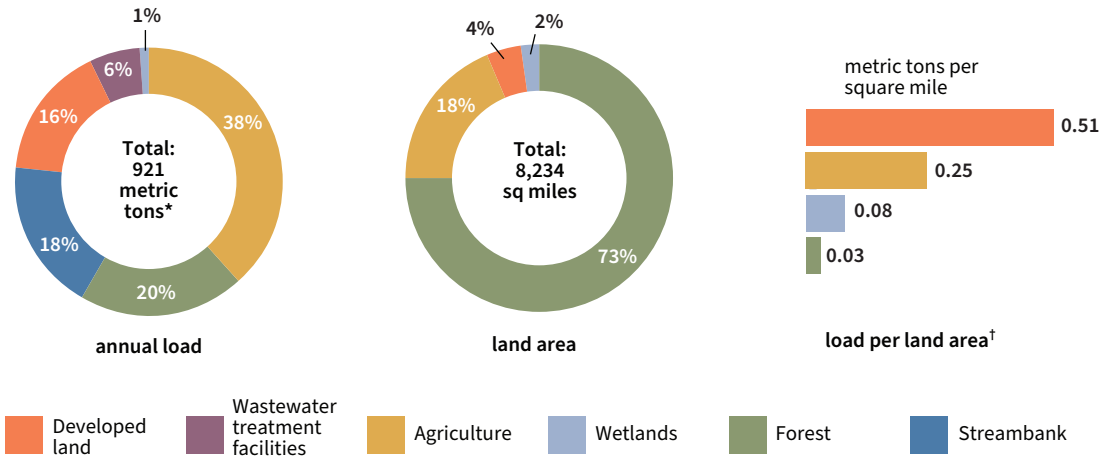
For every square mile on the surface of Lake Champlain, 18 square miles of land in the Lake Champlain Basin deliver water to the Lake and contribute sediment, nutrients, and other potential pollutants. For the Great Lakes, this ratio is much lower: there is only 1.5 to 3.4 times as much land as lake surface area in those basins. Most nutrients come from sources on the land (Figure 5), so the relatively high land-to-lake area ratio for Lake Champlain poses a significant challenge in limiting nutrient pollution.

Rivers are the pathways for water, sediment, and nutrients to move into Lake Champlain. Each year, the Lake's tributaries deliver about 921 metric tons (roughly 2 million pounds) of phosphorus. Annual changes in phosphorus delivery to the Lake depend upon the amount of rain and runoff in the watershed; this variability due to precipitation and temperature may confound efforts to reduce phosphorus loading. While management practices may help to reduce inputs, the increasingly intense rainstorms associated with climate change may release more phosphorus, possibly canceling out some gains made through pollution-reduction efforts.

Research has shown that the primary drivers of annual in-lake nitrogen and phosphorus levels differ for shallow and deep regions of Lake Champlain. In deep regions, these nutrient levels are driven by tributary inputs of "dissolved" nitrogen and phosphorus—forms that are not bound to larger sediments and that are small enough to be invisible in the water. In shallow regions, nutrient levels are driven by internal processes such as biological transformations of nitrogen and legacy phosphorus released from lake-bottom sediments and are less impacted by year-to-year changes in river loading. In the long term, reducing tributary loading is the only way to reduce nutrient levels in Lake Champlain.

Phosphorus is a key nutrient driving cyanobacteria blooms.

Photosynthesizing plants, algae, and cyanobacteria all require a supply of carbon, nitrogen, phosphorus, and light in their environment to grow. Because other nutrients are generally plentiful in Lake Champlain, phosphorus is often the resource that limits growth of cyanobacteria. In order to reduce the occurrence and persistence of cyanobacteria blooms, lake managers have set targeted limits on phosphorus concentrations for each segment of the Lake and work to reduce the loading of phosphorus to the Lake from tributaries.



* Estimated 2001–2010

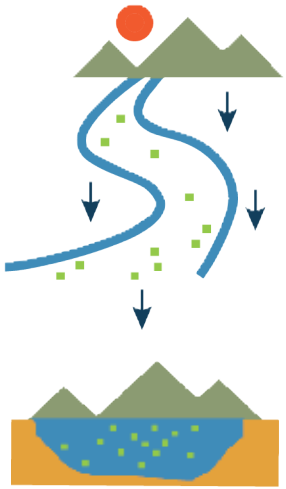
† Does not include load from streambanks and wastewater treatment facilities

DATA SOURCES: Lake Champlain Long-Term Monitoring Program; 2016 Phosphorus TMDLs for Vermont Segments of Lake Champlain

Figure 5 | Annual phosphorus loading to Lake Champlain by land cover

Many Lake segments have phosphorus concentrations that are often near or below targeted limits. However, phosphorus concentrations in Lake Champlain's shallow bays are often above these limits.

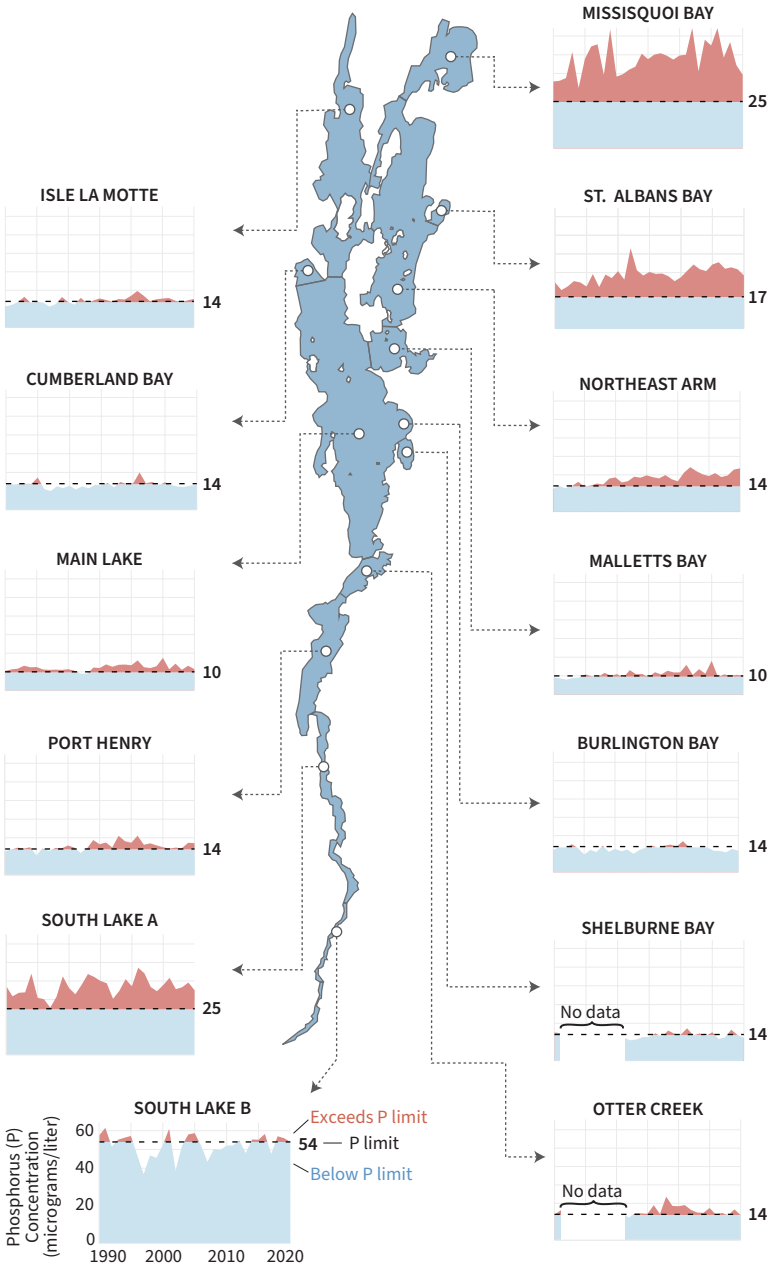
Excessive phosphorus has a significant impact on a lake's ecosystem and is a contributing cause of cyanobacteria blooms. Phosphorus concentration limits for 13 segments of Lake Champlain (Figure 6) were established in 1991, and the LCBP has supported monitoring efforts for phosphorus concentrations in the Lake since 1990. From 1990 to 2020, most segments did not show long-term trends in phosphorus concentration, though the Northeast Arm showed an increasing trend over this time period. Annual average concentrations often have been near or below targeted limits since 1990 in the Main Lake, Isle La Motte segment, Cumberland Bay, Port Henry, South Lake B segment, Malletts Bay, Burlington Bay, and Shelburne Bay, which together make up approximately 82% of Lake Champlain's volume.



LOAD
Total amount delivered to the Lake in a period of time, typically reported as metric tons* per year (mt/yr).

CONCENTRATION
The amount measured in a unit volume of water, typically reported as micrograms per liter (µg/L).

*One metric ton = 2,205 lbs.



NOTE: Data for Isle La Motte includes two stations.
DATA SOURCES: Lake Champlain Long-Term Monitoring Program (LCBP, VT ANR, NYSDEC)

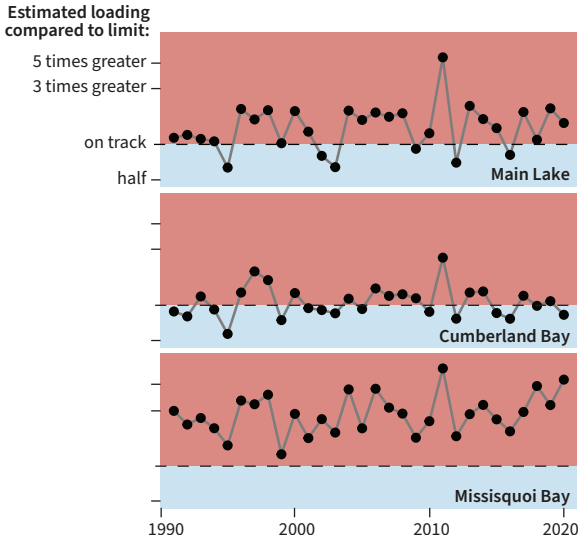
Figure 6 | Annual average phosphorus concentration by Lake segment

Phosphorus concentrations above established limits have been observed in the shallow waters of Missisquoi and St. Albans Bays, the South Lake A segment, and also in the deeper Northeast Arm segment. Some of these areas have high phosphorus loads from their contributing sub-watersheds. Also, shallow bays are more susceptible to problems associated with excess phosphorus than the deeper bays and Main Lake because there is less water to dilute nutrients. Shallow bays are also more affected by "legacy phosphorus" that is released from bottom sediments into the water column during low-oxygen conditions.

