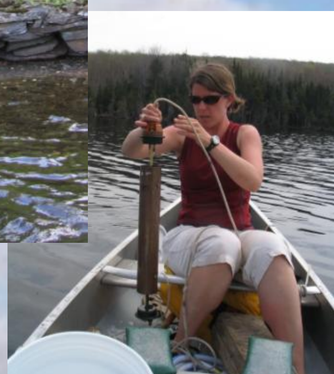
VERMONT
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Gauging the Health of Vermont Lakes

Results of the 2007 National Lake Assessment

14 March 2013



Acknowledgements

The results presented in this final report are the culmination of work of both Vermont Department of Environmental Conservation (DEC) and United States Environmental Protection Agency (EPA) employees. The study design was created by EPA and eleven lakes in Vermont were selected to be part of the random draw of lakes to be included in the National Lakes Assessment. Neil Kamman of DEC asked EPA to randomly draw an additional forty lakes in Vermont so that this statewide assessment would be possible. Neil then dedicated DEC staff, resources and oversight sufficient to accomplish this expanded survey. Sarah Wheeler, McKaylyn Garrity, Julia LaRouche and Danielle Owczarski pulled the logistics together to sample a total of fifty-two lakes over 2007 and 2008, which was no small feat given the breadth of sampling techniques employed on each lake. Eric Howe provided field assistance. Mark Mitchell from DEC, with assistance from Steve Paulsen, Phil Kaufmann, Tony Olsen and Richard Mitchell of EPA Office of Research and Development, applied EPA's analyses to Vermont's data set so this report can show how the condition of Vermont's lakes compare to the region and nation. Mark Mitchell performed the data analysis and he and Kellie Merrell of DEC compiled this report. Neil Kamman, Susan Warren, Jeremy Deeds, Phil Kaufmann and Steve Paulsen provided technical reviews of this report. Jim Kellogg and Heather Pembrook contributed to the portion of the report addressing acid neutralizing capacity.

Additional Reports and Information

For detailed information about the methods used in this study for sampling, sample processing and data analyses see *EPA's Technical appendix, Field Methods and Laboratory Protocols* at http://www.epa.gov/lakessurvey/. EPA's final report (USEPA, 2010) on the condition of the Nation's lakes can also be found at that website. The initial analysis of Vermont's data, which predated the development and release of the metrics used by EPA in the national lake assessment final report can be found at http://dec.vermont.gov/sites/dec/files/wsm/lakes/docs/lp_VT_LakeSurvey_07-08.pdf (Larouche, 2009). For the New England perspective, see *Gauging the Health of New England's Lakes and Ponds: A Survey Report and Decision Making Resource* found at http://www.neiwpcc.org/waterquality/wq-docs/NELP_Report_Web.pdf (NEIWPCC, 2010).

Cover Photo is of Lake Eden with inset photos of field crews on various lakes.

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EXECUTIVE SUMMARY

"Wherever modern Science has exploded a superstitious fable or even a picturesque error, she has replaced it with a grander and even more poetical truth."

-George Perkins Marsh, 1860

These words by Vermonter and America's first Environmentalist capture the essence of the purpose of the statistical approach employed by the Vermont National Lake Assessment. While the Vermont Department of Environmental Conservation has conducted long term monitoring of inland lakes to track trends in phosphorus enrichment and acidification and monitors the spread of aquatic invasive species, this survey represents the first statistical study. The purpose of such a study is to set aside preconceived notions of what we think are the most widespread stressors to Vermont's lakes and measure it. Since Vermont and EPA lack the resources to sample every lake in the state for every stressor, by selecting a statistically representative subset of lakes and sampling them it is possible to characterize the condition of all lakes in the state and the extent to which they are impacted by different stressors. This type of sampling design is frequently used in human health, summarizing such things as the percentage of the population at risk to heart disease.

By surveying fifty-one lakes in Vermont using the same methods used by the National Lakes Assessment and over roughly the same index period, the summers of 2007 and 2008, for the first time it was possible to directly compare the condition of Vermont's lakes to the Ecoregion and to the Nation. Some very interesting findings were made.

Key Findings

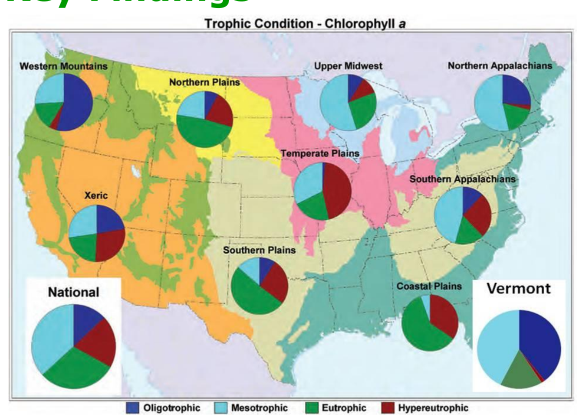

Figure 1. Trophic state across 9 ecoregions, the nation and Vermont (based on NLA chlophyll-a thresholds).

With respect to trophic condition as measured by chlorophyll-*a*, Vermont has a preponderance of lakes in what the NLA considered oligotrophic. Vermont had a higher proportion of oligotrophic lakes than the nation and eight of the nine ecoregions (Figure 1). This finding is consistent with the nutrient enrichment findings that 95% of Vermont lakes were rated in good condition for nitrogen concentrations and 67% were rated in good condition for phosphorus concentrations. Only 7% of lakes were rated in poor condition for total phosphorus. Overall, the water quality of Vermont lakes is at least as good as the region and typically better than the nation.

In Vermont, the largest proportion of lakes in poor condition is for physical habitat complexity (Figure 2).

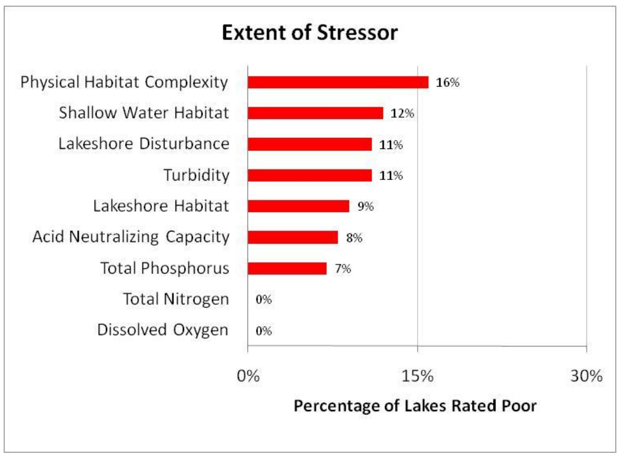

Figure 2. Percentage of lakes rated poor for each stressor.

Poor physical habitat complexity affects more than twice the percentage of Vermont lakes that are affected by high levels of phosphorus. Physical habitat complexity is a measure of the condition of the lakeshore and shallow water habitat combined. Natural shorelines are complex, they are made up of wetlands and diverse structured vegetation including vertically stratified layers of groundcover, understory and canopy plant, shrub and tree species. Natural shallow water habitats are complex as well, they are made up of woody snags, emergent, submersed and floating leaved plants, boulders and diverse sediment types. These structurally complex shallow and nearshore environments provide habitat and niches for a wide diversity of both terrestrial and aquatic organisms. Humans tend to simplify this complexity by converting the diverse lakeshore structure to a monoculture of lawn and impervious surfaces. They 'clean' up the shallow water environment by removing woody snags and aquatic plants. Often the sediment itself is changed by the importation of sand. All of these activities simplify the physical habitat and result in poor conditions. As the stressor with the greatest proportion of lakes in poor condition, it is important that Vermont seek ways to protect the existing fair and good physical habitat complexity that exists on the majority of its lakes. To do so will mean changing the way humans simplify this environment. It will mean educating lakeshore residents on the importance of complexity on both the land and in the shallow water and implementing better management practices so that the use of Vermont lakeshores does not result in the degradation of them.

Echo Lake *(VTDEC)*

Unfortunately, Aquatic Invasive Species were not measured as part of the NLA. However, using the NLA selection of lakes and 2008 VTDEC data, we were able to estimate that 65% of Vermont's lakes do not have one or more of the five major AIS (Eurasian watermilfoil, water chestnut, curly pondweed, zebra mussels and/or alewife). This means that at least 65% of Vermont's lakes would be rated in the Good category for AIS stress.

Most of the parameters measured as part of the NLA were measuring the extent of stressors. One parameter, the macroinvertebrate index of biotic integrity measured the response of the lakes to the various stressors. Alarmingly, Vermont had a higher proportion of lakes rated poor by this metric than five of the ecoregions in the nation (Figure 3). Since nearshore macroinvertebrates respond to multiple stressors, it is hard to tell which stressor is most responsible for the degraded biology in Vermont. It seems probable that the extent of simplification of the nearshore physical habitat and lakeshore disturbance are stressors in part responsible for the degraded biology found in the littoral zone of Vermont lakes.

Macroinvertebrate Index of Biotic Integrity

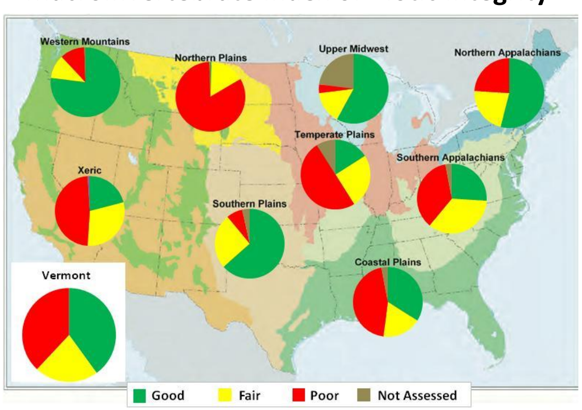

Figure 3. Proportion of lakes in Good, Fair, or Poor condition for Biological Integrity as measured by the Macroinvertebrate Index across 9 Ecoregions and Vermont.

The most worrisome finding in this assessment was that only 18% of Vermont lakes are in good condition for lakeshore disturbance. In this stressor category, Vermont is lagging behind both the region and the nation. The vast majority of lakes (71%) in the state are in Fair condition (Figure 4).

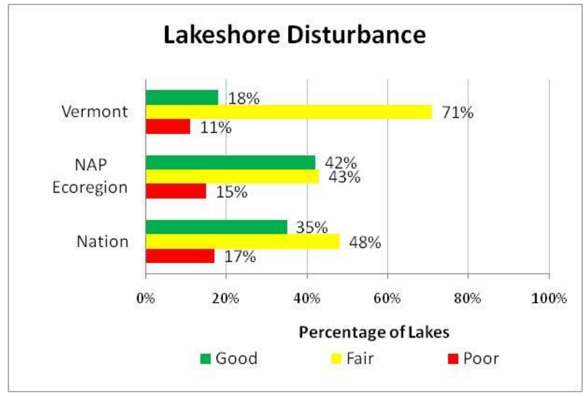

Figure 4. Comparison of lakes in Good, Fair and Poor condition for lakeshore disturbance for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

No other stressor puts as great a proportion of lakes in the nation, state or Ecoregion in either the Poor or Fair condition categories. This is a red flag, especially given how well Vermont compared in most other stressor categories. Lakeshore disturbance "reflects direct human alteration of the lakeshore itself. These disturbances can range from minor changes (such as the removal of trees to develop a picnic area) to major alterations (such as the construction of a large lakeshore residential complex complete with concrete retaining walls and artificial beaches). The effects of lakeshore development on the quality of lakes include excess sedimentation, loss of native plant growth, alteration of native plant communities, loss of habitat structure, and modifications to substrate types. These impacts, in turn, can negatively affect fish, wildlife, and other aquatic communities" (USEPA, 2010), which appears to be what the macroinvertebrate IBI results are telling us. In Vermont, lakeshore disturbance was characterized by sea walls, lawns and the placement of buildings and roads within 100' of the lakeshore. Act 250 guidelines set buildings, roads and driveways back 100' and recommend the retention of natural vegetation. However, few lakeshore development projects trigger Act 250.

Implications

For water resource managers, policymakers, boaters, swimmers, and others, the Vermont NLA findings suggest:

- Poor physical habitat complexity imparts a significant stress on Vermont lakes and suggests the need for stronger management of shoreline development and in-lake removal of snags and plants, especially as development pressures on lakes keep steadily growing.

- Local and state initiatives to protect the integrity of lakes should center on minimizing lakeshore disturbance within 100' of the lake. Buildings and roads should be set outside this zone and natural vegetation should be retained or restored. Lawns should not be located in the buffer zone. Limiting the removal of vertically stratified and diverse natural vegetation will reduce the need for the construction of new seawalls.

Norton Pond *(VTDEC)*

INTRODUCTION

The National Lakes Assessment (NLA) is a collaborative survey of the nation's lakes, ponds and reservoirs initiated by the United States Environmental Protection Agency (EPA). The aim of the survey is to estimate the condition of lakes on a national and ecoregional scale using a statistically-based sampling design with consistent protocols. The reason Vermont sampled more lakes than needed for EPA's national survey was to be able to see what the most widespread stressors to Vermont's lakes are and to see how the condition of Vermont's lakes compare to the Ecoregion and Nation.

Over the summers of 2007 and 2008, Vermont's Department of Environmental Conservation (VTDEC) sampled a total of 51 lakes (Table 1 and Figure 5) using the EPA's NLA approach. Forty-nine of the lakes were randomly selected. Two of the lakes were selected as reference lakes, to be used along with other reference lakes in the Ecoregion and Nation to set the Ecoregional and National thresholds. The two reference lakes and nine of the randomly selected lakes were the 'original draw' EPA made to be used in the Ecoregional and National level comparisons (Figure 6 and Figure 7). The original draw lakes will be referred to as the NLA core lakes throughout this report. The 40 additional lakes were supplied to Vermont as an 'overdraw' by EPA to permit a statistically valid assessment of lakes across Vermont (Figure 5). With the development and release of the analytical methods used to process the NLA data at the Northern Appalachian Ecoregion and National scales, the Vermont data was analyzed following the same statistical criteria with EPA's assistance. Using thresholds developed for the Northern Appalachian Ecoregion and Nation, results from Vermont are presented in this report for direct comparisons. In addition, Vermont's own thresholds are applied to investigate the utility of this approach in determining if lakes are meeting standards from a statewide perspective. This report also aims to help other states consider their level of involvement in the next national lake assessment scheduled for 2017.

Crystal Lake *(VTDEC)*

Table 1. Vermont lakes (n=51) sampled in the National Lake Survey. *Asterisk indicates Core NLA lakes. *Italics* denotes reference lakes. No Physcial Habitat Data was collected for Lake Champlain. Data from Lily Pond and Little Rock Pond were not used in the analyses because the size class of lakes their data would represent were undersampled.