Phosphorus loading to Lake Champlain varies greatly from year to year and generally needs to be reduced to meet water quality goals.

Phosphorus loading has remained a challenge for Lake Champlain, and long-term trends have not improved in most tributaries. Although long-term decreases have been documented in the Great Chazy, Salmon, Ausable, Little Ausable, LaPlatte, and Pike Rivers, long-term increases in phosphorus loading have been documented in Lewis, Otter, and Little Otter Creeks and in the Missisquoi and Poultney Rivers. All other monitored tributaries show no significant long-term trends in phosphorus loading.

In 2016, the U.S. Environmental Protection Agency produced an updated Vermont Total Maximum Daily Load (TMDL) for phosphorus loading into 12 Vermont segments of Lake Champlain while New York continues to work toward the TMDL set in 2002 for New York segments of the watershed. Phosphorus loading to some Lake segments, such as Cumberland Bay, has been at or below these limits; phosphorus loading to other segments, such as Missisquoi Bay, has been well above limits (Figure 7). Because nutrients and sediment are primarily transported to the Lake during periods of high river flows, phosphorus loading is strongly influenced by annual differences in snowpack, rainfall, and periods of drought. This year-to-year variability in loading is likely to continue and may increase as a result of changing precipitation patterns due to climate change. This means that reducing the average annual phosphorus loading is critical for the future of Lake Champlain's water quality.



NOTES: The vertical axis is log-transformed in order to clearly show how phosphorus loading compares to limits. Three representative Lake segments are shown out of 13 in Lake Champlain.
DATA SOURCE: Lake Champlain Long-Term Monitoring Program (LCBP, VT ANR, NYSDEC)

Figure 7 | Phosphorus loading to Lake segments compared to TMDL limits

Many efforts are underway to reduce phosphorus loading and ultimately reduce phosphorus concentrations in Lake Champlain.

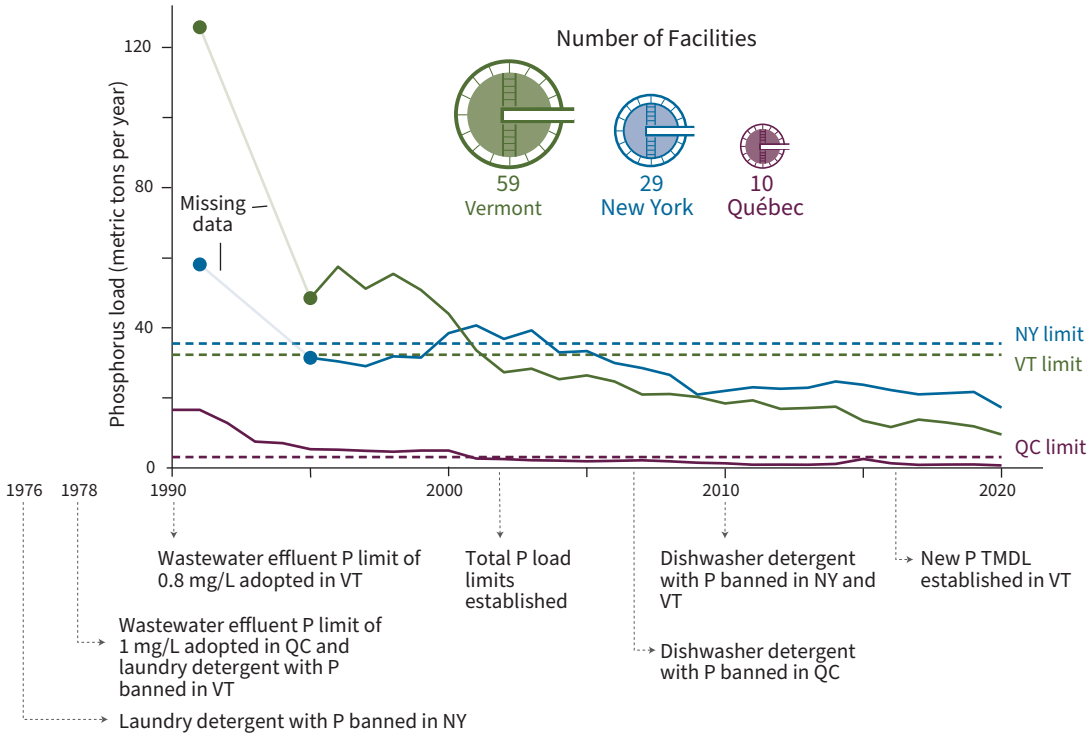
Lake Champlain has been the focus of renewed investments in watershed management practices by the U.S. federal government, state and provincial agencies, and municipalities. Recent investments in wastewater treatment facilities have driven significant reductions in phosphorus loading from these sources in all three jurisdictions (Figure 8). In 2015, the Vermont legislature passed the Clean Water Act (Act 64), which established several new rules and established revenue requirements for the Vermont Clean Water Fund to reduce the amount of phosphorus and other pollution entering the state's waterways. Vermont and Québec adopted an agreement concerning phosphorus reduction in Missisquoi Bay in 2002. The agreement reaffirmed the phosphorus concentration limit for the bay and established a phosphorus loading limit for the bay's watershed. The two jurisdictions recently renewed the agreement and shared common goals for the restoration of Missisquoi Bay.

Sediment plume at the Missisquoi River Delta. Photo: LCBP

Farmers, resource management agencies, and local watershed organizations have long recognized that farms in the Basin play a significant role in nutrient pollution challenges. Several initiatives are underway to help the agricultural sector in meeting targeted phosphorus loading limits and ultimately reducing in-lake phosphorus concentrations. Ongoing grant programs, wastewater treatment upgrades, agricultural support to implement best management practices, and outreach programs all contribute to the reduction of phosphorus loading.

The relative amounts of nitrogen and phosphorus in lake water can influence cyanobacteria blooms, and several factors are changing the balance of these nutrients in Lake Champlain.

Although it usually is not the primary driver of cyanobacteria growth, nitrogen is another key nutrient that has important influence over ecosystems and can impact how cyanobacteria blooms are established. Many species of cyanobacteria have the remarkable ability to capture their own nitrogen from the atmosphere. This means that when the in-lake



NOTE: The Québec target is an estimate based on the 2002 VT/QC agreement for Missisquoi Bay. The New York target is based on the 2002 TMDL. The Vermont target is based on the 2016 TMDL.
DATA SOURCES: NYSDEC, VTDEC, QC MELCC

Figure 8 | Annual phosphorus load from wastewater treatment facilities by jurisdiction

What You Can Do

Test your soil. To reduce nutrient runoff from your property, test lawn and garden soil to determine the nutrients the soil needs to support your plants before using fertilizer. It may be possible to use less fertilizer than you think or none at all.

Foster healthy soil. Improve soil health in your lawn and garden rather than relying on lawn care products that import nutrients into waterways. Adding compost and increasing aeration can help build healthy soil.

Raise the blade. Set your lawn mower blade to 3 inches, and leave grass clippings on the lawn. Tall grass is healthier and has deeper roots that hold more water, reducing stormwater runoff.

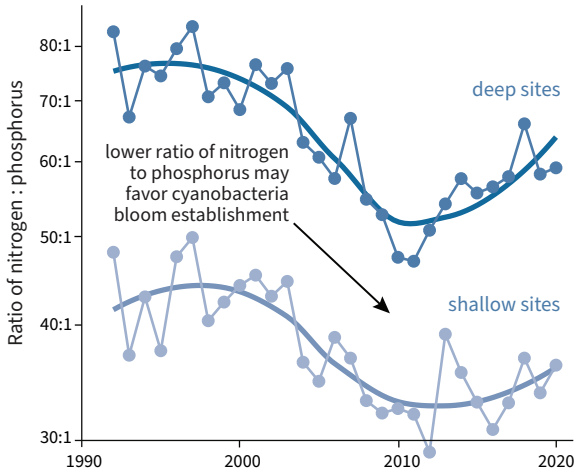
Reduce runoff. Try simple ways to reduce stormwater runoff around your home. Redirect your gutter downspouts to a lawn, plant a rain garden, or install a rain barrel.

Wash your car on the lawn. Wash your vehicle on a lawn instead of a driveway to prevent detergents from running into waterways. Or use a car wash where the water is treated after use.

Create natural buffers. Protect and plant native vegetation, especially along shorelines and riverbanks to hold soil in place and reduce erosion.

balance of nitrogen and phosphorus is tilted toward relatively less nitrogen, cyanobacteria can sometimes outcompete other phytoplankton growing in the water and may be more likely to develop into bloom conditions.

There has been a Lake-wide decrease in nitrogen concentration since monitoring began in 1990, which is likely driven by decreases in nitrogen inputs from fossil fuel emissions following the implementation of the U.S. Clean Air Act. This decline contributes to changes in the relative balance of nitrogen and phosphorus in the Lake (Figure 9).



NOTE: The vertical axis is log-transformed in order to clearly show changes in this ratio.
DATA SOURCE: Lake Champlain Long-Term Monitoring Program (LCBP, VT ANR, NYSDEC)

Figure 9 | Annual average ratio of nitrogen to phosphorus in Lake Champlain

CONTAMINANTS

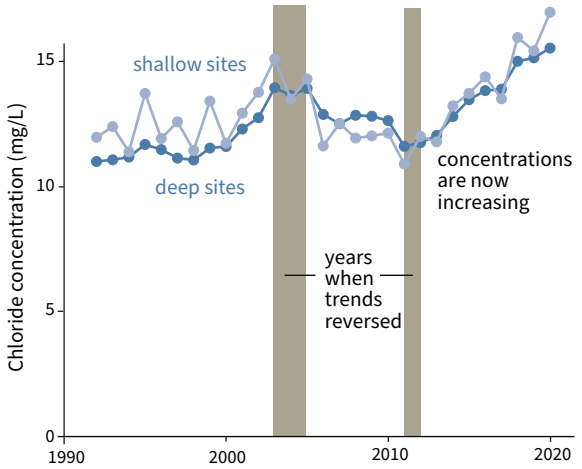
Some toxic substances and contaminants are present in Lake Champlain and its tributaries, but their effects and prevalence are not well understood.

A number of pollutants are of potential concern in Lake Champlain; these include microplastics, pharmaceuticals, road salt, pesticides, PCBs, mercury, and other bioaccumulating toxic substances. Many of these substances are often not detected when tested for or are sometimes found at very low concentration levels. The long-term effects of low-concentration toxic substances on ecosystem and human health are not well understood. Efforts to better understand the prevalence of contaminants in Lake Champlain and its tributaries are currently underway.

Long-term chloride concentration increases in the Basin's lakes and rivers are well documented and can be attributed to winter road deicing.

Deicing salts applied to road surfaces during the winter contain chloride, which can be transported to the Lake throughout the year by snowmelt or rain runoff and by groundwater inputs to rivers and streams. This makes rivers and lakes saltier, a process known as salinization. Recent human-caused salinization of freshwater systems has been found throughout the Lake Champlain region and the world. Negative effects of low- and high-level salinization can impact all levels of an ecosystem, including primary producers, zooplankton, macroinvertebrates, amphibians, and fish communities.

Although chloride concentrations found in Lake Champlain remain well below established benchmark levels for drinking water and aquatic life toxicity (250 mg/L and 230 mg/L, respectively), chloride concentration in the Lake is increasing (Figure 10). This upward trend is driven by long-term increasing trends of chloride loading from nearly all Lake Champlain Basin rivers. For example, the Winooski River alone delivered roughly 20,000 metric tons of chloride per year when monitoring began in the early 1990s; in recent years, it delivered approximately twice that amount annually.



DATA SOURCE: Lake Champlain Long-Term Monitoring Program (LCBP, VT ANR, NYSDEC)

Figure 10 | Annual average chloride concentration in Lake Champlain

LCBP partners and public works departments across the Basin are taking initiatives to safely reduce winter deicing salt application and to educate individuals and property managers on best deicing practices to reduce impact to Lake Champlain and other water bodies. Reducing the amount of deicing salt applied to our parking lots and roadways should reduce the amount of chloride measured in the Lake.

Microplastics are present in Lake Champlain, but their effects are not well understood.

Microplastics, small pieces of plastic less than 5 mm in diameter, are a growing concern in Lake Champlain. Microplastics come from a variety of sources and come in different forms; microbeads are found in some personal care products, microfibers from synthetic clothing, and eroded pieces of material from litter and other human sources. These materials often pass through wastewater treatment systems. Research conducted by SUNY Plattsburgh found that between 10,000 and 15,000 microplastic particles were discharged every day at monitored treatment facilities in the Lake Champlain Basin.

Microplastics can be ingested by fish and other wildlife and can cause digestive blockage and altered feeding behavior, which can in turn affect reproduction and overall health. Harmful bioaccumulating chemicals have been found in microplastics around the world; heavy metals and PCBs have been found in microplastics in Lake Champlain. The SUNY Plattsburgh study found fibers to be the most common plastics ingested by the bird and fish species upon which the research focused. The study also found greater amounts of plastics in organisms higher in the food chain, particularly cormorants, bowfin, and lake trout.

The Ausable River Association is studying the impact of deicing salts used on roads and sidewalks in waterways in the Lake Placid area. Photo: Ausable River Association

What You Can Do

Don't trash toxics. Take toxic waste and hazardous items to designated waste drop-off centers. This includes electronics, paint, pesticides, herbicides, motor oil, and items that contain mercury, such as non-digital thermometers and compact fluorescent light bulbs (CFLs).

Check for leaks. Repair leaking cars, trucks, boats, and other machinery to reduce oil and gas pollution.

Properly dispose of unused medications. Don't flush medications. Instead, return them to a pharmacy or authorized drug collection site.

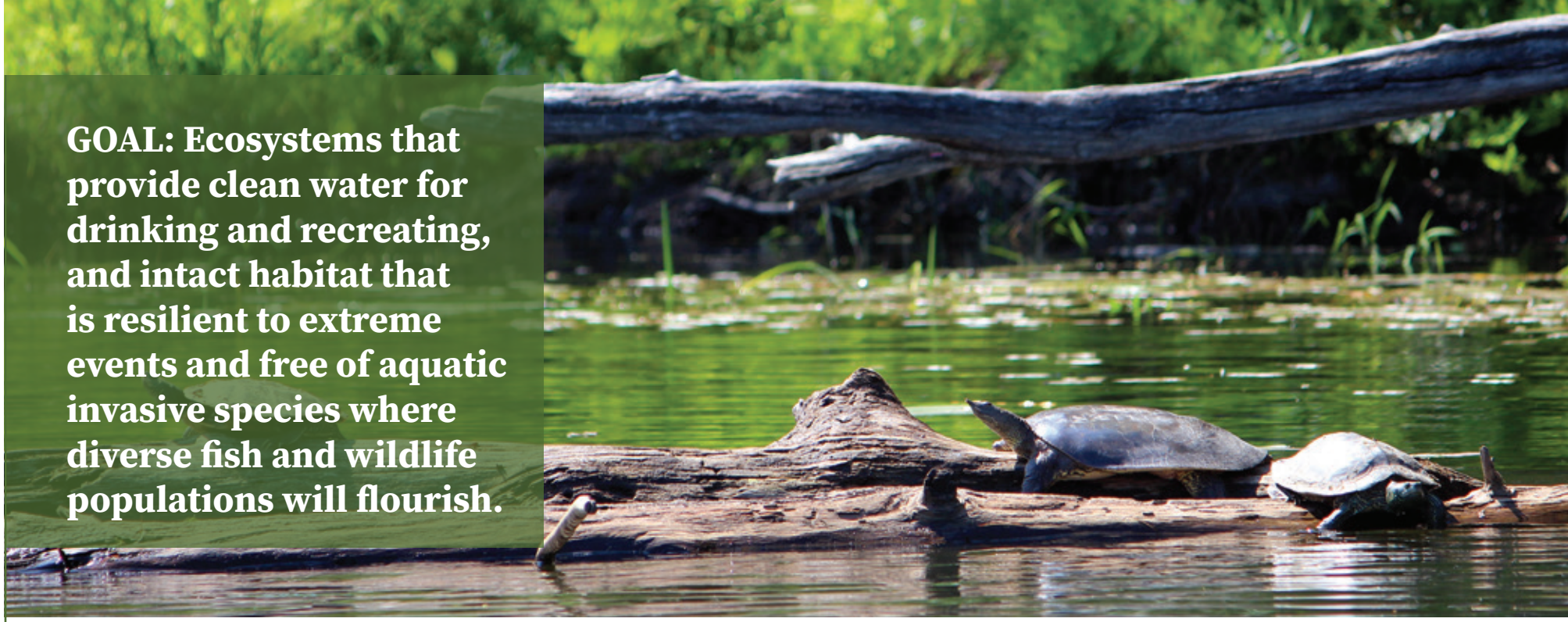
Reduce or eliminate pesticides and herbicides. Choose natural alternatives for pest and weed control.

Clean greener. Use less toxic household cleaners. Toxic substances may not be removed in the wastewater treatment process.

Avoid single-use plastics. Reduce plastic pollution by investing in reusable coffee mugs, water bottles, grocery bags, utensils, straws, and takeout containers. Reduce microplastics by choosing alternatives to fleece and by using a microfiber catcher in the laundry.

Hold the salt. The chloride compounds used to deice sidewalks and driveways wash into waterways, harming wildlife and plants. Use as little salt as possible, and try alternatives like sand for increased traction.

Scoop the poop. Rain and snowmelt wash pet waste into waterways, creating public health issues. Pet owners should always carry a scoop bag and carry it out.



GOAL: Ecosystems that provide clean water for drinking and recreating, and intact habitat that is resilient to extreme events and free of aquatic invasive species where diverse fish and wildlife populations will flourish.

Each of the organisms found in the Lake Champlain Basin relies on a balance of resources necessary for survival and reproduction, including an intact and functioning habitat and a climate that aligns with its evolutionary history. Although nearly 40% of the land in the Lake Champlain Basin is conserved in some way, many habitats are in need of restoration and protection. Native species face a variety of pressures, including from increased human development, invasive species, and the changing climate.

BIOLOGICAL DIVERSITY AND ECOSYSTEM FUNCTION

The Lake Champlain Basin's species and habitat diversity is rich, though some habitats are fragmented and need protection.

Native species rely on intact and functioning habitats such as forests, floodplains, and wetlands. These habitats also provide other invaluable ecosystem functions, including nutrient cycling, sediment retention, carbon storage, and air and water purification. Vegetated lake shorelines and riparian (river) buffers help mitigate flood impacts by absorbing water, reducing erosion, and providing shade and refuge that help keep these waterbodies cool and habitable for fish, amphibians, and insects.

Fragmented habitat and the pressures of climate change can put rare, threatened, and endangered species at risk. Habitat fragmentation mostly comes from human development and land use and can limit species' ability to reproduce, thrive, and move under natural conditions. Native species' habitat becomes stressed even further when intense rainfall creates disturbed areas that favor non-native and invasive species.

About 40% of the Basin's land area is conserved to some degree; this protects these lands from future exploitation such as surface mining, waste dumping, and development. Conservation efforts can increase the biodiversity, resilience, and functioning of ecosystems and expand opportunities for human use and enjoyment of the Basin.

More research is needed to support the Basin's rare, threatened, and endangered species.