Lake Name (click for more information)	Town	Area (hectares)	Lake Name (click for more information)	Town	Area (hectares)
Beebe Pond*	Hubbardton	38.46	Lily Pond	Poultney	7.2
Berlin Pond	Berlin	115.81	Little Averill Pond	Averill	177.56
Bliss Pond	Calais	12.09	Little Rock Pond	Wallingford	5.47
Bomoseen, Lake	Castleton	943.83	Lowell Lake	Londonderry	44.1
Branch Pond	Sunderland	20.12	Martins Pond	Peacham	31.88
Carmi, Lake	Franklin	541.22	Miles Pond*	Concord	82.16
Caspian Lake*	Greensboro	306.67	Mill Pond	Windsor	32.37
Cedar Lake	Monkton	50.14	Mud Pond	Craftsbury	10.88
Champlain*, Lake	Main lake off Burlington	66,414.37	Neal Pond	Lunenburg	72.28
Chandler Pond	Wheelock	23.81	North Springfield Reservoir	Springfield	53.37
Clyde Pond	Derby	59.53	Norton Pond	Norton	216.56
Coles Pond	Walden	44.08	Old Marsh Pond	Fair Haven	50.64
Crystal Lake	Barton	274.4	Parker*, Lake	Glover	83.35
Curtis Pond	Calais	35.06	Peacham Pond	Peacham	136.92
Derby*, Lake	Derby	76.2	Reservoir Pond	Ludlow	13.87
Doughty Pond	Orwell	301.5	Richville Pond	Shoreham	61.35
East Long Pond	Woodbury	76.08	Round Pond	Newbury	11.05
Echo Lake	Charleston	191.71	Sabin Pond	Calais	51.1
Eden, Lake	Eden	71.43	Salem, Lake	Derby	52.34
Elmore, Lake	Elmore	79.19	Seymour Lake	Morgan	667.57
Hardwick Lake	Hardwick	79.75	Shippee Pond	Whitingham	10.9
Harriman Reservoir	Whitingham	812.42	Silver Lake	Barnard	34.05
Indian Brook Reservoir	Essex	21.63	Silver Lake*	Leicester	41.13
Iroquois, Lake	Hinesburg	96.52	*Spring Lake**	Shrewsbury	26.22
Island Pond*	Brighton	220.65	Turtlehead Pond*	Marshfield	27.83
*Jobs Pond**	Westmore	12.55			

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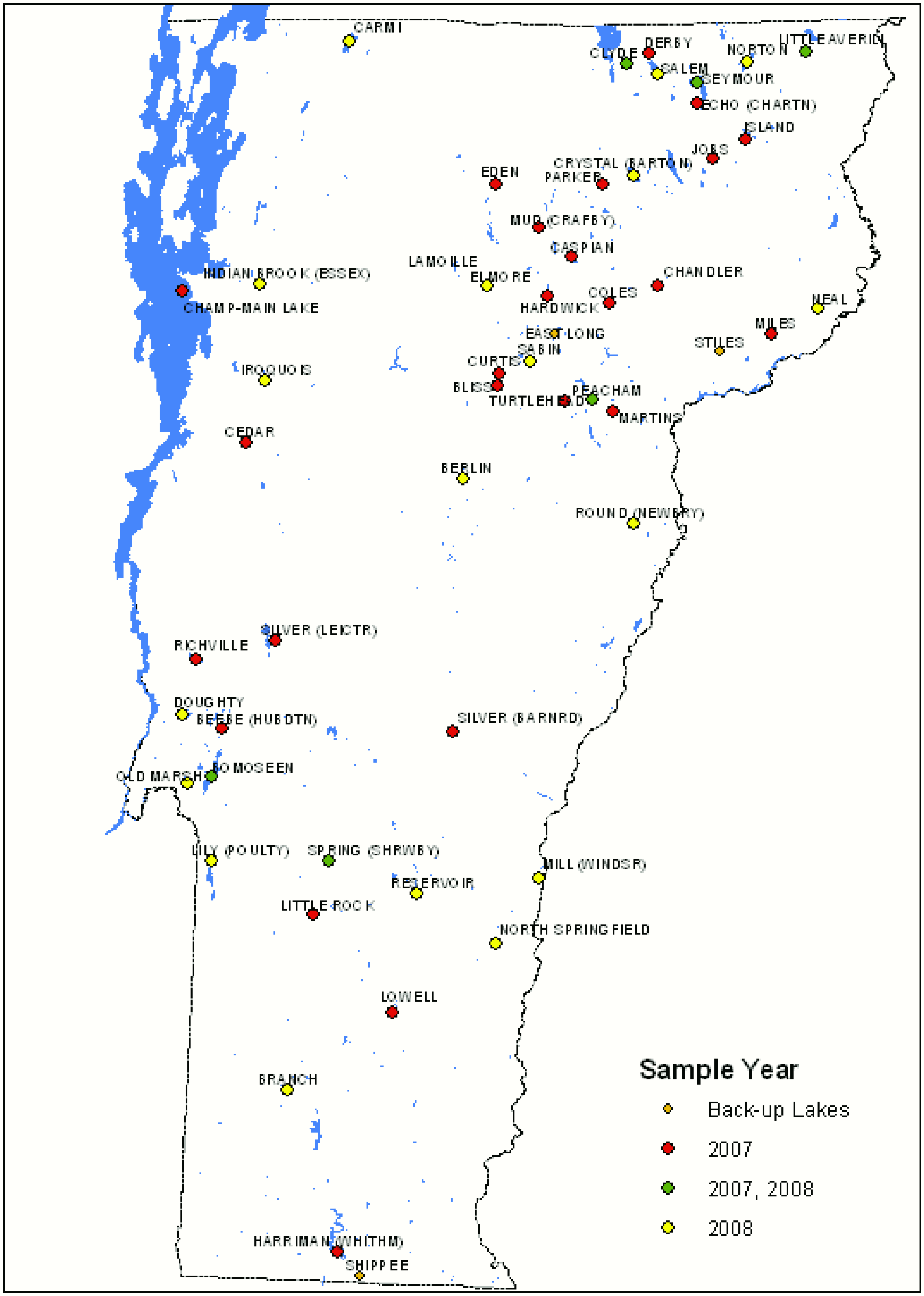


Figure 5. Distribution of Vermont lakes from the random selection provided by the National Lake Survey.

Throughout this document, Vermont's results will be compared to the results from the Northern Appalachian Ecoregion (Figure 6, (NEIWPCC, 2010)) and Nation (Figure 7, (USEPA, 2010)).

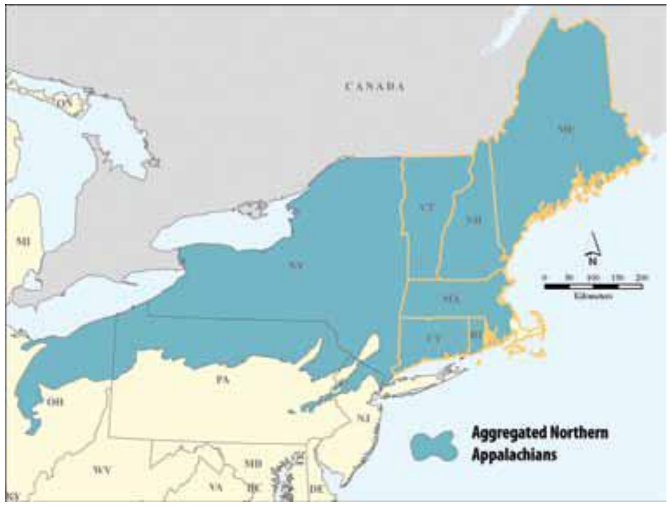


Figure 6. The Northeastern Appalachian Ecoregion.

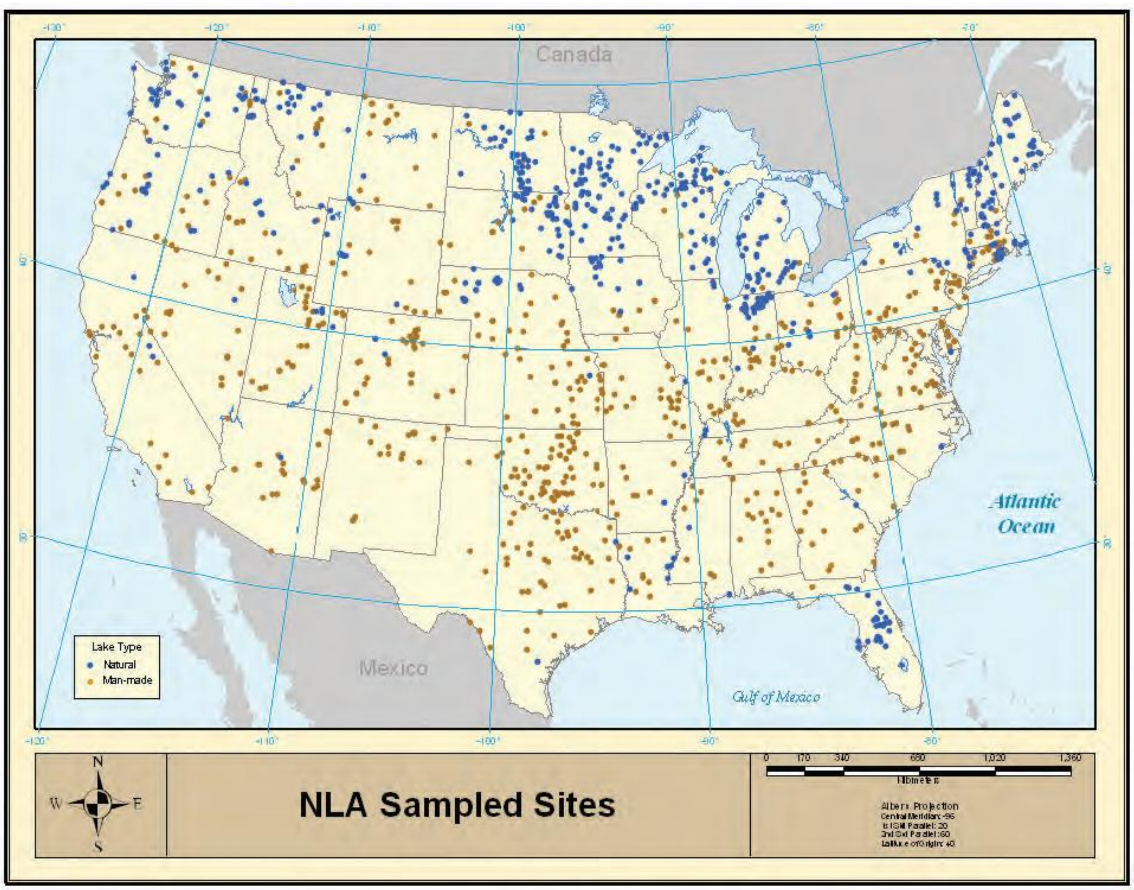


Figure 7. Location of lakes sampled in the NLA. Natural lakes are the blue dots; Man-made lakes are brown.

Lake Extent - Natural and Man-made Lakes

Natural lakes were defined by the National Lakes Assessment as those that existed pre-European settlement, even if presently augmented by means of an impoundment or earthworks. Using this definition, 84% of Vermont's lakes are of natural origin. Interestingly, this is the first big difference between Vermont, the Ecoregion and the Nation. The Northern Appalachian Ecoregion is dominated by man-made lakes, with only 46% of natural origin, whereas, lakes of natural origin make up 59% of the nation's lakes and Vermont is dominated (84%) by lakes of natural origin (Figure 8). The only ecoregion with a higher proportion of natural lakes than Vermont is the upper Midwest. Since man-made lakes can be subject to greater water level fluctuations than natural lakes, it will be important to keep this difference in mind when looking at how Vermont's data compares to the region and nation throughout this report.

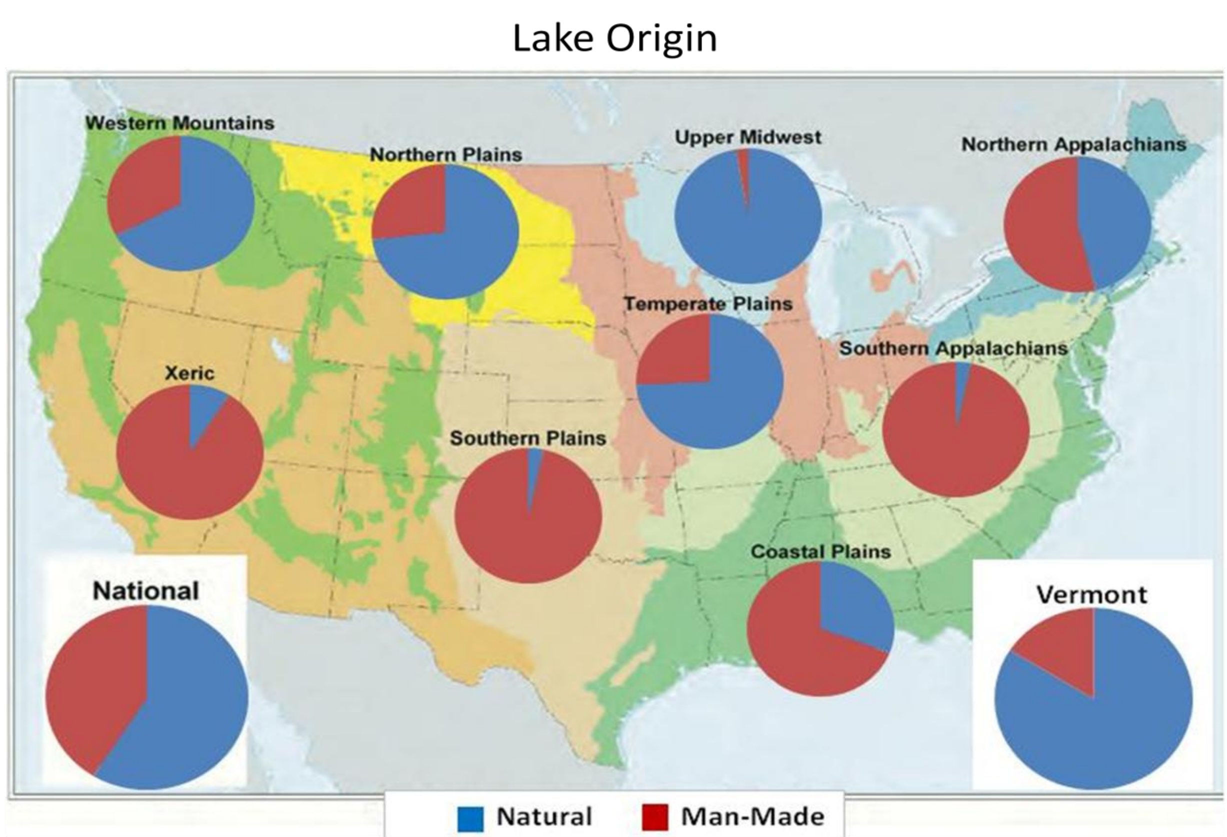


Figure 8. Proportion of Lakes of Natural and Man-Made Origin in Vermont, the Ecoregions and Nation.

How well does the statistical design infer the statewide condition?

The advantage to using the statistical design is that it maximizes the use of limited resources. Since it is not physically or financially possible to actually visit and sample all of the lakes in Vermont. When that is the case, a statistical survey design allows us to sample a limited but representative subset of lakes and makes estimates that can be applied to the full set of lakes in Vermont. This is much like the design tools used in census bureau estimates and human health surveys.

DEC maintains a database of information on Vermont Lakes called the Lakes Inventory, while many of the other statistical-based inferences about Vermont lakes cannot be checked against the Lakes Inventory because DEC does not have data for every lake in the state, in the case of lake origin or outlet type DEC does have data for 97% of all the lakes greater than 25 acres in the state. Seventy-two percent of these lakes in the Inventory are of natural origin, 25% are man-made and 3% DEC does not have data on (Figure 9).

While the DEC information is based on data from 228 lakes, the NLA data is based only on data from 46 lakes. The estimates we get from the Vermont Inventory of 228 lakes is very similar to the estimates derived from a statistically designed survey sampling only 46 lakes. It inferred that 84% of lakes as natural (vs 72% DEC Lakes Inventory) and 16% man-made (vs 25% DEC Lakes Inventory) (Figure 9). Given that only 22% of the lakes the statistical design made inferences about were actually visited, this demonstrates how statistical sampling designs can save both time and money.