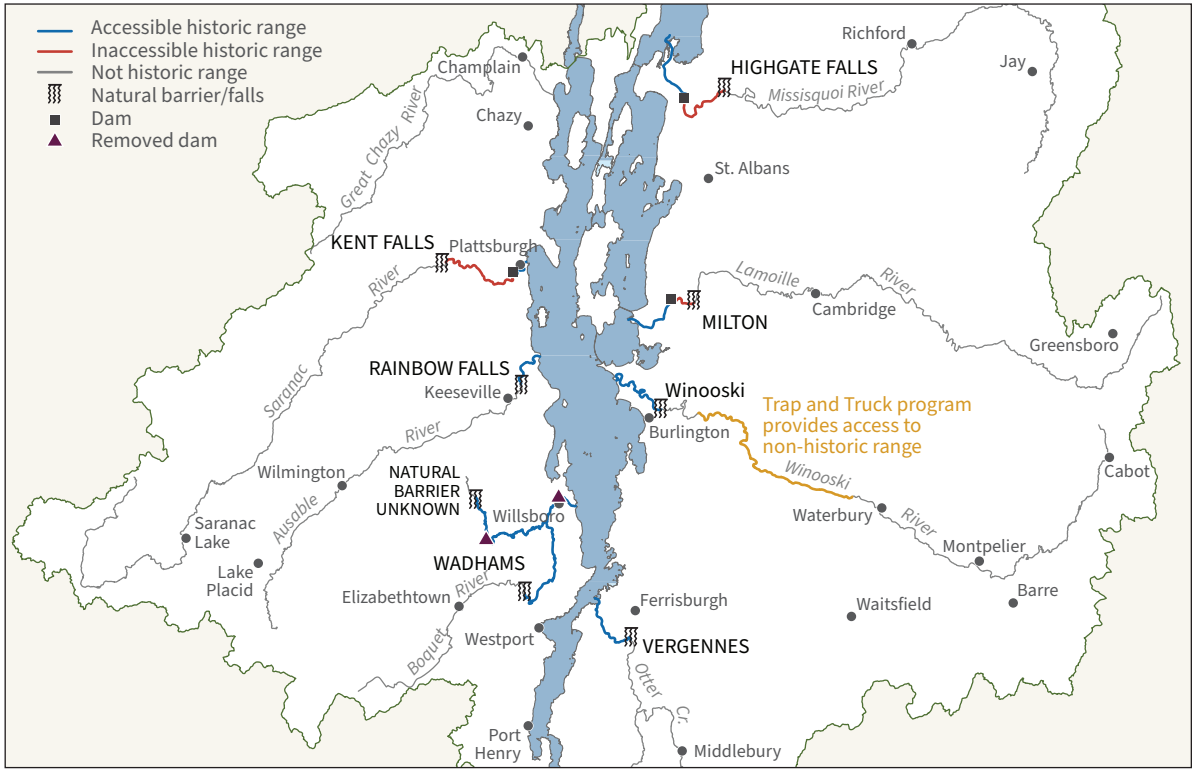
Fish and wildlife biologists are working hard to better understand and protect the Basin's rare, threatened, and endangered species such as the spiny softshell turtle, lake sturgeon, Indiana bat, common tern, and mudpuppy.

While some species like the bald eagle and the common loon are making great recoveries as a result of habitat protection, pollution reduction, and reintroduction methods, more research is needed for the recovery of other species. The Vermont Fish and Wildlife Department is relocating mudpuppies to an upper reach of the Lamoille River and tracking their movement to determine if a viable population may be established in more protected habitat. Five of the ten known native mussel species in Lake Champlain are listed as threatened or endangered in Vermont. The Lake Champlain Committee studied the impacts of invasive zebra mussels on native mussel species and identified the Lamoille River delta as suitable refugia habitat from zebra mussels. Protection of these areas will help endangered species thrive in the future.

Landlocked Atlantic salmon have more access to historic river habitat, and passage for all aquatic species is being addressed through culvert replacements.

When connected and well buffered, Lake Champlain's river systems are home to many native species. They absorb flood waters, retain sediment, and provide cool water habitat for species like trout and salmon. However, this network has been disrupted by dams, development, agriculture, industry, and road crossings. Stream culverts at road crossings are often undersized or damaged. These culverts can be plugged with sediment and debris or are "perched" from the streambed; thus, they make passage difficult for fish and other species.

Fisheries biologists are working to restore fish passage in Lake Champlain's tributaries, especially for landlocked Atlantic salmon (Figure 11). Salmon have upstream access to most of their historic range in most major tributaries, except the Saranac and Missisquoi Rivers. More work is needed in these systems to restore salmon access to spawning grounds.



DATA SOURCES: USFWS, VT FWD, NYSDEC

Figure 11 | Landlocked Atlantic salmon habitat access in Lake Champlain tributaries

In the Winooski River, intensive restoration efforts have focused on the use of fish ladders and trapping and trucking salmon upstream, thus extending the historic range of this species. In the Ausable River, biologists are using environmental DNA to map native and non-native fish distributions, including brook trout, brown trout, and rainbow trout to prioritize future connection and Atlantic salmon habitat restoration efforts. Other groups, including Dam Task Forces in New York and Vermont, identify, prioritize, and implement river passage restorations.

Lake Champlain's fish are enjoyed by anglers, and more research is needed to determine the status of the Lake's fish populations.

Lake Champlain is home to 80 species of fish, including sport fish that attract fishing tournaments of all sizes. Lake Champlain has great angling opportunities year-round. The largest lake trout on record was caught in August 2020; it weighed 19 lbs., 6 oz., and measured over 36" long.

Restoration projects for certain fish species are underway, but the status of many other species in Lake Champlain is unknown. The University of Vermont is leading a fish community monitoring study to determine the best approach to collecting information on the abundance and condition of forage fish such as alewife and rainbow smelt. Changes in the availability of forage fish will affect predator species, like trout and salmon, in the Lake.

Lake trout stocking will be reduced due to successful natural reproduction, and stocking of other salmonid fish will continue.

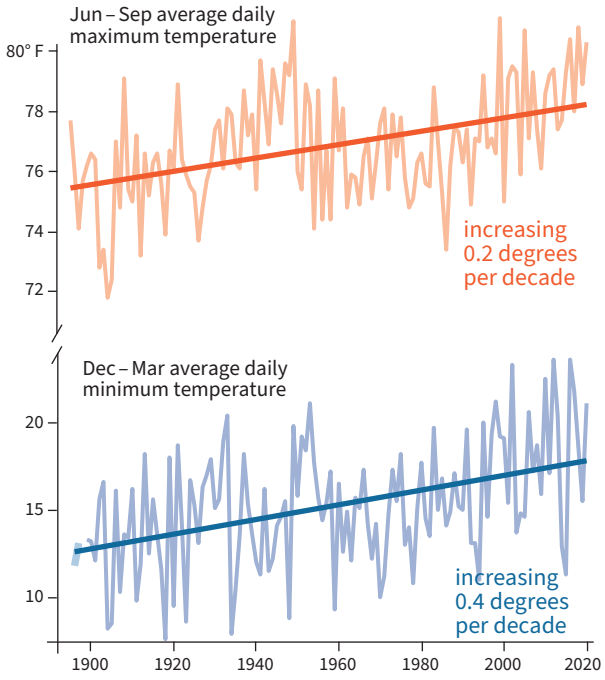
Lake trout, Atlantic salmon, brown trout, and rainbow trout/steelhead continue to be stocked in Lake Champlain to support the Lake Champlain angling fishery. The University of Vermont biologists have found nine age classes of wild (not stocked) lake trout. Lake trout were gone from Lake Champlain by 1900, and this discovery has led to the first-ever planned reduction in lake trout stocking by 33% in 2022 to maintain a healthy balance between wild and stocked lake trout and their forage fish base. Fishery managers continue to monitor adult landlocked Atlantic salmon and collect eggs from wild fish for hatchery production. The majority of salmon collected from 2018–2020 have been from Hatchery Brook and the Lamoille River in Vermont and Boquet River and Saranac River in New York. Each fall, three- and four-year-old salmon undergo a spawning migration from the Lake to rivers to reproduce. These river-run salmon provide fishing opportunities and are critical to ongoing efforts to restore natural populations.

The recent removal of dams has increased habitat for landlocked Atlantic salmon. Photo: Concordia University

Climate change and invasive forest pests are putting pressure on the Basin's forested habitats.

Climate change may be the greatest threat to the Basin's forest health. Northern hardwood species such as maple, yellow birch, and American beech are threatened by warmer and drier growing seasons that can stunt growth and shift forest compositions toward warmer-climate species like oak and pine.

Two invasive forest pests, the emerald ash borer and hemlock woolly adelgid, have recently been detected in the Basin. These pests have spread with assistance from humans as they hitchhike in firewood and infested nursery stock and then naturally disperse. Ash and hemlock trees are important species in the Basin's natural landscape, and these pests' impacts can kill host trees quickly, causing erosion and water quality impacts from the steep slopes and riparian areas they occupy. Forest managers are conducting routine monitoring and rapid-response containment of hemlock woolly adelgid infestations in the Lake George watershed, where hemlocks make up 80% of the forested watershed.



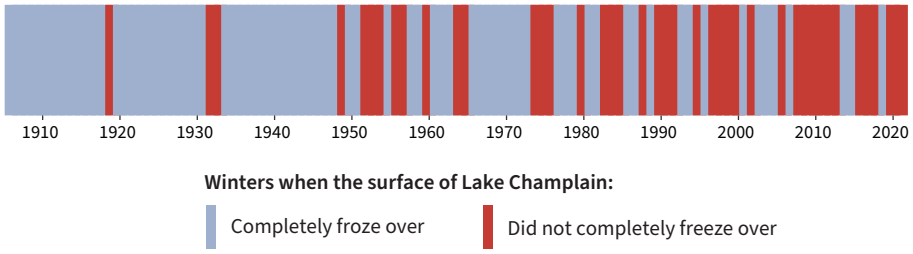
DATA SOURCE: NOAA National Centers for Environmental Information

Figure 12 | Seasonal air temperature trends in Burlington, Vermont

Air temperatures are rising, and the Lake freezes over less often than in the past, though the full impacts of climate change on habitats, fish, and wildlife are difficult to quantify.

Air temperature measurements indicate that winter minimum and summer maximum air temperatures have increased since the early 1900s, with pronounced warming in recent decades (Figure 12). Burlington experienced its hottest summer on record in 2020, with an average temperature of 72.3°F and a record 41 consecutive days above 60°F, breaking a previously held record in 1898 of 37 days. These trends may affect ice cover in the winter and lengthen the "growing" period in the summer for biological activity, including the growth of invasive plants and cyanobacteria blooms.

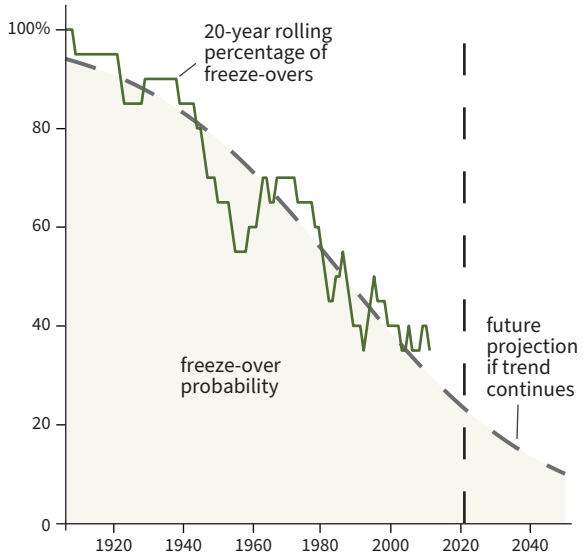
Although the surface of Lake Champlain froze over nearly every year in the early 1900s, it is now freezing much less frequently (Figure 13). Currently, the Lake freezes about once every four years; modeling suggests that by 2050, the Lake may freeze fully just once per decade (Figure 14).



NOTES: Each year represents the second year of each winter (e.g., 2021 indicates winter 2020–2021). Unconfirmed records of Lake Champlain surface freeze-over date back to 1816; more reliable records by U.S. Weather Bureau or National Weather Service are shown beginning in 1906.
DATA SOURCE: U.S. Weather Bureau/U.S. National Weather Service

Figure 13 | Surface freeze-over of Lake Champlain

Scientists continue to track the impacts of climate change as the Basin experiences more frequent intense storms in the spring and fall that increase erosion, dry spells in the summer that impact crops and increase the chance of wildfires, and milder winters that reduce ice cover. The warming climate impacts species diversity, habitat, and natural ecosystem function. Future winters may have shorter recreational seasons with limited ice fishing, and summers may be hotter with increased water quality impacts, thereby limiting recreational opportunities and other uses of the Lake.



DATA SOURCE: U.S. Weather Bureau/U.S. National Weather Service

Figure 14 | Probability of Lake Champlain surface freeze-over

AQUATIC INVASIVE SPECIES

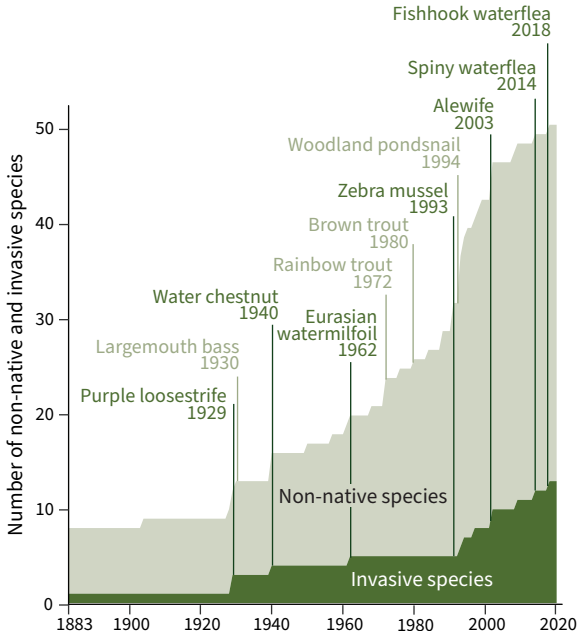
Most waters in the Lake Champlain Basin are free of aquatic invasive species and need protection; human behavior can cause the spread of invasive species.

Aquatic invasive species are plants, animals, and pathogens that are non-native to the watershed and have been proven to cause harm to the economy, environment, or human health. Invasive species can divert food resources from native species, reduce light penetration, change habitats, impair water quality, interfere with recreational opportunities, and reduce property values. Invasive pathogens also threaten the health of native fish and sport fisheries.

Most introduced non-native species do not become established populations in the ecosystem. Those that do establish can cause serious widespread impacts that require significant resources to manage. Just over a dozen established aquatic non-native species are considered invasive in Lake Champlain, including the zebra mussel, water chestnut, Eurasian watermilfoil, phragmites, alewife, and spiny and fishhook waterflea (Figure 15).

Inventories completed by state programs and community monitor groups supported by the Adirondack Park Invasive Plant Program and volunteers in the Vermont Invasive Patroller Program indicate that 75% of lakes in the Adirondacks and 80% of the lakes in Vermont are free of aquatic invasive species.

The primary source of new aquatic invasive species to our region is ballast water taken in by ships at their freshwater ports of origin around the world and then released into the Great Lakes. Once these invasive species are established in the Great Lakes, the primary pathway for their introduction into Lake Champlain is through canals that connect the Great Lakes, St. Lawrence River, and Hudson River to Lake Champlain (Figure 16).



NOTE: Data reflects the year of first reported sighting of species.
DATA SOURCE: Ellen Marsden, University of Vermont, Lake Champlain Long-Term Monitoring Program

Figure 15 | First detection of aquatic non-native and invasive species in Lake Champlain

The fishhook waterflea invaded Lake Champlain in 2018 and has changed the base of the food web.

The fishhook waterflea is the 51st aquatic non-native species to be detected in Lake Champlain and poses a significant risk of spread to other waterbodies in the region. Like the invasive spiny waterflea (detected in Lake Champlain in 2014), this crustacean is a voracious predator. It has impacted the Lake's phytoplankton community and now is outcompeting the spiny waterflea. Its small size and resting egg life stage can hitchhike unnoticed in bilge, motor, or bait bucket water. However, when thousands of the species' barbed tails get hooked onto and foul fishing line and gear, they are hard to miss.

The fishhook waterflea is native to northern Europe and Asia. The species was likely introduced with released ballast water into the Great Lakes and then spread overland on boats, trailers, and other recreational and fishing equipment to Lake Champlain. Over the past three years, boat launch stewards helped to remove and decontaminate fouled gear and flush out boat motors and compartments from watercraft exiting Lake Champlain during the species' population peak in late June through early July.

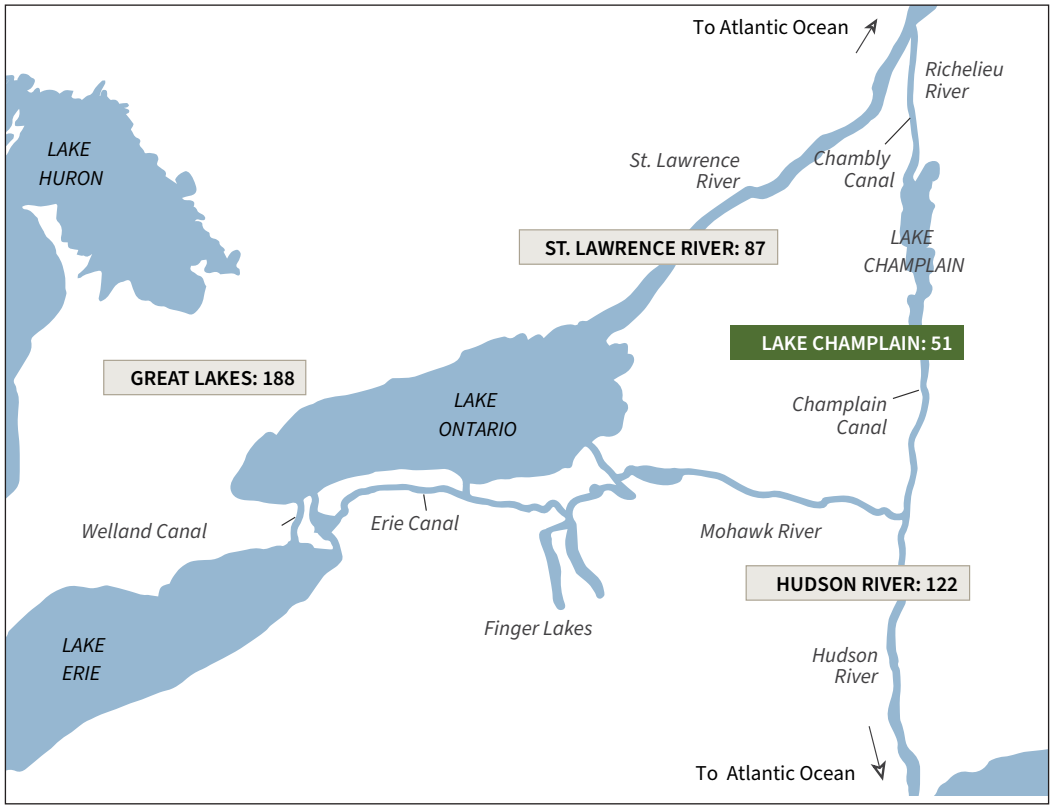
Invasive species are impacting Lake Champlain's fishery.

Non-native and invasive species continue to challenge Lake Champlain, and it is difficult to quantify their impacts. When a population increases, it pressures other species that compete for similar food and habitat. Zebra mussels have colonized most of the Lake and filter untold amounts of plankton each day, reducing food availability. Alewife continue

to outcompete native smelt, thus changing the food web, and are now the primary source of food for Atlantic salmon and lake trout. Alewives are rich in thiaminase, an enzyme that destroys thiamine in the fish that eat them, leading to early mortality syndrome in newly hatched fish or immune dysfunction. Hatchery-reared eggs are now bathed in thiamine to address thiaminase deficiency and improve survival.

Sea lamprey wounding rates on lake trout and Atlantic salmon are varied.

Sea lamprey are a parasitic eel-like fish that feed on Atlantic salmon, lake trout, and other sport fish in Lake Champlain. They spend the first four years of their lives as larvae in the Lake's rivers and then transition to the Lake and survive by attaching to fish to feed on their body fluids.



NOTE: Data current as of January 2021. All waterways contain some overlap of species.
DATA SOURCES: UVM, LCBP, Lake Champlain Sea Grant, Great Lakes Environmental Research Laboratory, Lafontaine and Costan 2002, Strayer 2012, Egan 2017, and GLANSIS 2020.

Figure 16 | Non-native species threats to the Lake Champlain Basin from connected waterways

Sea lamprey wounding rates on lake trout and Atlantic salmon have varied over the past three years. Wounding rates on lake trout are well above the target wounding rate of 25 wounds per 100 fish, but wounding on Atlantic salmon is hovering just above the goal of 15 wounds per 100 fish (Figure 17). Sea lamprey wounding rates have historically been used as an indicator of the impact of sea lamprey on the health of fish populations, though these rates are not a direct, accurate measure of the size of the sea lamprey population. Primary methods for sea lamprey management include application of pesticides to most sea lamprey-bearing tributaries every four years and barrier installation to prevent spawning in tributaries. Nontarget impacts of pesticides on rare species are a concern in several tributaries.

Some new aquatic invasive species are getting closer to the Basin.

The invasive aquatic plant hydrilla, round goby, and quagga mussels all are approaching Lake Champlain and are considered to be major threats here.