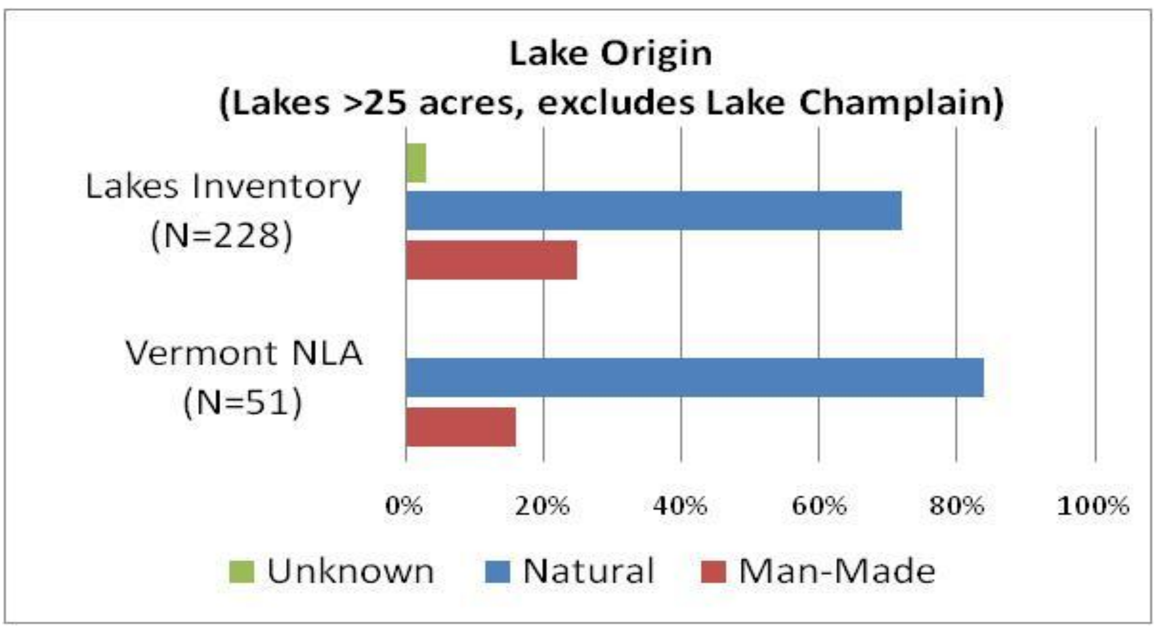


Figure 9. Comparison of the Vermont NLA statistical design's lake origin inferences and the DEC Lakes Inventory Database.

Mud Pond in Craftsbury *(VTDEC)*

METHODS

For information on sampling, please refer to The National Lakes Assessment Report, Field Methods and Laboratory Protocols currently available on EPA's website at http://www.epa.gov/lakessurvey. Results presented in this report were produced following the data analysis approach documented in The National Lakes Assessment: Technical Appendix, which is also available on EPA's website above.

Percent population estimates of lakes in each condition class (e.g. good, fair or poor) were calculated for key water quality indicators (total phosphorus, total nitrogen, chlorophyll-*a*, turbidity, dissolved oxygen, and acid neutralizing capacity) and key physical habitat indicators (lakeshore disturbance, lakeshore habitat, shallow water habitat, and physical habitat complexity). National and Northern Appalachian Ecoregion (NAP) thresholds for condition classes can be found in The National Lakes Assessment Report and Technical Appendix.

A critical component in the statistical survey design is assigning each lake a numeric weight, which corresponds to a relative population of similar lakes. Weights were assigned to each lake based on size class and representation in Vermont (Figure 10). Two lakes had very high weights because they are in the smallest size class (10-25 acres) and represent the sampled size class with the largest number of lakes in the state. Consequently, these two lakes heavily influence condition class estimates.

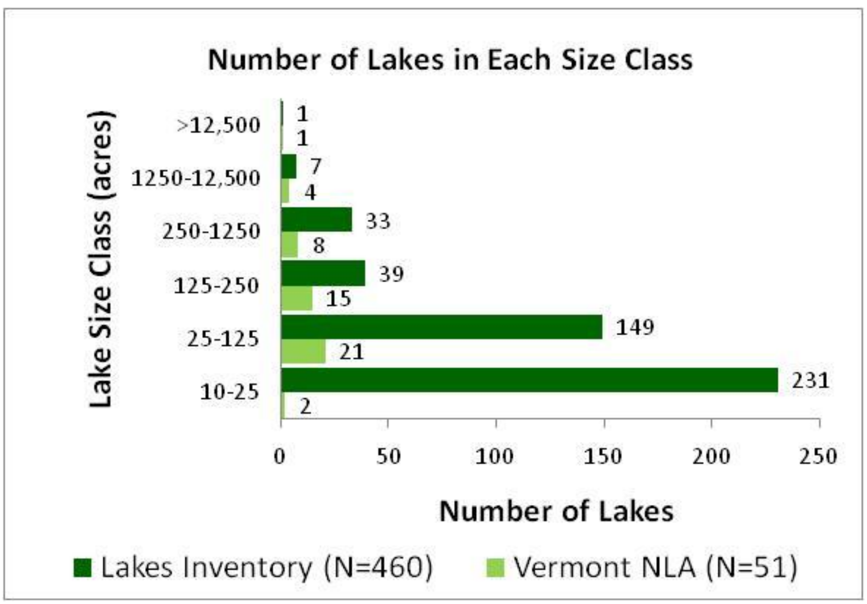


Figure 10. Number of Vermont lakes in each size class. The 10-25 acre size class was eliminated from the analyses in this report, because the 2 randomly selected lakes were unusual and not representative of the population of lakes in that size class.

Two lakes were not a sufficient sample size to characterize the largest class of lakes in the state. Therefore, data from these two lakes were not included in the calculations, resulting in condition class estimates only for Vermont lakes greater than 25 acres. The data reported for the ecoregion and nation include the 10-25 acre class and this should be kept in mind when looking at the comparisons presented in this report. While these small lakes are the most numerous on the landscape, Vermont lakes 10-25 acres comprise only 7% of the assessed inland lake acreage in the state. VTDEC has typically limited it's monitoring and assessment to lakes greater than 20 acres for logistical and statutory reasons. EPA and DEC choose more lakes in the 10-25 acre size class for the second round of the National Lakes Assessment, which was conducted in 2012.

Unless otherwise noted, the Vermont results presented in this report are based on a total of 47 randomly selected lakes. While 51 lakes were sampled, the data from the 2 reference lakes were used to develop the ecoregional and national thresholds, and hence these two lakes were excluded from the analyses. The 2 small size class lakes were excluded as well. While one site on Lake Champlain was sampled for water quality, the physical habitat parameters were not sampled. So, a total of 46 lakes were used in the physical habitat results.

Jobs Pond *(VTDEC)*

RESULTS

The statistically random lake selection design enables Vermont to compare the condition of Vermont lakes to those in the ecoregion and nation. The results presented from the ecoregions and nation are from the EPA National Lake Assessment Final Report (USEPA, 2010).

Water Quality Indicators

Trophic Status

The trophic state assigned to a lake by the National Lake Assessment is based on the chlorophyll-*a* measurement taken during the onetime NLA visit. The results can be thought of as a snapshot taken during the same index period across a population of lakes. It tells you what the chlorophyll-*a* based trophic condition was of a population of lakes during that window of time. It does not tell you the trophic condition of a particular lake that was sampled, that is why no individual lake results are presented in this report. Based on chlorophyll-*a* thresholds for trophic state applied to NLA data, Vermont has a larger proportion of oligotrophic lakes than both the Northern Appalachian Ecoregion and Nation (Table 2 and Figure 11).

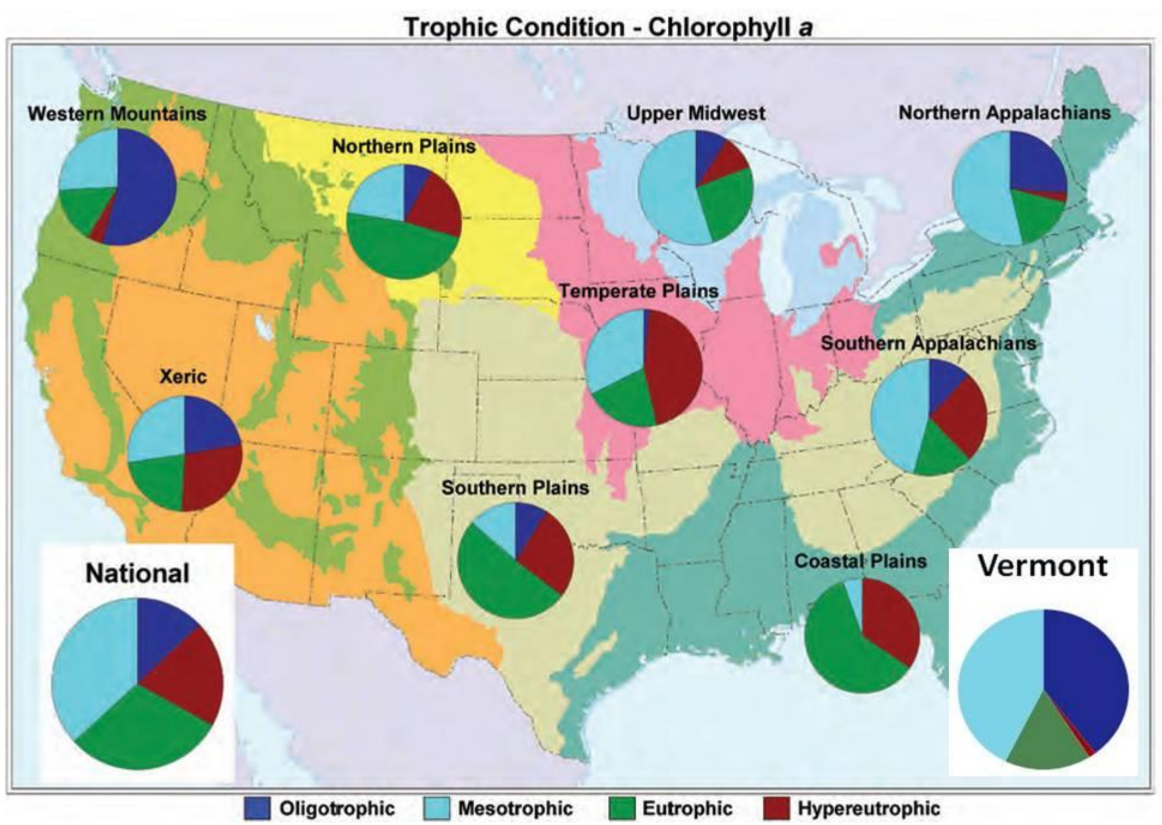


Figure 11. Trophic state across 9 ecoregions, the nation and Vermont (based on NLA chlorophyll-a thresholds).

Only the Western Mountain Ecoregion has a higher proportion of oligotrophic lakes than Vermont. The proportion of mesotrophic lakes in Vermont is similar to the national proportion, but the proportion of lakes in the hypereutrophic category is very small compared to most of the nation.

Figure 11 uses the National chlorophyll-*a* thresholds for trophic state. However, Vermont has its own thresholds for defining trophic condition and these use a combination of the secchi transparency (the water clarity), total phosphorus concentration (nutrient availability) and chlorophyll-*a* (Table 3).

When just the Vermont chlorophyll-*a* threshold is applied to Vermont's lakes based on the single visit data from the National Lakes Assessment, oligotrophic lakes are shown to be the dominant condition in Vermont and the proportion of eutrophic and mesotrophic lakes are only 19% and 18% respectively. Figure 12 demonstrates why EPA initiated the statistical surveys. Vermont, like other states has its own thresholds. Even though the same data set is used, those differences are enough to make comparisons between Vermont, the ecoregion and nation impossible. If you also add to the mix that different states sample at different depths, use different laboratory methods and sample at different times of the year, then direct comparisons between the condition of Vermont lakes to those throughout the nation has been impossible until the 2007 National Lakes Assessment.

Table 2. NLA chlorophyll-a trophic state thresholds.

NLA Thresholds	Chlorophyll-*a* (µg/L)
Hypereutrophic	**>30**
Eutrophic	**>7 - 30**
Mesotrophic	**>2 -7**
Oligotrophic	**<2**

Because Vermont has two long term monitoring programs, DEC utilizes those datasets when determining the trophic state for a particular lake. The National Lake Assessment trophic designation was a snapshot of Vermont lake trophic condition that provides the opportunity to see how Vermont compares to the Ecoregion and Nation. However, when Vermont determines the trophic state for a lake, it does not rely on a one time visit to the lake and only chlorophyll-*a*. Rather, it uses phosphorus concentrations, secchi depth readings and chlorophyll-*a* from its citizen lay monitoring, spring phosphorus monitoring and long term

Table 3. Trophic state thresholds from Vermont Lake Water Quality Assessment 1996, VTDEC (or as noted).

Trophic State	Secchi Depth	Chlorophyll-*a*	TP	TP *(Nurnberg, 1996)*	TN *(Nurnberg, 1996)*	Color
	Summer mean (m)	Summer mean (ug/L)	Spring mean (ug/L)	Summer photic zone (ug/L)	Summer photic zone (mg/L)	(PtCo)
Hypereutrophic			>100		>1.2	
Eutrophic	0 - 3.0	≥ 7.0	> 15	>24	0.65-1.2	
Mesotrophic	3.0 - 5.5	> 3.5 - 7.0	>7 - 15	10-24	0.35 - <6.5	
Oligotrophic	≥ 5.5	0 - 3.5	≤7	<10	<0.35	
Dystrophic			<20	<24		>50*

Table 3 notes:

**Acid sensitive <12.5 Alkalinity.*

Note: A lake's data will not always fall into one trophic category; in these cases DEC considers phosphorus concentration most heavily, then chlorophyll-a concentration, then Secchi disk clarity.

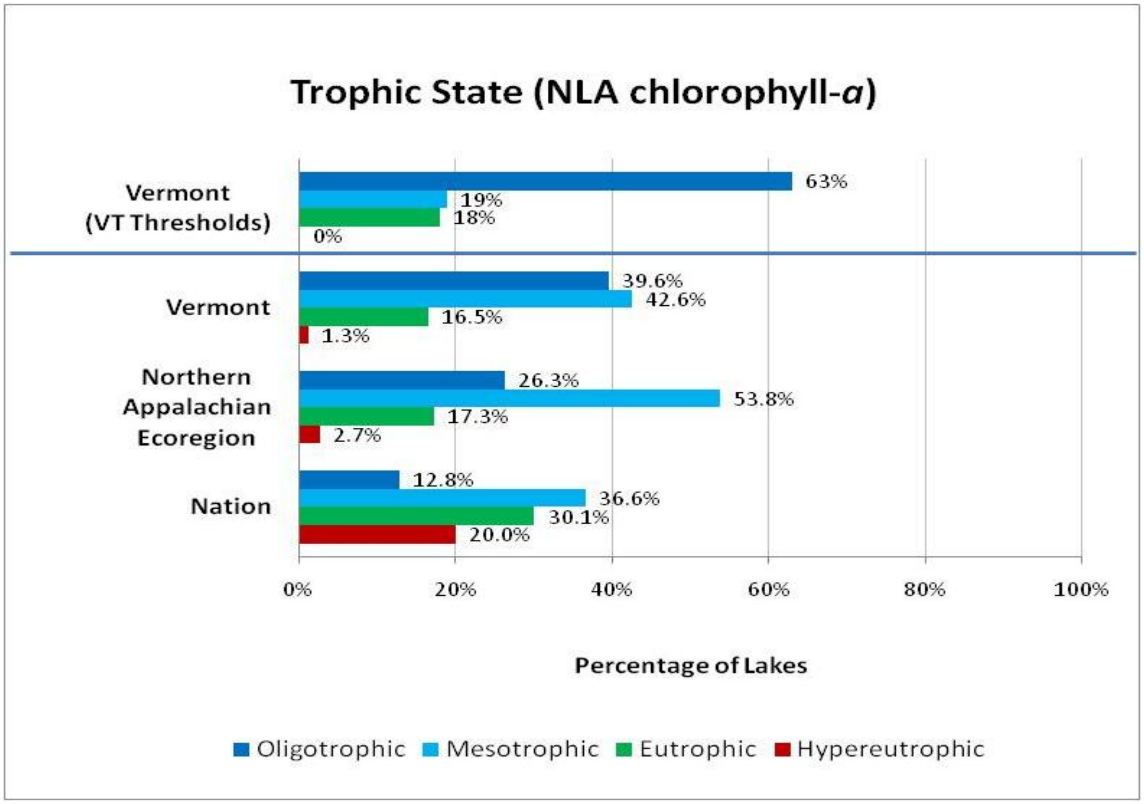


Figure 12. Proportion of lakes within each trophic state as determined by Chlorophyll-*a* using Vermont thresholds and the NLA thresholds and data for Vermont (lakes >25 acres), the Northern Appalachian Ecoregion (lakes >10 acres) and Nation (lakes >10 acres). Applying Vermont-specific thresholds makes comparisons to Ecoregions, the Nation and other states impossible.

acid rain monitoring programs (Table 3). Vermont happened to have long term water quality data on all of the NLA lakes samples.

The statistically valid random lake draw allows us to use these lakes and their long term data to see what proportion of lakes in Vermont are in each trophic class using a larger and more long term data set. It does not allow us to compare Vermont lakes to the Ecoregion or Nation, but allows us to characterize the overall trophic condition of Vermont lakes using additional trophic indicators. Rather than providing a snapshot, it is more a measure of the overall trophic condition over time, which integrates both the high and low values collected during individual visits. Long-term data for trophic state based on total phosphorus, chlorophyll-*a* and Secchi depth show that the majority of lakes in the state are actually mesotrophic (60%) by Vermont's thresholds, while a much smaller percentage are oligotrophic (14%) (Figure 13). The additional class of dystrophic lakes was included in this breakdown of trophic class.

Figure 14 demonstrates how the statistical design could be used with existing data sets to make inferences about the overall condition of a population of lakes. In this example, since Vermont DEC had enough long term monitoring data on all 46 of the NLA selected lakes to characterize the trophic condition using Vermont thresholds and parameters, and since Vermont had defined the trophic condition on 95% of its lakes greater than 25 acres, it was again possible to test how representative the statistically selected lakes were of lakes in the state. It turns out that it was a good approximation, it shows that by focusing ones efforts monitoring 46 lakes selected in a statistical manner one can infer the general proportions of condition of 228 lakes. Sampling 46 lakes takes a lot less resources than sampling 228 lakes.

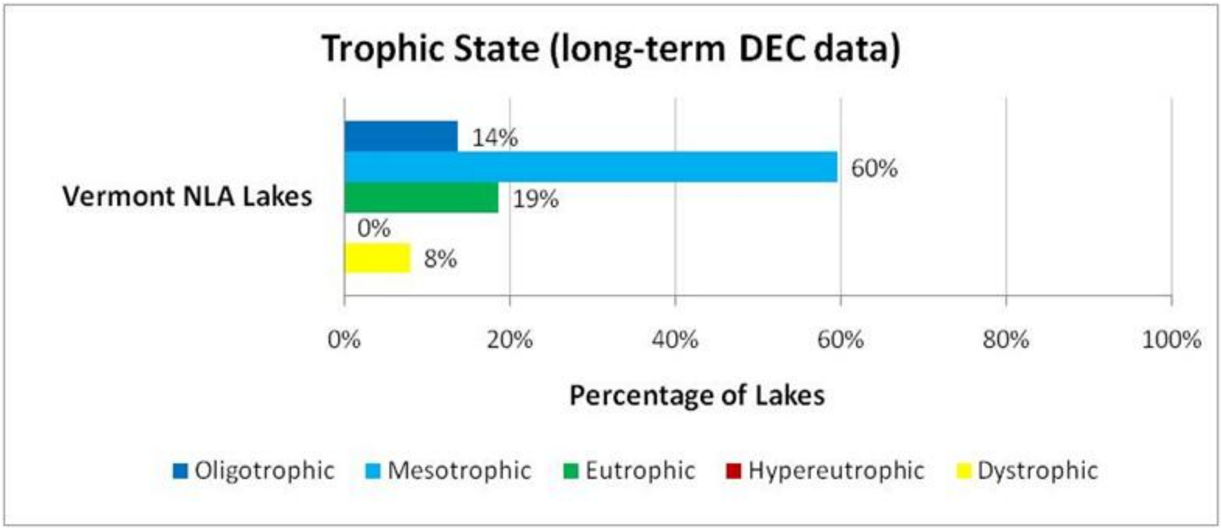


Figure 13. Trophic state of Vermont lakes (> 25 acres, excluding Lake Champlain) using long-term data from the Vermont Lay Monitoring, Lake Assessment and Spring Phosphorus Programs for the 46 VT NLA lakes for total phosphorus, chlorophyll-a and Secchi

Harriman Reservoir *(VTDEC)*

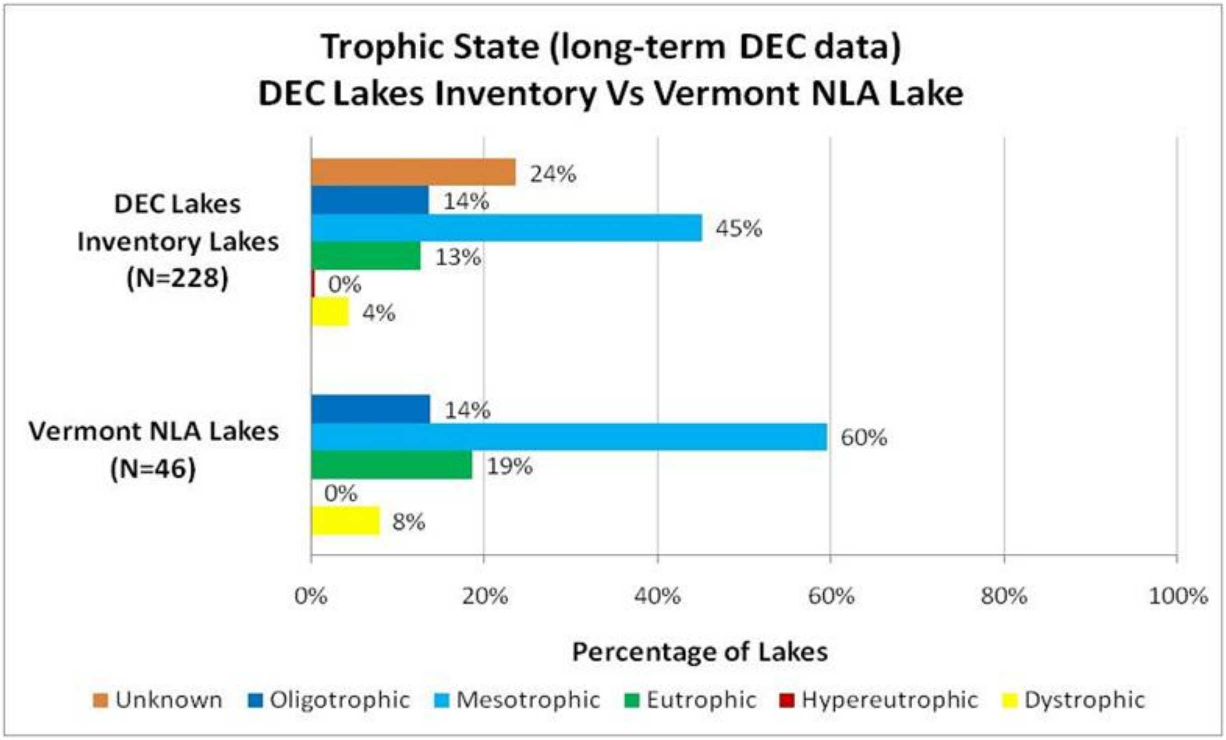


Figure 14. Comparison of how well the NLA probabilistic approach does at predicting lake trophic condition for the state when long term monitoring data is used. Forty-six randomly selected lakes gives similar proportions as the DEC Lakes Inventory which doesn't have trophic condition defined for all lakes greater than 25 acres, but does have it for 95% of them. Note: This figure does not include data collected during the NLA sampling effort.

Little Averill Pond *(Jeff Merrell)*

Total Phosphorus

Relative to regionally-specific reference expectations, total phosphorus levels are considered good in two-thirds of Vermont lakes, which is better than the Nation but not as good as the Northern Appalachian Ecoregion (Table 4, Figure 15 and Figure 16).

Table 4. NAP Ecoregion total phosphorus Good, Fair and Poor thresholds.

NAP Ecoregion Thresholds	Good	Fair	Poor
Total Phosphorus µg/L	<16.5	16.5 - <36	≥36

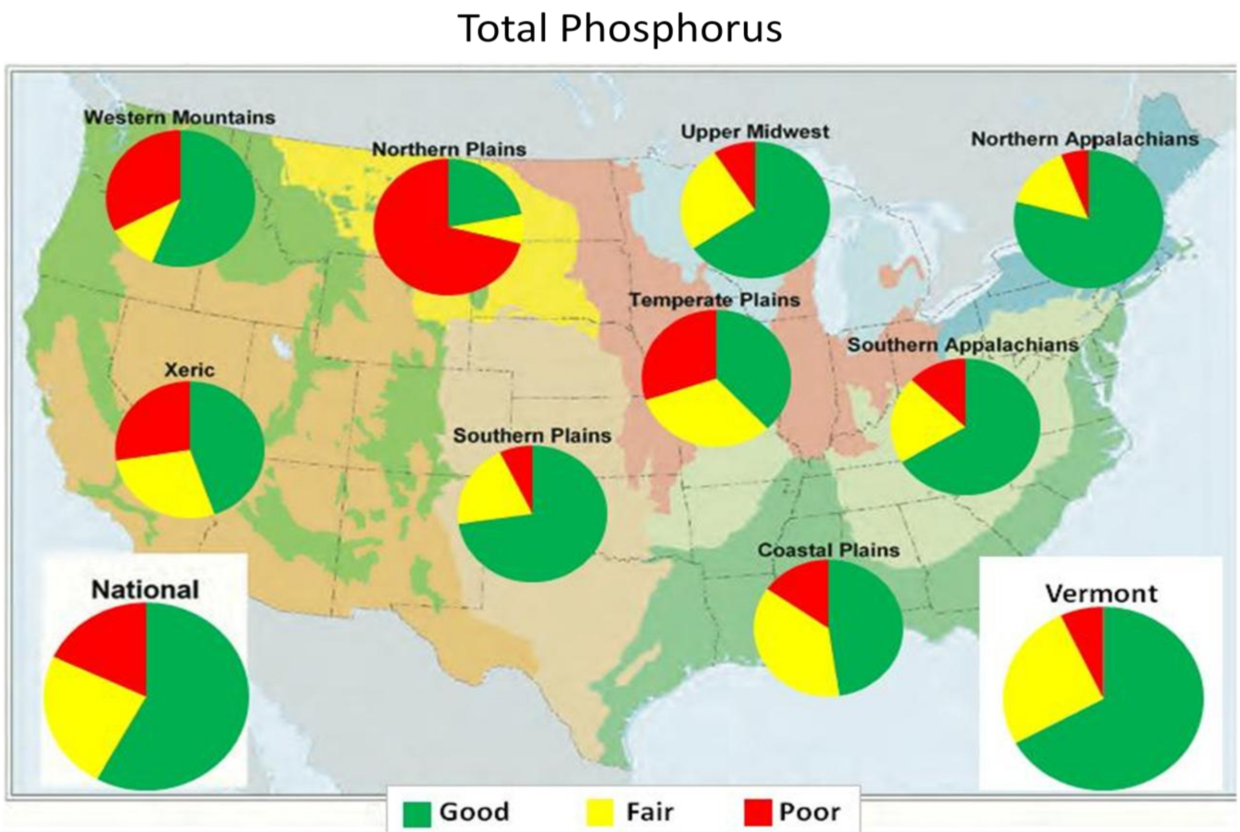


Figure 15. Proportion of lakes in Good, Fair, or Poor condition for Total Phosphorus across 9 Ecoregions, the Nation and Vermont.

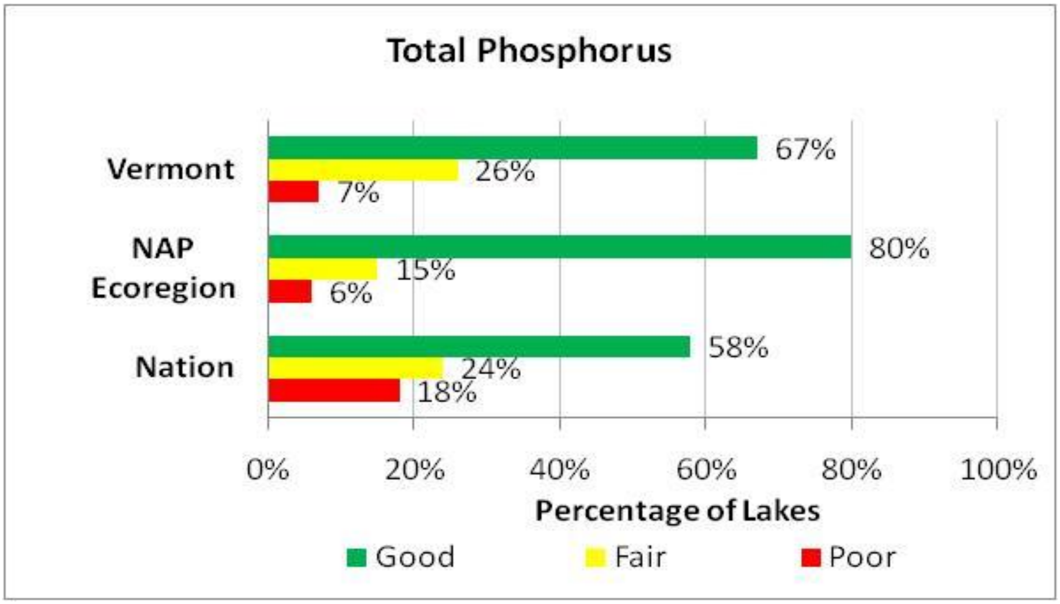


Figure 16. Comparison of lakes in Good, Fair and Poor condition for phosphorus for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

Silver Lake in Leicester Vermont *(VTDEC)*

Total Nitrogen

Under regional thresholds, total nitrogen levels are considered good in 95% of Vermont lakes, which is better than both the Nation and the Northern Appalachian Ecoregion (Table 5, Figure 17 and Figure 18). If nitrogen is present in lower concentrations than at the Ecoregional scale, as these results suggest, that might also explain why more lakes ranked as oligotrophic (Figure 11 and Figure 12) in Vermont than at the Ecoregional scale.

Table 5. NAP Ecoregion total nitrogen Good, Fair and Poor thresholds.

NAP Ecoregion Thresholds	Good	Fair	Poor
Total Nitrogen mg/L	<0.674	0.674 - <1.174	≥1.174

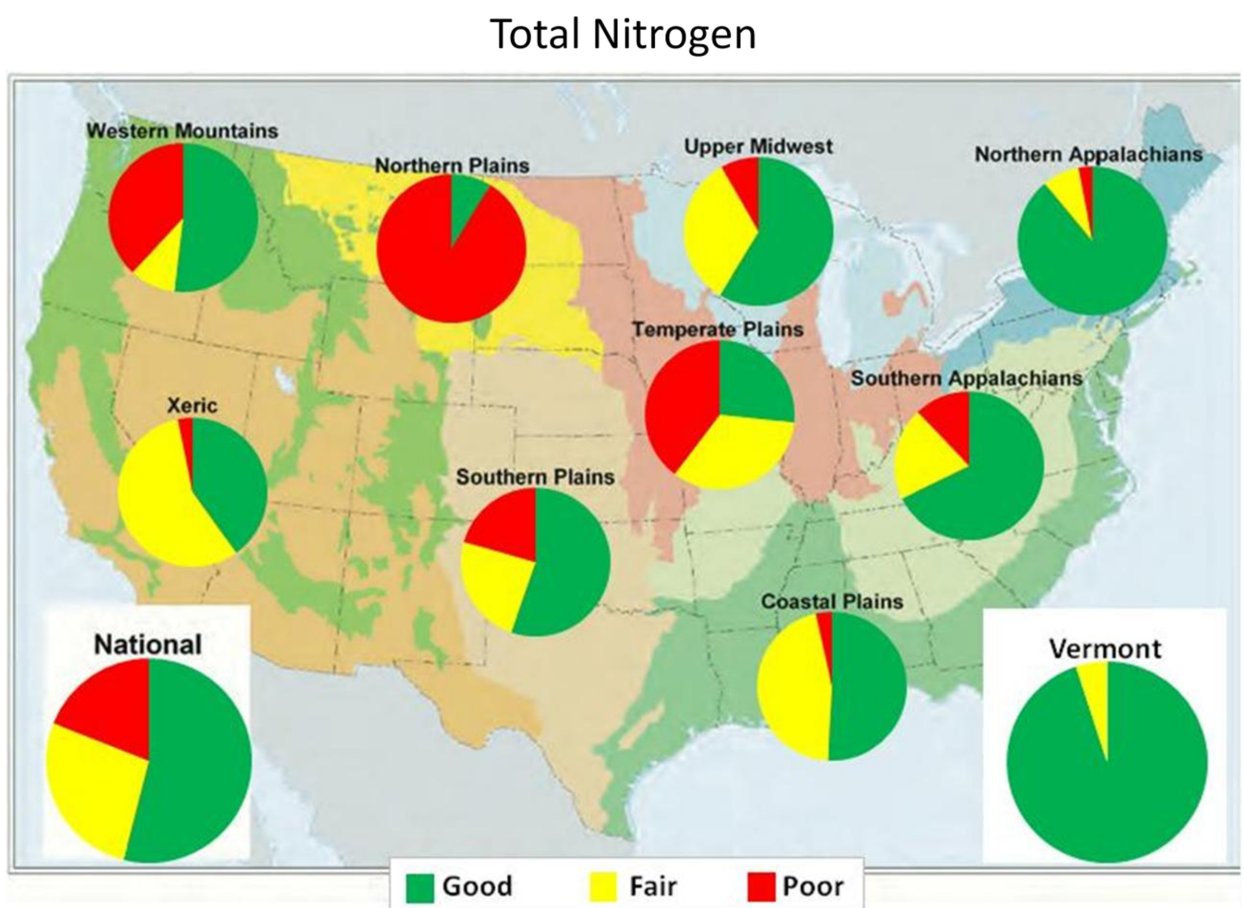


Figure 17. Proportion of lakes in Good, Fair, or Poor condition for Total Nitrogen across 9 Ecoregions, the Nation and Vermont.