Hydrilla is an aggressive aquatic plant that could overwhelm shallow areas of the Lake; it requires years of herbicide treatment to manage. Hydrilla plant fragments were intercepted by a Lake Champlain boat launch steward in 2019 on a jet ski coming from the Connecticut River.

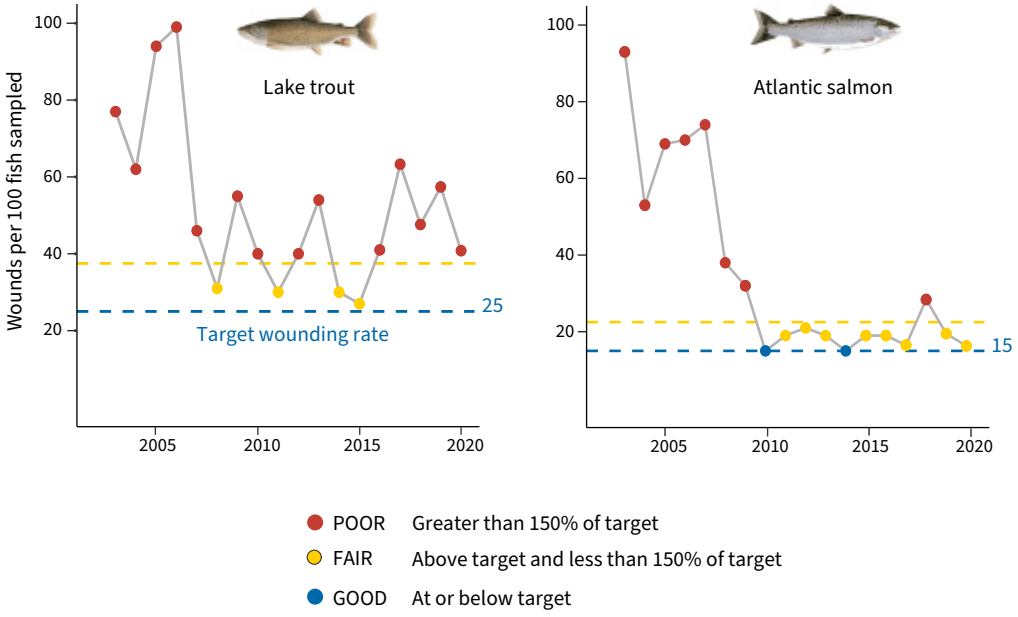
Round goby fish are aggressive egg predators that outcompete native benthic fish like slimy sculpin. Round gobies can bioaccumulate toxic substances, such as PCBs, from eating zebra mussels, making them a threat to their predators. Gobies have been linked to bird deaths in the Great Lakes. They are present in the St. Lawrence and

Richelieu Rivers to the north and have been recently detected moving farther east in the Erie Canal toward the Hudson River by the U.S. Geological Survey.

Quagga mussels are similar to the zebra mussel that invaded in 1993, but they would have a greater impact if introduced to Lake Champlain. Quagga mussels can grow in deeper waters and have greater reproductive advantages than zebra mussels. Their arrival would put many historic shipwrecks at risk, and their filter feeding would have significant impacts on plankton at the base of the Lake Champlain food web. Quagga mussels were intercepted on a watercraft that had previously visited Lake Ontario while it was attempting to launch into Lake Champlain in 2018.

Aquatic invasive species spread prevention efforts are focused on managing the pathways and human activities that may unintentionally aid their introduction.

Once introduced, aquatic invasive species are often impossible to eliminate and very costly to manage. Preventing the introduction of these species is key to maintaining the health of the Lake Champlain ecosystem.

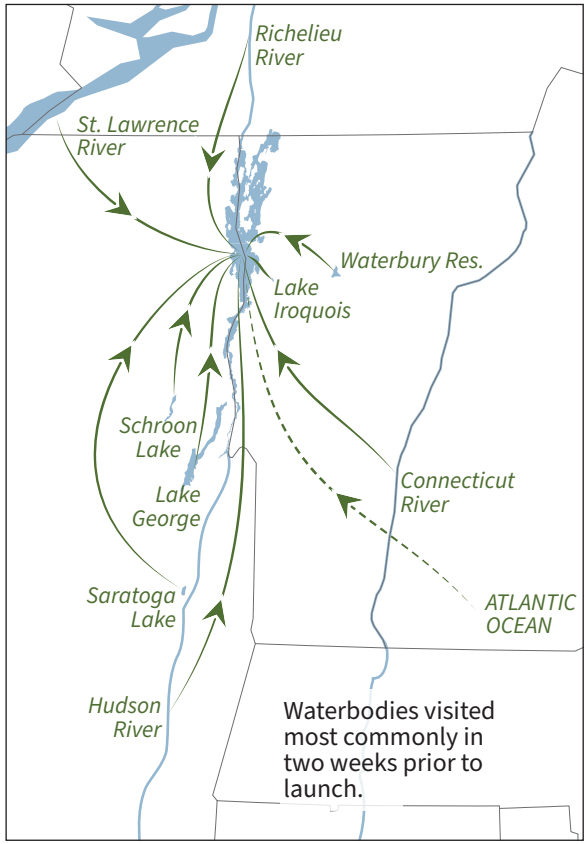


DATA SOURCE: USFWS
FISH ILLUSTRATIONS © Flick Ford

Figure 17 | Annual sea lamprey wounding rates in Lake Champlain

Hydrilla, quagga mussel, and round goby (from top) are the most threatening invasive species "on the doorstep" of Lake Champlain. Photos: University of Florida, LCBP, USFWS.

The Champlain Canal that connects the Lake Champlain and Hudson River basins is a pathway for aquatic invasive species introduction. The U.S. Army Corps of Engineers is leading a study to determine how to best prevent the transfer of aquatic invasive species between these two basins. Groups in New York also are examining the Erie Canal system as part of the governor's Reimagine the Canals Initiative to identify opportunities to prevent the spread of aquatic invasive species, boost tourism, reduce flooding, enhance irrigation and recreational fishing, and restore wetlands. These efforts examine alternatives that would allow for recreational traffic to move through the system but would prevent fish, plants, plankton, mollusks, and viruses from swimming or floating from one watershed to another.



DATA SOURCE: LCBP and Adirondack Watershed Institute Boat Launch Steward Programs

Figure 18 | Waterbodies with aquatic invasive species visited prior to launch into Lake Champlain

Boats, trailers, and recreational equipment also can carry invasive species to the Lake Champlain Basin. The LCBP and Adirondack Watershed Institute of Paul Smith's College operate watercraft inspection and decontamination programs on Lake Champlain and across the region to prevent the spread of invasive species. Data from this program show that watercraft coming from high-risk waterbodies were most frequently from the Hudson River, St. Lawrence River, and Connecticut River, where there are more and different aquatic invasive species present that could be introduced to Lake Champlain (Figure 18).

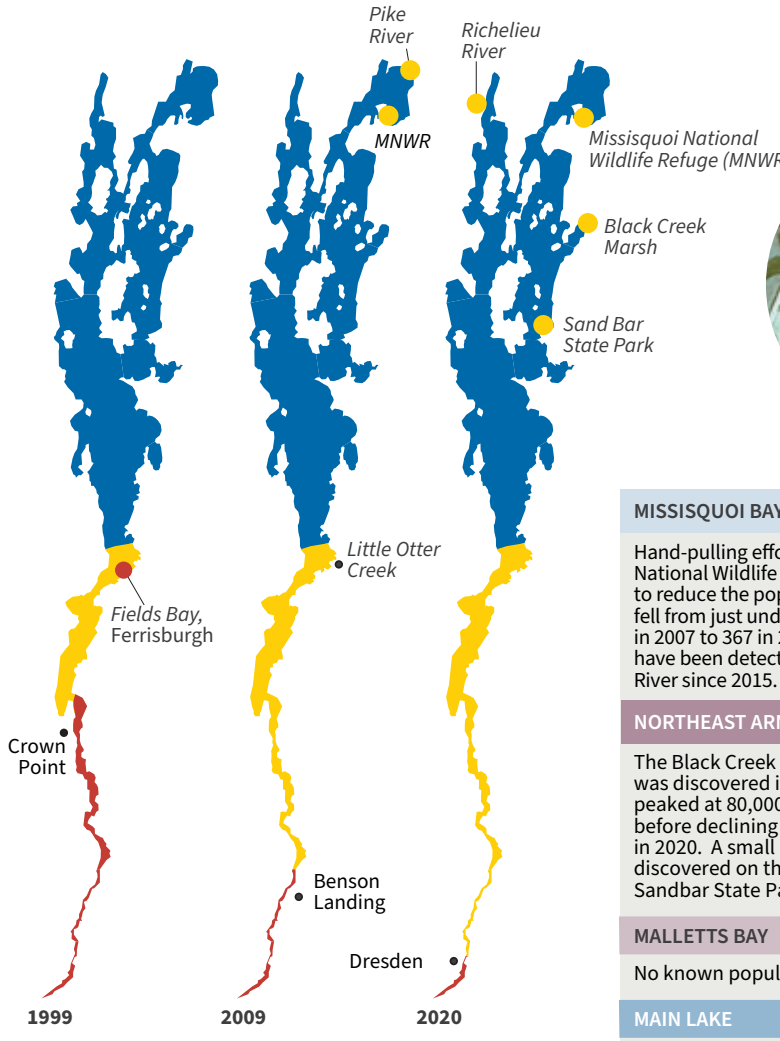
There are simple steps that residents in the watershed can take to prevent the spread of invasive species, such as planting native species; surrendering aquarium fish instead of releasing them into the water; following baitfish regulations; and cleaning, draining, and drying watercraft and recreational equipment after each use.

Hot-water pressure washing helps prevent the spread of AIS. Photo: LCBP

Coordinated and intensive annual water chestnut management efforts in Lake Champlain are slowly reducing the extent of this species.

The water chestnut is an invasive annual plant that forms dense leafy mats that float on the water surface. In the southern end of Lake Champlain, water chestnut limits boat traffic and recreational use, crowds out native species, and creates areas without oxygen that are uninhabitable to fish and other organisms. Isolated populations of water chestnut are found in other areas of the Lake.

Lake Champlain's water chestnut control program is a long-standing success story. U.S federal agencies, state and provincial bodies, and nongovernmental organizations provide support to harvest water chestnut mechanically and by hand in Lake Champlain and other inland waters in the Basin. While management from year to year may have varied results, efforts have pushed the dense (>25% cover) populations from Crown Point down to the Dresden Narrows over the past 20 years (Figure 19).