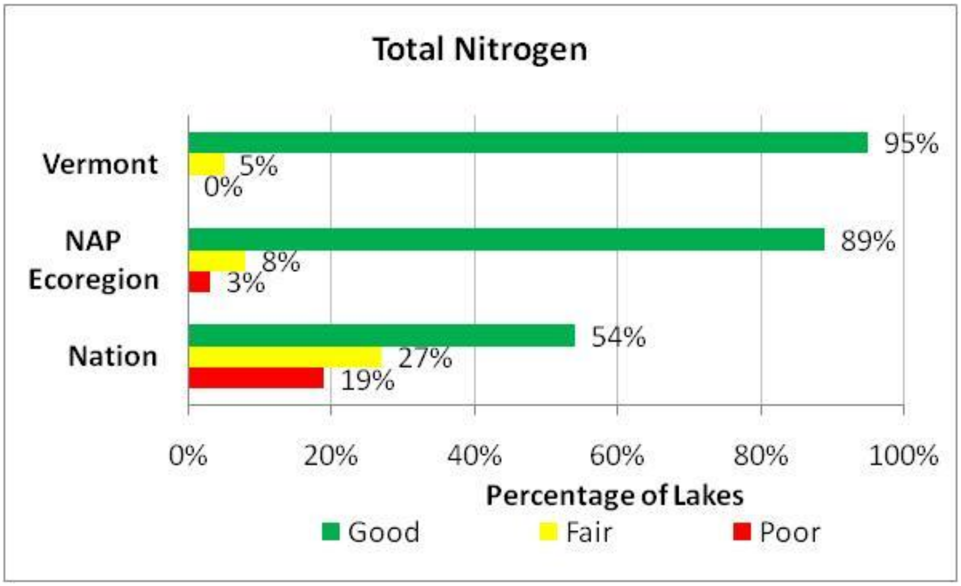


Figure 18. Comparison of lakes in Good, Fair and Poor condition for nitrogen for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

Lake Caspian *(VTDEC)*

Chlorophyll-a

Ecoregional thresholds for chlorophyll-*a* suggest that 90% of lakes in Vermont are in good condition, with results being similar to those for the Northern Appalachian Ecoregion (Figure 19). Results were not compared with the nation, since chlorophyll-*a* thresholds varied with Ecoregion. Since the NLA trophic ratings were based solely on chlorophyll-*a* it is tempting to compare the graph for chlorophyll-*a* to that for trophic condition. However, the thresholds for good, fair and poor chlorophyll-*a* do not coincide with the thresholds for oligotrophic, mesotrophic, eutrophic and hypereutrophic (Figure 19 and Table 6). Most notably, the vast majority of Vermont lakes are in good condition with respect to chlorophyll-*a.* It is interesting that none of Vermont's lakes fall into the Fair condition for chlorophyll-*a* (Figure 19), which equates to what would be the lower end of the eutrophic range (Figure 11 and Table 2).

Instead, ten percent of Vermont lakes are in poor condition for chlorophyll-*a.* So, in Vermont, with respect to water column algae as measured by chlorophyll-*a* concentrations, the vast majority of lakes have low concentrations, but when lakes have high concentrations they are very high. This suggests that the general condition of Vermont lakes is good, but once algal populations find a niche the do very well.

Table 6. NAP Ecoregion chlorophyll-*a* Good, Fair and Poor thresholds.

NAP Ecoregion Thresholds	Good	Fair	Poor
Chlorophyll-*a* µg/L	<7.56	7.56 - <12.5	≥12.5

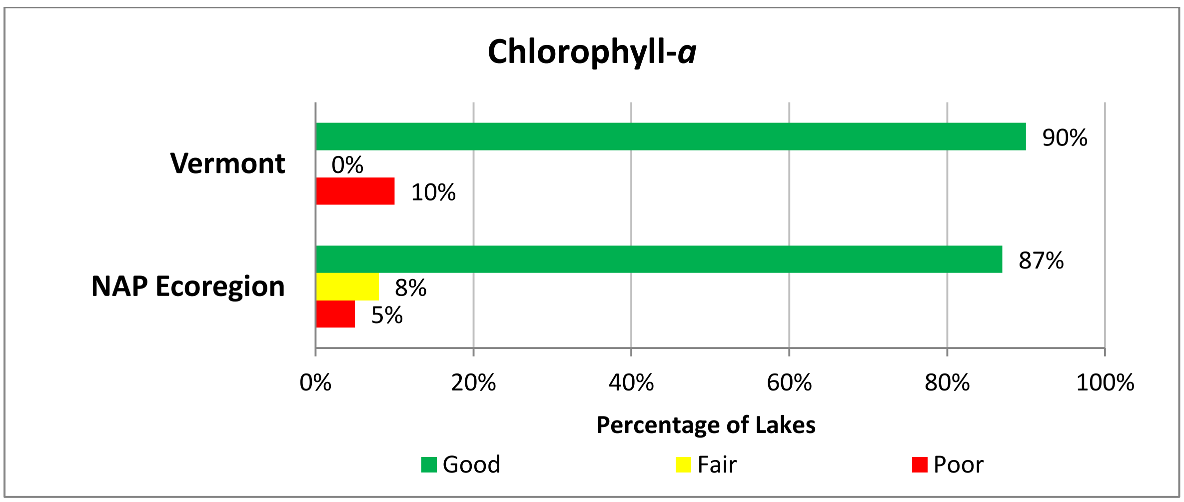


Figure 19. Comparison of lakes in Good, Fair and Poor condition for Chlorophyll-*a* for Vermont (lakes >25 acres) and the Northern Appalachian (NAP) Ecoregion (lakes >10 acres).

Turbidity

Using ecoregional thresholds for turbidity (Table 9), two-thirds of Vermont lakes are considered to be in good condition, which is worse than both the Nation and Northern Appalachian Ecoregion (Figure 20 and Figure 21). While the majority of lakes in Vermont are in good condition for turbidity, of note is how Vermont compares to the region, nation and even other ecoregions. This finding is curious given how well Vermont rated in all the other water quality parameters measured.

One explanation may be that methods used to measure turbidity on the 11 NLA core lakes and the 40 Vermont overdraw lakes were different. The method used on the 11 core lakes was a laboratory method used on samples collected and shipped to the laboratory. The method used on the 40 overdraw lakes was an in-situ measure taken with a turbidity sensor. Since both methods were used on the 11 core lakes, Figure 22 shows that four out of eleven times the Vermont in-situ method resulted in higher readings, and four out of the eleven times the opposite was true. At this point, it is difficult to say whether Vermont lakes are truly doing poorer than the region or the nation for turbidity. This question will be investigated in the 2012 national lake assessment.

Table 7. NAP Ecoregion turbidity Good, Fair and Poor thresholds.

NAP Ecoregion Thresholds	Good	Fair	Poor
Turbidity NTU	<2.75	2.75 - <5.41	≥5.41

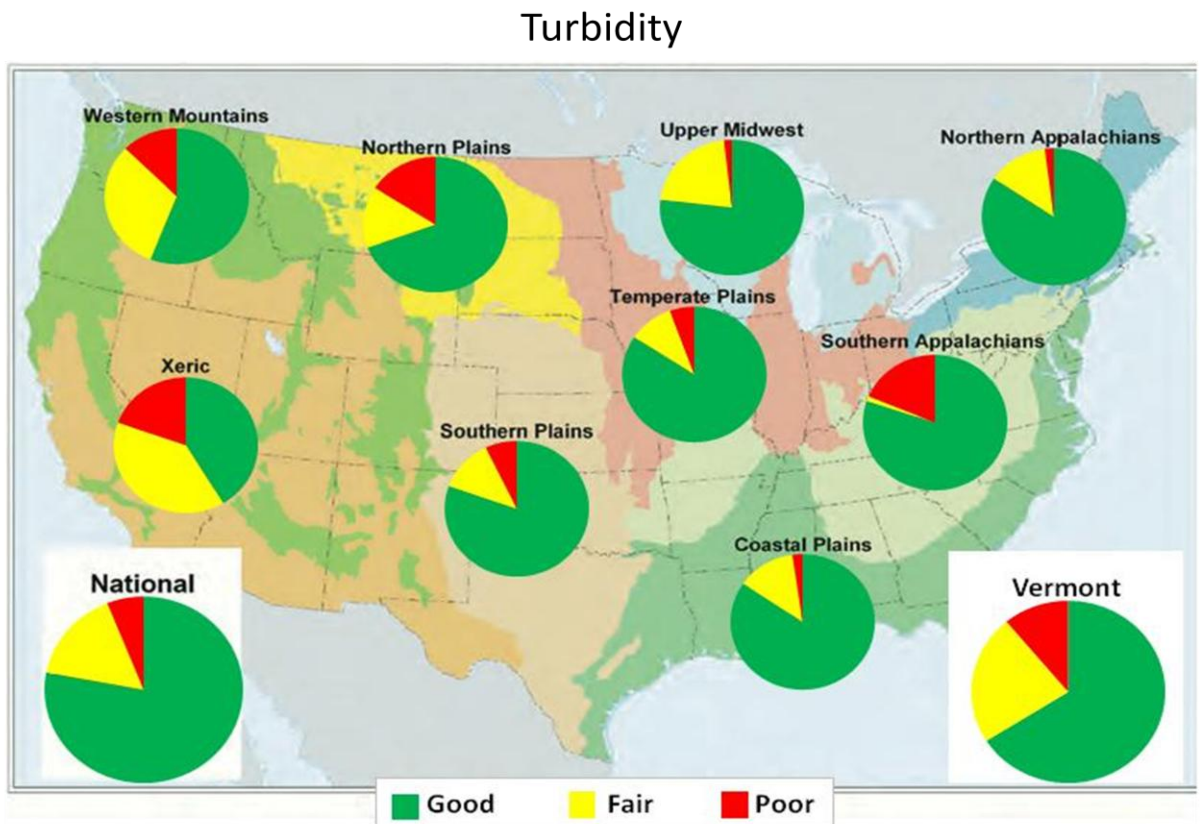


Figure 20. Proportion of lakes in Good, Fair, or Poor condition for Turbidity across 9 Ecoregions, the Nation and Vermont.

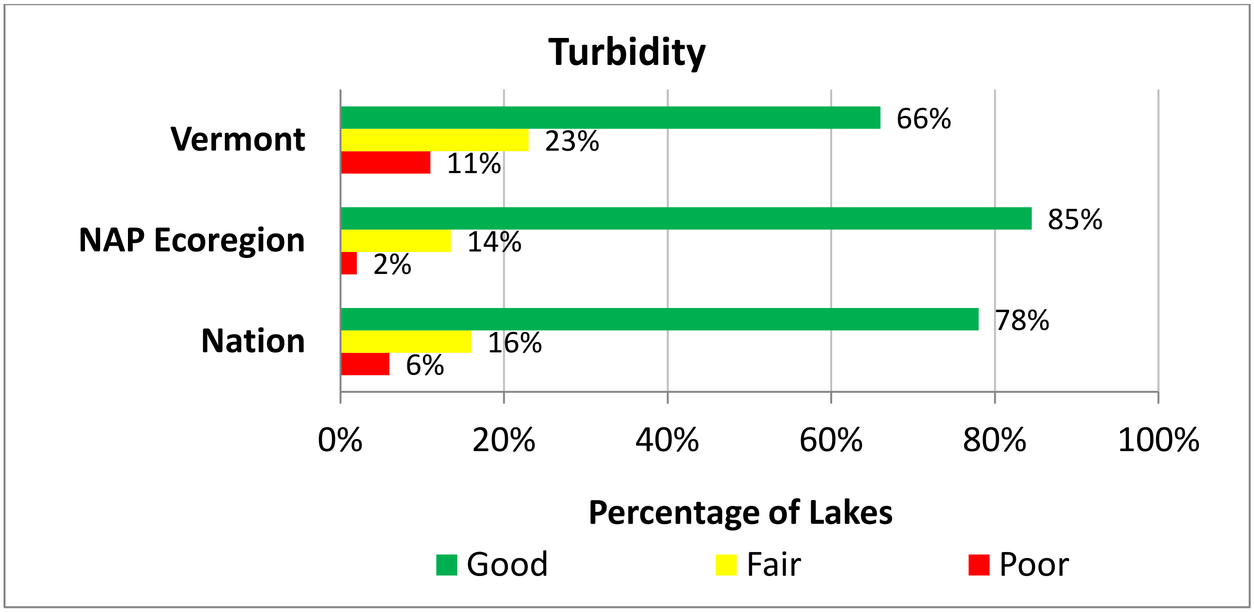


Figure 21. Comparison of lakes in Good, Fair and Poor condition for turbidity for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

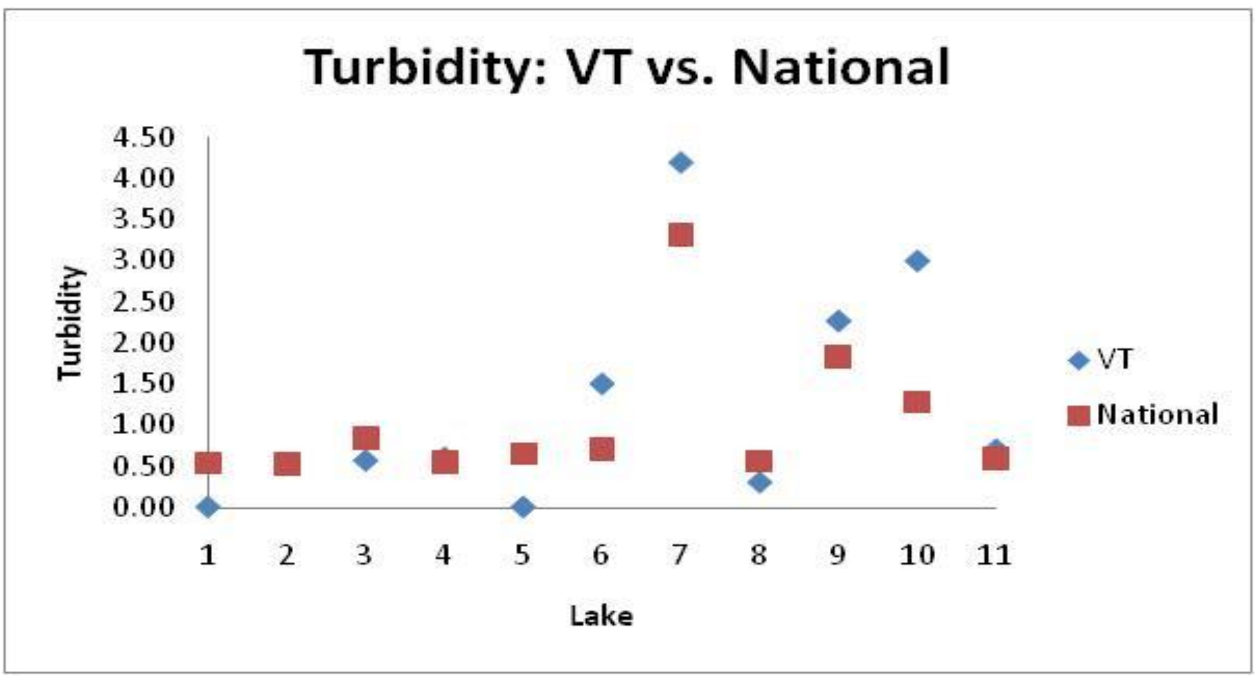


Figure 22. Comparison of the two turbidity methods used on the 11 core lakes. The national method was a laboratory method and the Vermont method used an in-situ Hydrolab sensor.

Mill Pond in Windsor *(VTDEC)*

Dissolved Oxygen

When compared to nationally-consistent thresholds, surface water dissolved oxygen levels are considered good in 100% of Vermont lakes, which is better than both the Nation and Northern Appalachian Ecoregion (Table 8, Figure 23 and Figure 24). Dissolved oxygen readings were taken at the surface (2 m depth) and not in the hypolimnion. It would be very surprising and unexpected if the surface waters in Vermont lakes were depleted of oxygen.

Table 8. NLA dissolved oxygen Good, Fair and Poor thresholds.

NLA Thresholds	Good	Fair	Poor
Dissolved Oxygen mg/L	≥5	<5 - 3	<3

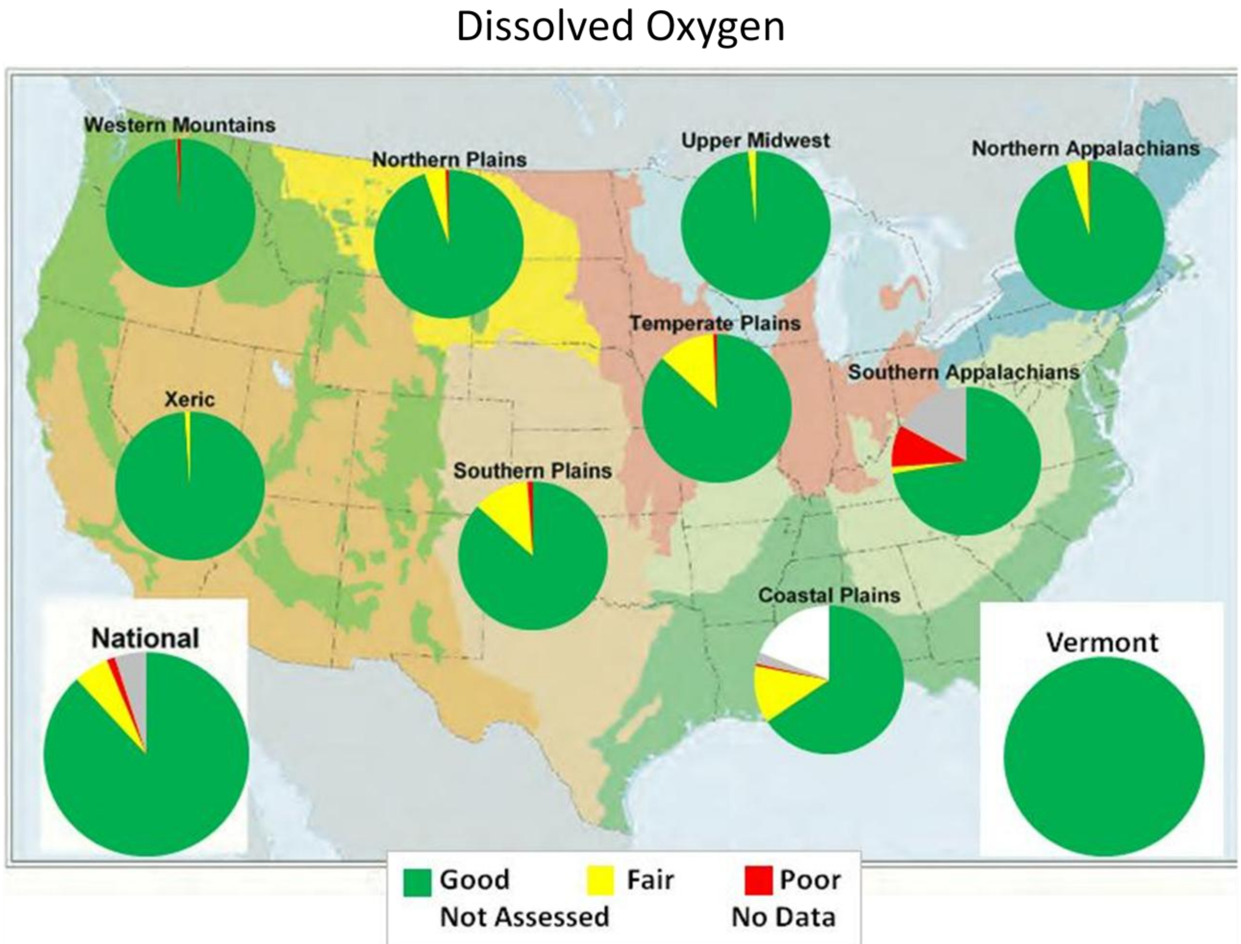


Figure 23. Proportion of lakes in Good, Fair, or Poor condition for Dissolved Oxygen across 9 Ecoregions, the Nation and Vermont.

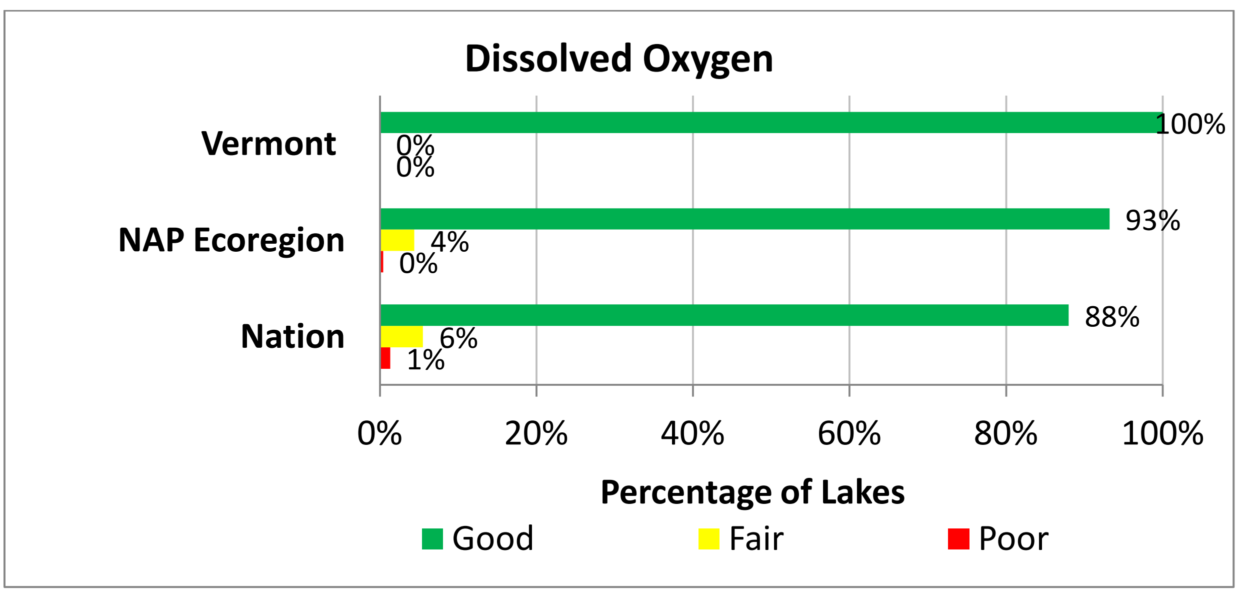


Figure 24. Comparison of lakes in Good, Fair and Poor condition for dissolved oxygen for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes> 10 acres).

Acid Neutralizing Capacity

Alkalinity and dissolved organic carbon (DOC) were used to assess the acid neutralizing capacity of lakes in the NLA, but DOC was not measured on the 40 additional overdraw lakes Vermont sampled. So, for Acid Neutralizing Capacity (ANC), DOC was predicted from color using a regression analysis of data from Northern Appalachian Ecoregion lakes (Figure 25).

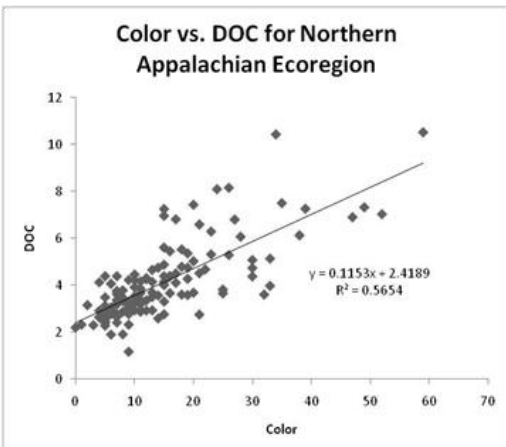


Figure 25. Regression analysis of color vs. DOC for Northern Appalachian Ecoregion lakes.

Using National thresholds for acid neutralizing capacity (Table 9), 100% of Vermont lakes are considered to be in good condition, similar to the results for both the Nation and Northern Appalachian Ecoregion (Figure 26 and Figure 27).

Table 9. NLA acid neutralizing capacity Good, Fair and Poor thresholds.

NLA Thresholds	Good	Fair	Poor
Acid Neutralizing Capacity: 1) Alkalinity mg $CaCO_3$/L 2) DOC mg/L	>2.5 NA	2.5 - >0 ≤5	≤0 <5

Branch Pond, one of Vermont's 39 lakes on the TMDL list of impaired waters due to acidity *(VTDEC)*

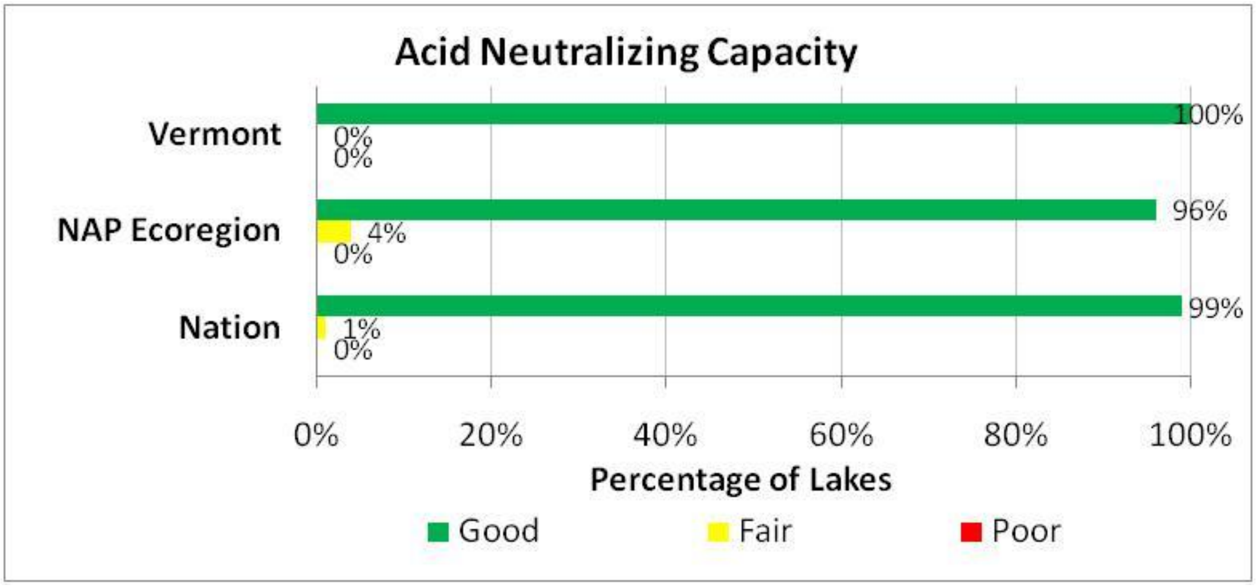


Figure 26. Comparison of lakes in Good, Fair and Poor condition for acid neutralizing capacity for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

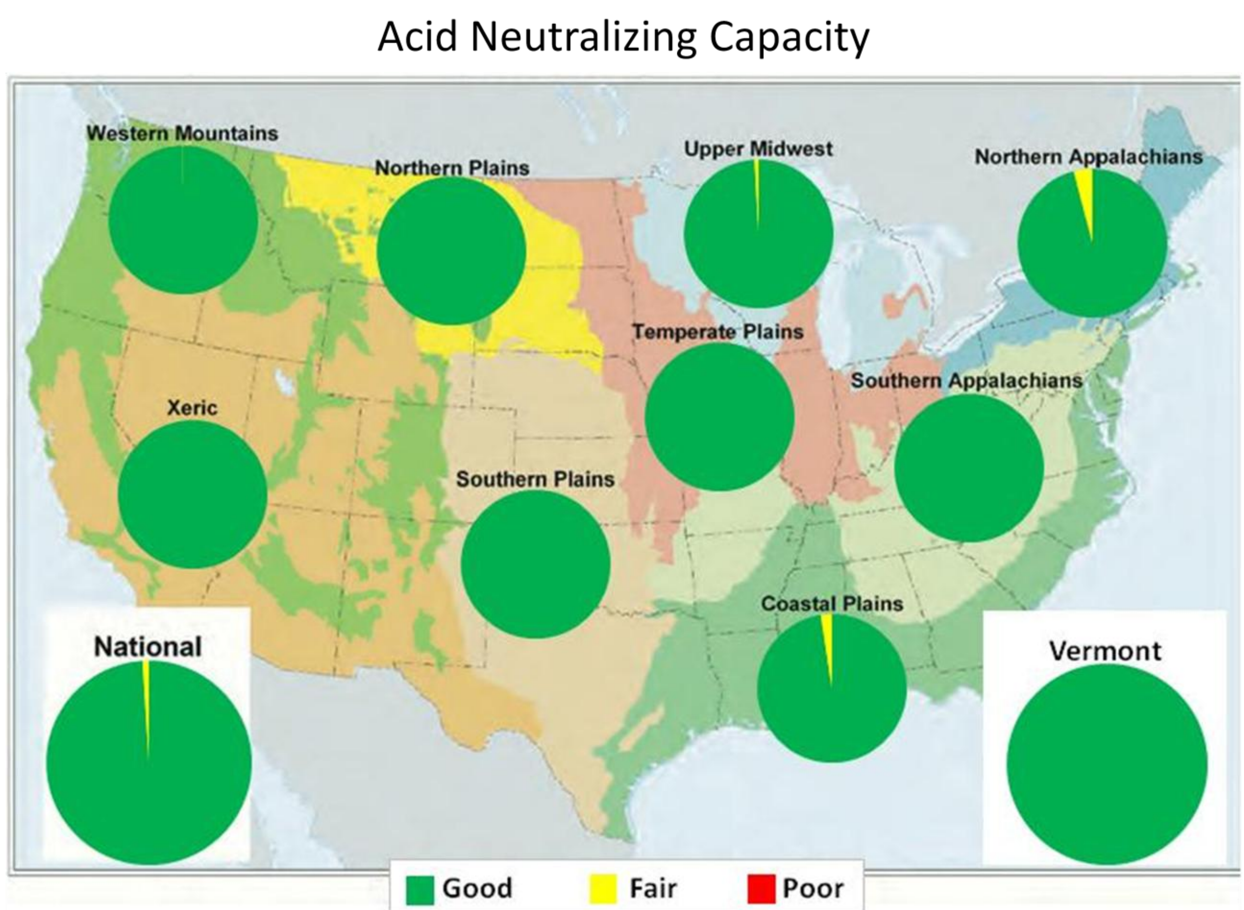


Figure 27. Proportion of lakes in Good, Fair, or Poor condition for Acid Neutralizing Capacity across 9 Ecoregions (lakes >10 acres), the Nation (lakes >10 acres) and Vermont (lakes >25 acres).