DATA SOURCES: VTDEC, NYSDEC, QC MELCC, USFWS

Photo: Martin Mimeault

MISSISQUOI BAY

Hand-pulling efforts in Missisquoi National Wildlife Refuge continue to reduce the population, which fell from just under 6,000 rosettes in 2007 to 367 in 2020. No rosettes have been detected in the Pike River since 2015.

NORTHEAST ARM

The Black Creek Marsh population was discovered in 2016 and peaked at 80,000 rosettes in 2019 before declining to 30,000 rosettes in 2020. A small population was discovered on the north side of Sandbar State Park in 2019.

MALLETTS BAY

No known populations are present.

MAIN LAKE

Monitoring is necessary between Little Otter Creek in Ferrisburgh, VT and Crown Point, NY. Control efforts continue for the Richelieu River populations.

SOUTH LAKE

Populations are mechanically harvested by VTDEC and NYSDEC in the red-shaded area, which has been steadily reduced over the past two decades.

Figure 19 | Invasive water chestnut coverage in Lake Champlain

What You Can Do

Plant native species. Plant safe alternatives to invasive species in your lawn and garden. Native plants are often more resilient to drought and pests and provide better habitat for pollinators, birds, and other wildlife.

Don't let it loose. Prevent the spread of invasive species from aquariums and aquatic gardens. Never release aquarium or domestic pond water, aquatic plants, or dead or live animals into the wild.

Clean, drain, and dry. Help stop aquatic hitch-hikers. Before bringing your boat and gear to a new waterbody, clean off mud and debris, drain completely, and dry thoroughly.

Know before you go. Before heading out, learn the local rules and regulations for hunting, fishing, and bait fish.

Dispose of bait properly. Never release aquatic bait or water from a bait bucket into any waterbody. Dispose of it in the trash.

Use local firewood. Don't move firewood between locations. Help stop the spread of forest pests and diseases.

Watch for invasives. Learn how to look for and identify invasive species. Contact groups such as Vermont Invasives, the Adirondack Park Invasive Plant Program, state conservation agencies, and your local watershed organization.

GOAL: Communities have an appreciation of natural and cultural resources, and the capacity to implement actions that will result in sound stewardship of these resources while maintaining strong local economies.

Visionary conservation efforts initiated more than a century ago provide tremendous public benefits. These conserved lands are vital to human health. During the COVID-19 pandemic, families found solace on waterways and mountaintops, where they re-engaged with the land and remembered how special "this place" truly is. Local economies benefit from cultural heritage initiatives that draw visitors from near and far. Programs that celebrate the heritage of Indigenous peoples are providing a richer understanding of our past and a more inclusive future.

COMMUNITY HEALTH

In addition to contributing to clean water and healthy ecosystems, conserved lands are important to human health and safety.

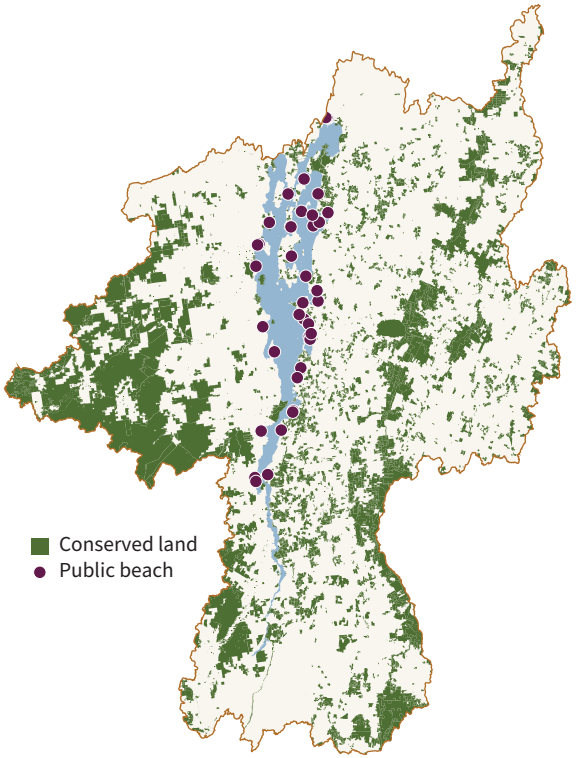
Almost 40% of the land area in the Lake Champlain Basin is conserved (Figure 20). The Adirondack Park, Green Mountain National Forest, Missisquoi National Wildlife Refuge, state parks and forests, and other parcels protected by local communities and land trusts contribute to the health of the environment and Basin communities.

The natural wetland systems found within these conserved lands provide important ecosystem functions including ground water storage, pollution reduction, and flood control. A 2016 study of Otter Creek found that wetlands and floodplains reduced flood damage by up to 78% in a 10-year period, limiting property damage and recovery costs significantly.

Conserved lands have an important role in protecting biodiversity and are home to many plants and animals that benefit human health. Studies show that West Nile virus can spread more easily in areas with low bird diversity, while a greater diversity of small mammals can limit the spread of Lyme disease and hantavirus.

As places of rejuvenation, inspiration, and sustenance, conserved lands are vital to human health.

Residents and visitors to the Basin hike, bike, camp, ski, bird-watch, fish, and hunt on conserved lands throughout the year. The COVID-19 pandemic illustrated the importance of these areas to the physical and emotional well-being of those who visit them.



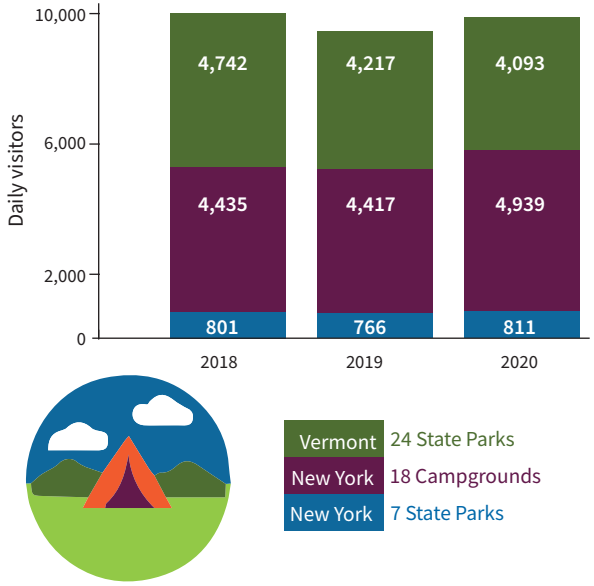
DATA SOURCES: Vermont Center for Geographic Information, New York State GIS Clearinghouse, OBVBM, MRC Brome Missisquoi, Appalachian Corridor, Réseau de Milieux Naturels, The Nature Conservancy

Figure 20 | Public beaches on Lake Champlain and conserved lands in its watershed

When the pandemic closed gyms and limited access to indoor public spaces in 2020, people flocked to the outdoors in record numbers. Most New York and Vermont state campgrounds opened a month later than usual in 2020 with capacity restrictions ranging from 50-75 percent. Even with those limitations, visitation matched previous years, which shows the importance of our public camping facilities (Figure 21). Trail use numbers from the Adirondack Mountain Club (ADK) and the Green Mountain Club (GMC) indicate that the Basin's conserved lands were heavily used. Mount Marcy, the highest peak in the Basin and in the state of New York, experienced a record number of hikers in 2020 with an average of 111 people on its summit each day in July and August. Summit stewards counted more than 300 people on sunny Saturdays. In Vermont, the GMC reported that use of the Long Trail jumped 35% in 2020 and that shelter use in September 2020 increased by 80%.

The impact caused by increased use was evident in 2020. Stewards reported more trash along paths, and additional visitors contributed to a trail network already stressed by erosion, overcrowding, and user conflicts. Land managers expect these trends to continue. Use of the High Peaks Region in the Adirondacks has grown exponentially in the past 20 years, and the COVID-19 pandemic exacerbated these challenges. Overcrowding has led to significant erosion, impact, and conflict in this trail network. In January 2020, the New York High Peaks Strategic Planning Advisory Group proposed a series of recommendations to immediately address overcrowding, including implementing a pilot trailhead shuttle system, enhancing interagency coordination on parking and pedestrian safety, installing more portable toilets, and increasing the amount of stewardship and Leave No Trace education programs.

Photo: LCBP



DATA SOURCES: NYSDEC, VT ANR, NYSOPRHP

Figure 21 | State park and campground visitation in the Lake Champlain Basin

CHAMPLAIN VALLEY NATIONAL HERITAGE PARTNERSHIP

Cultural heritage programs provide a lens on inclusion and diversity in the Basin.

The Champlain Valley National Heritage Partnership (CVNHP) marks its 15th anniversary in 2021. Established in 2006, CVNHP has awarded 195 grants totaling $1.3 million. These grants, ranging from $1,000 to $40,000, have made significant impacts on communities and institutions, big and small. Funding has supported projects as varied as local heritage education programs in schools to new HVAC systems in museums. The grants have generated not just improvements and new opportunities to cultural institutions, recreation programs, and municipalities in New York, Vermont, and Québec, but they have also generated more than $2.4 million in matching funds.

The CVNHP gained momentum during the Lake Champlain Quadricentennial—the 400th anniversary of Samuel de Champlain's 1609 exploration of the lake he named after himself. The Quadricentennial also served as a platform to highlight the rich cultural heritage of the Champlain Valley's Indigenous peoples. The LCBP has long acknowledged the history and culture of these nations and recognizes that we are all stewards of our natural and cultural resources. Since 2008, the CVNHP has provided $194,262 in grants for 21 projects that researched, interpreted, and showcased Native American history and culture.

Each year, the CVNHP focuses on one of its interpretive themes: Making of Nations, Corridor of Commerce, or Conservation & Community. In 2019, the CVNHP and LCBP collaborated with partners by focusing on the Conservation & Community interpretive theme, which highlighted the 2019 International Year of the Salmon (IYS). The theme was supported through several partnership-based programs, including the tour of the replica canal schooner, *Lois McClure*; three interpretive theme grants; traveling displays; and a signature-event Salmon Festival in October 2021. The IYS observance strengthened partnerships with many natural heritage organizations, including the U.S. Fish and Wildlife Service, the Vermont and New York departments of fish and wildlife, Trout Unlimited, individual fishery biologists, and the angling community.