Vermont DEC considers the ANC thresholds used by the NLA to be entirely too liberal and hence under representative of the extent of acid precipitation stress to lakes. Vermont has worked cooperatively with the EPA since 1982 to monitor its acid lakes through the Long Term Monitoring Program (LTM). Over this time period, the chemical status has improved, yet biological recovery has not occurred on these lakes. Due to the LTM program, Vermont has documented the presence and status of its acid lakes for over 30 years. Vermont has 39 lakes on the TMDL list of impaired waters due to acidity. This represents 8% of the lakes in Vermont over 10 acres in size (n=460, VTDEC Inventory).

The NLA considered ANC equal to or less than 2.5 mg/L to be either fair or poor condition. Vermont considers anything less than 2.5 mg/L (50 ueq/L) to be poor condition and has set that as the $[ANC]_{limit}$ in order to protect the most sensitive aquatic biota. The $[ANC]_{limit}$ is the lowest ANC concentration that does not damage selected biota (Henriksen & Posch, 2001). NLA thresholds are too low according to aquatic life uses, which require a minimum of 2.5 mg/L $CaCO_3$ to maintain populations of brook trout, an acid tolerant fish. Other studies in North America have chosen ANC values in the range of 40-50 ueq/L (Hindar & Henriksen, 1998) (Dupont, et al., 2002)

Lakes with ANC values between 2.5 and 12.5 are vulnerable to episodic acidification. During spring runoff, pH and alkalinity can drop precipitously. Since this is the time of year when many species are mating, hatching, spawning or molting, aquatic life uses can be stressed at a critical stage in the life cycle. For this reason, an ANC range between 2.5 and 12.5 is used in Vermont to classify lakes as stressed for acid precipitation, which might otherwise be defined as 'fair' condition. The NLA samples are collected in the summer and do not represent the most vulnerable time of the year for acid sensitive lakes, so applying these thresholds to this dataset may have underrepresented the extent of this condition class, but not to the extent the NLA thresholds did.

Lakes with ANC >12.5 are considered buffered not only from long term acid rain effects but also from episodic acidification (Jim Kellogg, VTDEC, personal communication). Hence, Vermont considers this to be a more defensible 'good' threshold for Vermont. Other states in the region, New Hampshire and Massachusetts, set even higher ANC thresholds than Vermont. Hence, the NAP Ecoregion threshold in the 2012 NLA analysis may need to be set even higher than the values used by Vermont.

When applying Vermont thresholds that use only alkalinity (Table 10) and not DOC, the state has a much lower percentage of lakes in good condition (78%) and a relatively high percentage of lakes in poor condition (8%). This is an example of where the thresholds used at the ecoregion and national levels are too low and the Vermont thresholds are more appropriate (Table 10 and Figure 28). It is Vermont DEC's opinion that the Vermont thresholds better represent the condition of the lakes. It is unfortunate that similar thresholds were not applied for the ecoregion and nation. If they had been, this stressor would highlight the fact that while the 1990s amendments to the Clean Air Act have resulted in improvements in lake chemistry, the reductions in emissions have not yet achieved biological recovery in our lakes. Further reductions in Sulfur and Oxides of Nitrogen are still needed.

Table 10. Vermont thresholds for acid neutralizing capacity.

Parameter	Measure	Source	Good	Fair	Poor
Acidification	Lowest RegAlk or GranAlk (mg CaCO3/L)	VT Standard	>12.5	2.5-12.5	<2.5

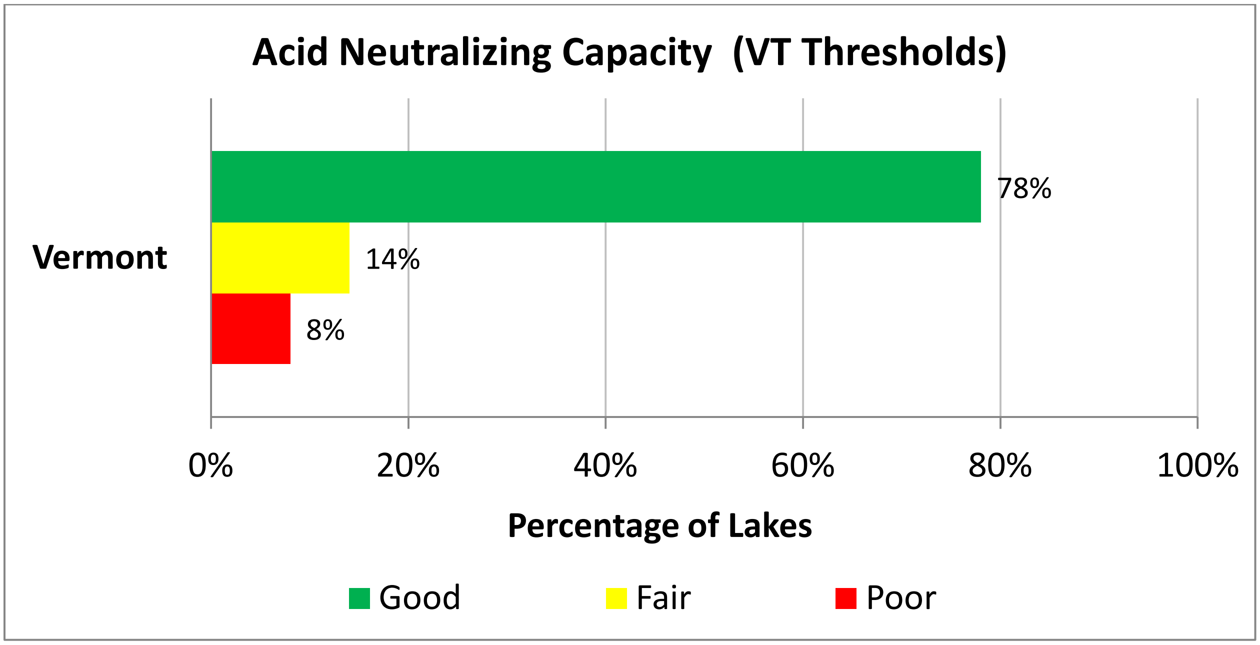


Figure 28. Comparison of lakes in Good, Fair and Poor condition for acid neutralizing capacity for Vermont (lakes >25 acres), using Vermont thresholds.

Little Rock Pond, one of Vermont's lakes moderately sensitive to acidification *(VTDEC)*

Physical Stressors

Lakeshore Disturbance

Lakeshore disturbance is a measure of the presence of human activity on the lakeshore and in the nearshore area. It can be thought of as how intensively we use our lakeshores and the likelihood that evidence of human activities will be visibly present on or near the lakeshore. Lakeshore disturbance levels in Vermont are considered fair or poor in more than 80% of lakes, notably worse than both the Nation and Northern Appalachian Ecoregion (Figure 29 and Figure 30). Only 18% of lakes are in good condition for lakeshore disturbance. For all the other stressors reported in this survey, Vermont's majority of lakes were in the good category (66-100%). This is the only stressor where only a small percentage of lakes rated good. Using thresholds published in a 2002 issue of Bioscience, more lakes score poor in Vermont than in the Nation or Ecoregion(Figure 31).

Figure 32 shows the twelve types of disturbance that are used in the lakeshore disturbance metric calculation. The high frequency of buildings, docks, trash, lawns, roads and seawalls present along Vermont lakeshores accounts for the vast majority of Vermont lakes falling into the fair and poor condition classes for lakeshore disturbance.

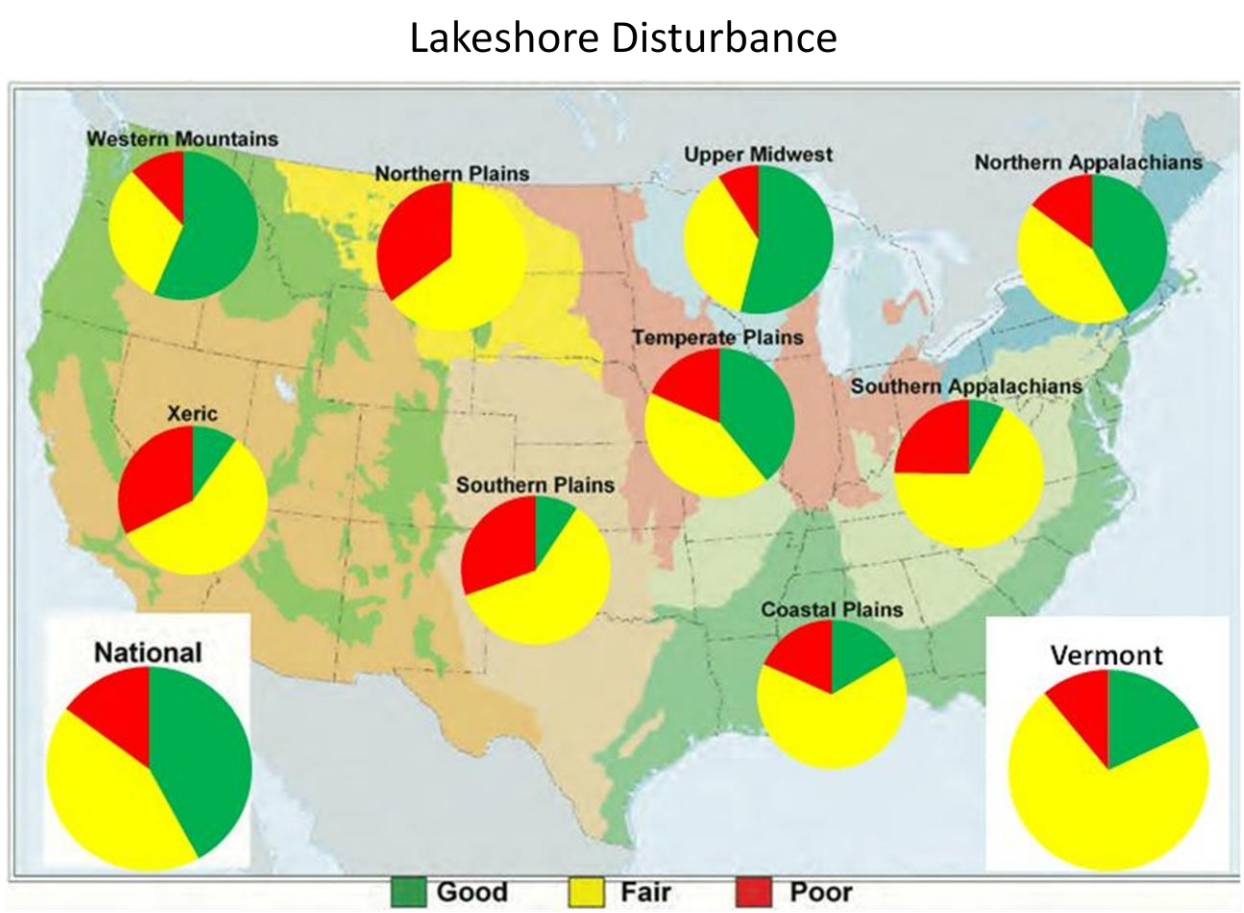


Figure 29. Proportion of lakes in Good, Fair, or Poor condition for Lakeshore Disturbance across 9 Ecoregions, the Nation and Vermont.

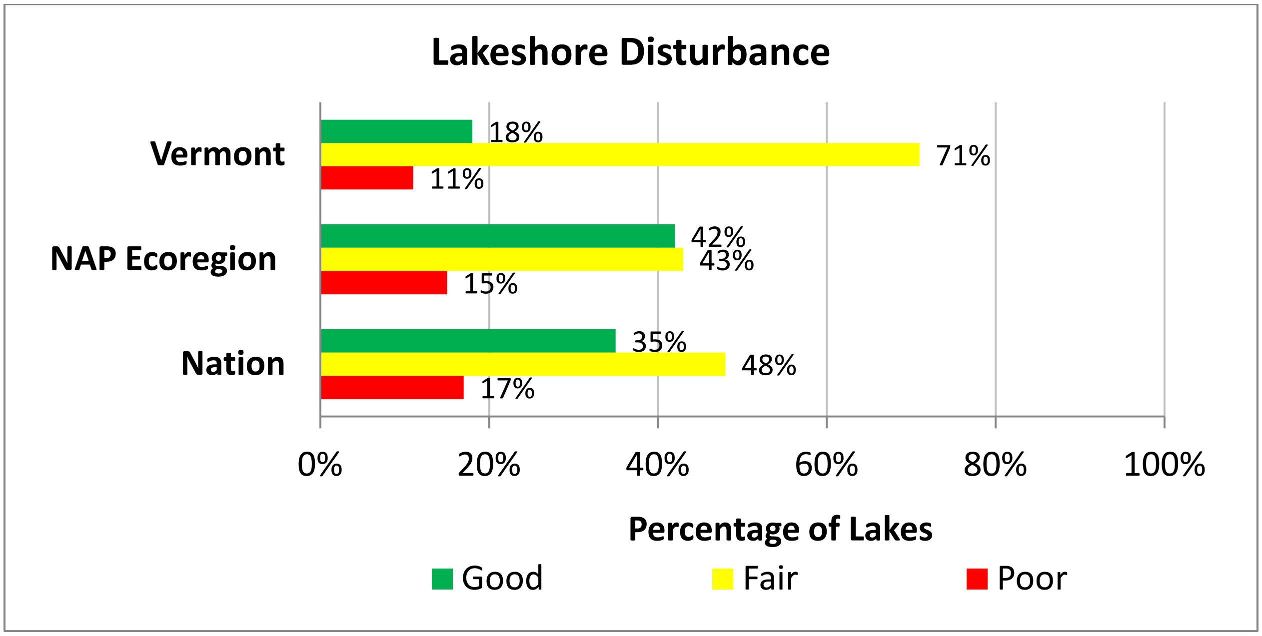


Figure 30. Comparison of lakes in Good, Fair and Poor condition for lakeshore disturbance for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

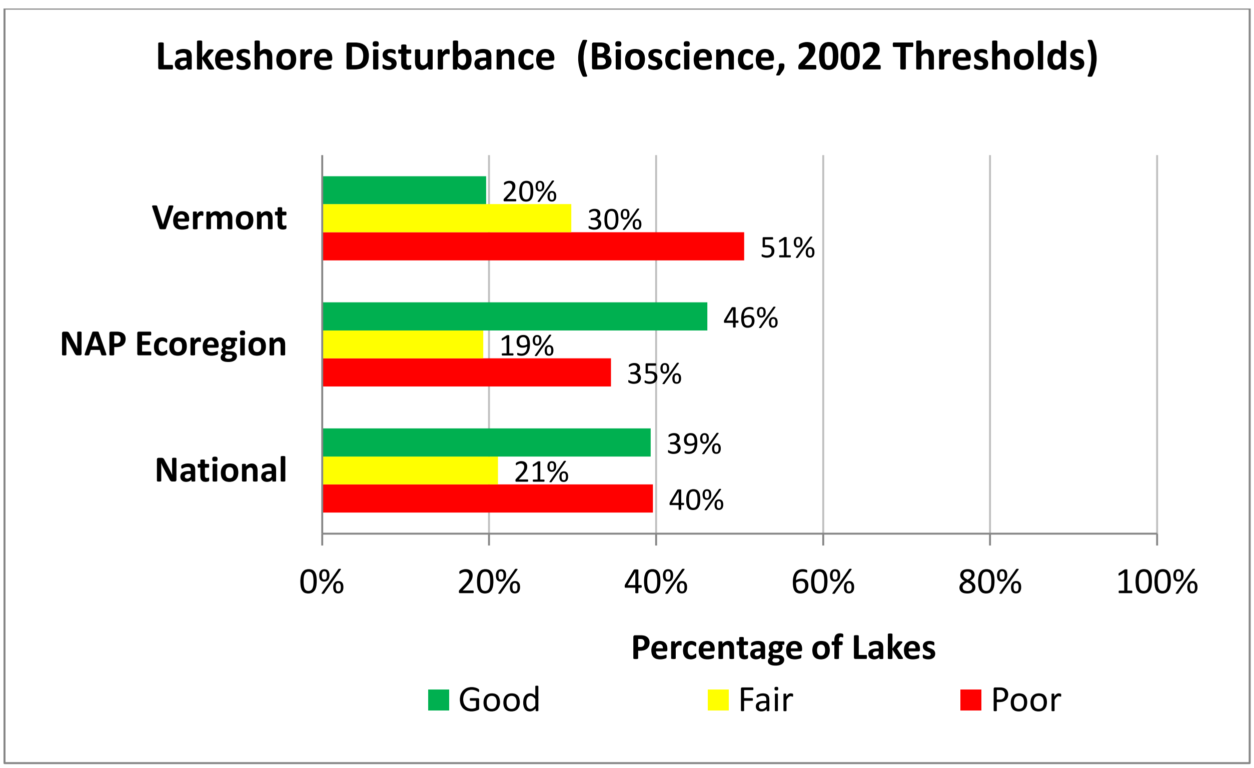


Figure 31. Comparison of lakes in Good, Fair and Poor condition for lakeshore disturbance for Vermont (lakes >25 acres), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres) using thresholds from (Whittier, Paulsen, Larson, Peterson, Herlihy, & Kaufmann, 2002)