The COVID-19 pandemic stifled plans to mark the centennial of the 19th Amendment to the U.S. Constitution, which gave women the right to vote. While some groups persevered with their plans and hosted special "socially distanced" events, most postponed their celebration until 2021, when the CVNHP will support both the Making of Nations theme through the 101st anniversary of women's suffrage and the Corridor of Commerce theme with a focus on temperance, prohibition, and smuggling. In 2022, the CVNHP will return to the Conservation and Community theme by celebrating the 50th anniversary of the U.S. Clean Water Act.

Photo: LCBP

What You Can Do

Visit natural and cultural heritage areas. The many stories of our heritage are told in museums, historic sites, and natural areas throughout the Lake Champlain region.

Get out and explore. Enjoy recreational opportunities and cultural events in the region. Explore a new hiking trail, shoreline, bike path, beach, or campground.

Support museums and conservation groups. Get involved: become a member, attend events, or volunteer.

Leave no trace. Protect natural areas by learning and sharing low-impact techniques. Plan your trip to make recreation safe and minimize damage to natural and cultural resources. For more information, visit www.lnt.org.

Find wayside exhibits. Seek out interpretive signage and historic markers in your community and beyond.

Discover Basin communities. Reach beyond your neighborhood to explore other cultures, old and new.

GOAL: Basin residents and visitors will understand and appreciate Lake Champlain Basin resources, and will possess a sense of personal responsibility that results in behavioral changes and actions to reduce pollution.

A public that understands the Basin's water quality and resource management challenges as well as possible solutions can make informed choices about protection and restoration. Organizations and institutions throughout the Basin are working on many fronts to educate citizens of all ages. Through formal education programs in classrooms and camps and with outreach efforts at public events, partners are equipping citizens to take action and change behavior to improve water quality.

EDUCATION AND OUTREACH

School programs are educating young learners about watershed issues, providing a foundation for informed decisions about the Lake's challenges.

Providing students an understanding of watershed science and natural and cultural resources at an early age is critical in fostering the next generation of stewards. Classroom and field-based learning centered on rich watershed content helps students make informed choices about their personal actions. This information is also often extended to family and friends when students share their knowledge and values at home.

Watershed education begins with teacher training. Recent professional development programs offered by Basin partners have included graduate-level coursework and focused place-based trainings that cover topics such as green infrastructure, phytoplankton, the Underground Railroad, and geology. The new knowledge that teachers have taken from these trainings to their classrooms is publicly displayed during the Champlain Basin Education Initiative's local celebration of the U.N. World Water Day. Since 2018, the event has showcased exemplary student work—often based on their teachers' own learning—from 34 classrooms representing 21 schools in the Basin.

Several new programs have brought watershed learning directly to students. In 2020, the Lake Champlain Sea Grant's Watershed Alliance program expanded from the Univer-

sity of Vermont to SUNY Plattsburgh, allowing 450 New York students to participate in lake and stream ecology programs. This and similar field programs offered by Paul Smith's College, Miner Institute, Lake George Association, and Trout Unlimited reached more than 4,000 students each year.

The COVID-19 pandemic has had the most evident and perhaps the greatest long-term effect on watershed education. The pandemic required a rapid retooling of traditional school outreach programs into virtual offerings. Interactive learning events, opportunities for students to meet scientists, and cultural heritage interpretation that are available to broad audiences and classrooms unable to travel are likely to continue in some form after the pandemic.

Public outreach programs and efforts to track their effectiveness are helping to inform all citizens about watershed issues.

Even during the COVID-19 pandemic, community members have had a variety of opportunities to participate in new science-based field trips, naturalist-led recreation opportunities, and history tours. This public programming is at the heart of local watershed organizations' work. The outings they lead provide hands-on learning about a range of topics, from redesigning residential driveways in order to slow runoff to diversifying habitat by planting native vegetation.

Tracking changes in personal behaviors that result from these programs can be challenging, but many partners have begun to focus on assessing the effectiveness of education and outreach efforts. Local organizations as well as larger programs and institutions are conducting program-specific evaluations and longer-term surveys to gauge success and guide future efforts.

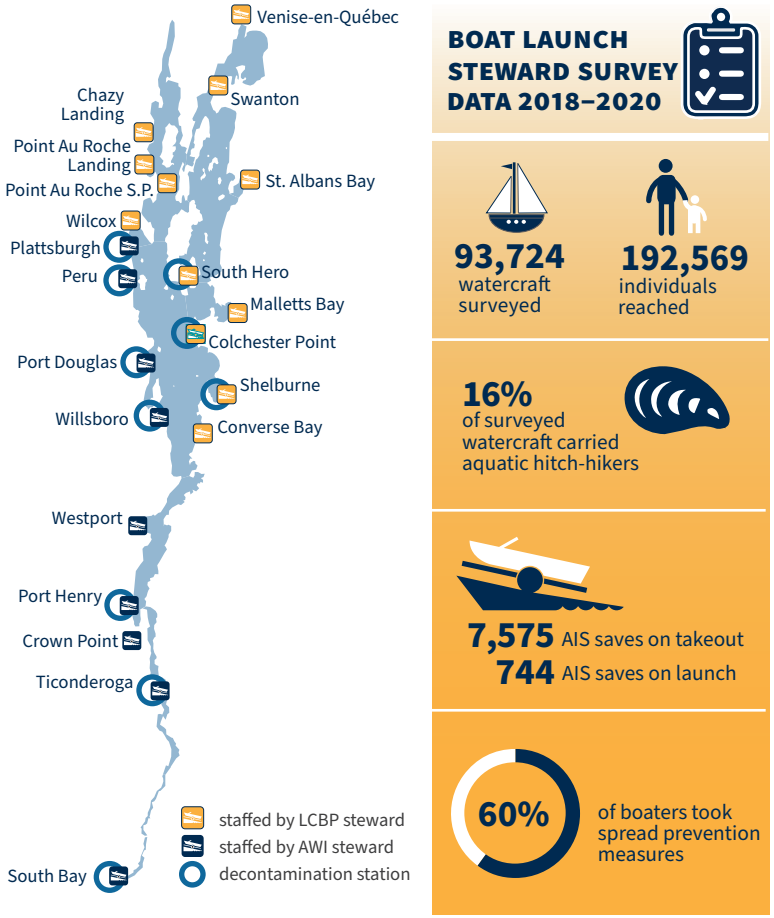
In one such evaluation, Lake Champlain Sea Grant surveyed participants in an educational boating excursion. They found that one year after the outing, 51% of respondents said they avoided purchasing plastics, 31% said they left grass clippings on their lawn to increase water infiltration, and 65% said they shared the knowledge they learned with others.

The LCBP is working with partners to conduct a Basin-wide survey that measures stakeholder knowledge of watershed issues and levels of engagement and stewardship by residents. The results of the survey will help to track the effectiveness of outreach efforts and to shape future public programming offered by partners.

The boat launch steward program on Lake Champlain continues to be an important element of public outreach. Stewards inspect boats for hitchhiking aquatic invasive species and provide information to the public about preventing the spread of these species. The Adirondack Watershed Institute (AWI) of Paul Smith's College, the Lake George Association, the LCBP, and numerous lake associations monitor launches.

LCBP and AWI staff reached nearly 193,000 people at launch sites on Lake Champlain from 2018–2020 (Figure 21). About 16% of vessels inspected during this time period carried aquatic species, and half of those carried invasive species. Stewards greeted about 30% more users at the monitored launch sites, and greeters at inland lakes saw increases of users of 25% or more in 2020.

These groups collaborate on data collection and analysis and on staff training to ensure that boaters receive consistent information across the region. The programs have refined their techniques for surveying boater behavior and have found that 60% of 93,724 boat owners surveyed took



DATA SOURCES: LCBP, AWI, OBVBM Boat Launch Steward Programs.

Figure 22 | Lake Champlain boat launch steward program summary, 2018–2020

measures to prevent the spread of aquatic invasive species. This metric will be useful going forward for monitoring the effectiveness of outreach efforts.

The LCBP's Resource Room at ECHO, Leahy Center for Lake Champlain in Burlington, Vermont, hosted over 30,000 visitors annually in 2018 and 2019, cultivating stewardship through personal action and community partnerships. Staff encouraged guests to explore watersheds near their homes and provided information about local conservation organizations. Resource Room staff shared interpretive materials about Lake Champlain, presented programs, and provided place-based educational resources to visitors. The Resource Room remained open during much of the COVID-19 pandemic, adding new cultural heritage resources, creating a more diverse library for guests, and fielding questions virtually.

What You Can Do

Volunteer. Many local groups need help with projects that improve water quality and habitat in the Lake Champlain Basin.

Be a community scientist. Participate in community-based scientific research by volunteering to conduct surveys, take measurements, or record observations.

Join a lake or river organization. Many regional and local watershed groups work to protect and restore our local waterways.

Learn more. Visit the LCBP website to learn more about what you can do and what personal actions others are taking. www.lcbp.org

COMMUNITY ACTION

Involvement and collaboration among community members, watershed organizations, and businesses is providing focus and consistency in actions to improve water quality.

More than 30 watershed groups and conservation districts are working to reduce pollution and improve habitat in the Basin. These efforts bring together community members to exchange ideas, inspire action, and encourage behavior change.

They have facilitated discussions between farmers and municipal districts about riparian buffers and the importance of setbacks from roadside ditches, trained realtors to help homeowners understand and minimize the impact of septic systems, and recruited private businesses and public institutions to commit to allowing lawns to grow longer for improved soil health. In an effort to improve stormwater management on residential properties, these organizations have collaborated to share messaging and technical assistance for property owners.

Watershed groups rely on community support and provide the most direct opportunity for residents to get involved. They are most familiar with local conditions and can best identify projects to address problems and foster community engagement. Each year thousands of volunteers gain a stake in their community by planting native trees, installing rain gardens, improving public access, and monitoring for cyanobacteria. Collectively, their actions have a significant impact on improving habitat and water quality.

Photo: Northern Forest Canoe Trail

Acknowledgments

The *2021 State of the Lake and Ecosystem Indicators Report* was compiled by the Lake Champlain Steering Committee and LCBP staff, with input from the LCBP Technical Advisory Committee, the LCBP Education and Outreach Committee, and community partners.

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Read the full *State of the Lake* report, including French translation, supplemental content, and citations for the scientific literature and technical reports that inform the report at:

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