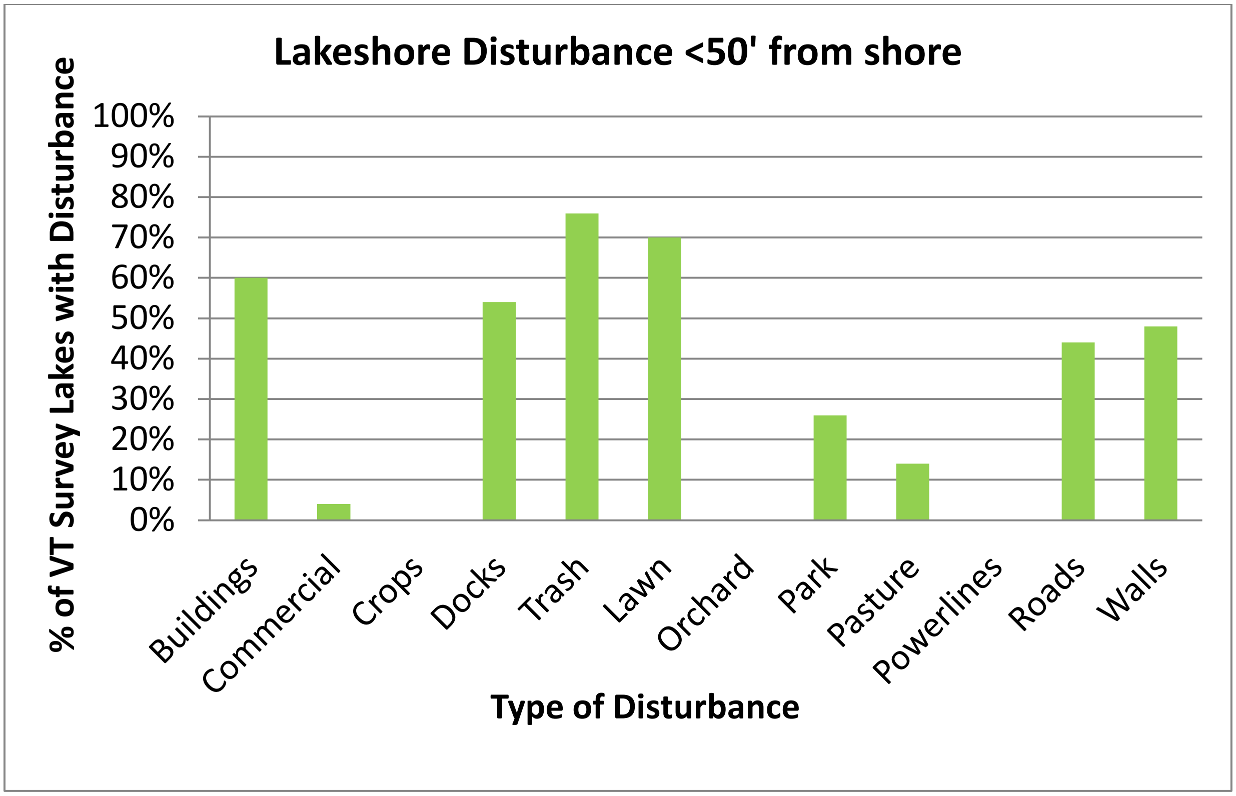


Figure 32. The percentage of Vermont lakes with each of the twelve types of disturbance used in the lakeshore disturbance metric calculation

Aerial view of example of lakeshore disturbance within 100' of a lakeshore on Lake Bomoseen (Google Earth)

Lakeshore Habitat

The lakeshore habitat indicator is a measure of the amount and type of shoreline vegetation, based on observations of three layers of riparian coverage (ground cover, understory, and canopy). This was the most widespread stressor to the nation's lakes (USEPA, 2010). 70% of Vermont lakes are considered to be in good condition for lakeshore habitat, which is markedly better than the Nation but only slightly better than the Northern Appalachian Ecoregion (Figure 33 and Figure 34).

Lakeshore habitat and lakeshore disturbance are related in Vermont. The more buildings, lawns, seawalls and roads along Vermont lakeshores, the less natural vegetation as measured by lakeshore habitat is found (Figure 35). Figure 35 suggests that the good threshold for lakeshore habitat may be set too low and EPA plans to take this into account when analyzing the data from the 2012 NLA. Recent studies in Vermont have found that as natural vegetation, especially trees, are removed from lakeshores, aquatic habitat is degraded (Merrell, Howe, & Warren, 2009).

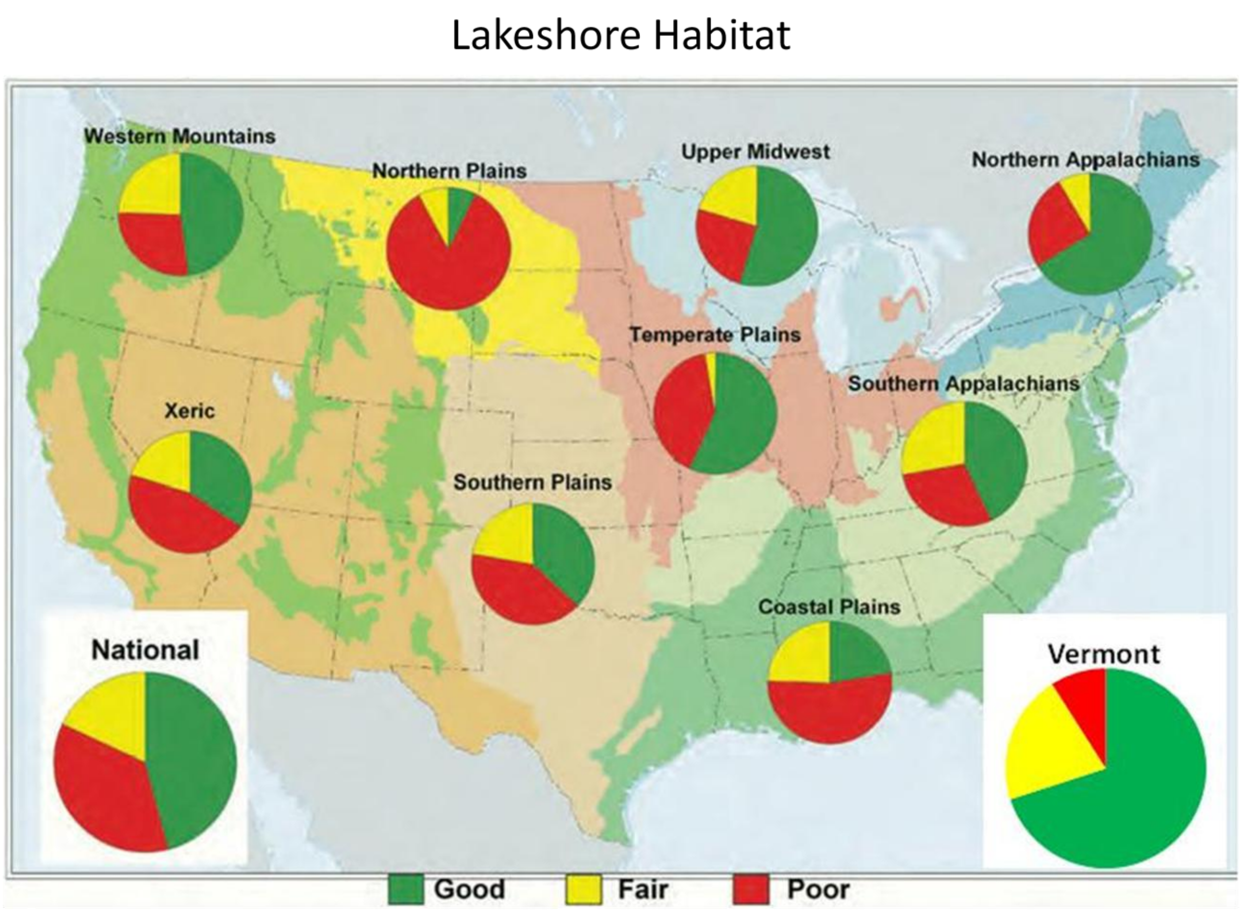


Figure 33. Proportion of lakes in Good, Fair, or Poor condition for Lakeshore Habitat across 9 Ecoregions, the Nation and Vermont.

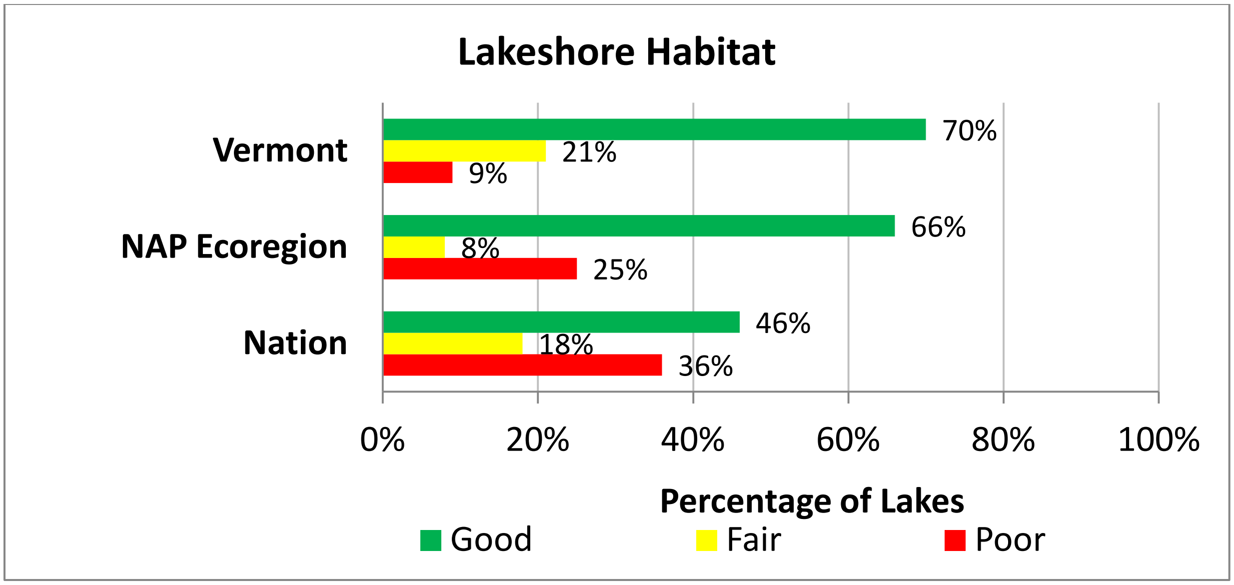


Figure 34. Comparison of lakes in Good, Fair and Poor condition for lakeshore habitat for Vermont (lakes >25 acres, excluding Lake Champlain), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

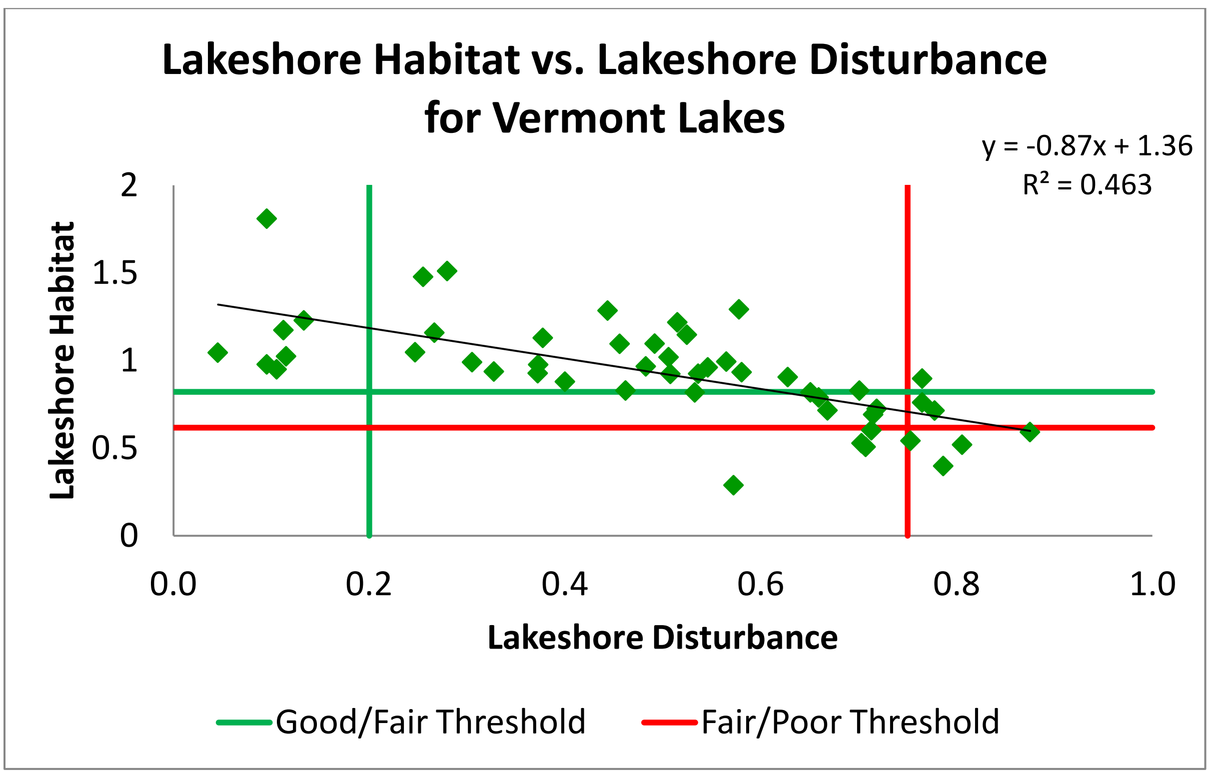


Figure 35. Comparison of Lakeshore Disturbance and Lakeshore Habitat for Vermont Lakes.

Shallow Water Habitat

The shallow water habitat indicator is a measure of the quality of the shallow edge of the lake, based on field visual estimates of the areal coverage of various types of littoral cover features. Two-thirds of Vermont lakes are considered to be in good condition for shallow water habitat, which is only slightly better than the Nation but markedly better than the Northern Appalachian Ecoregion (Figure 36 and Figure 36).

Shallow water habitat is made up of snags/coarse woody structure, emergent vegetation, floating leaved vegetation, and boulders. Lakeshore residents tend to remove most of these habitat features with the exception of boulders. Vermont scored as well as it did in shallow water habitat in part because boulders were commonly observed. Typically, no matter how much lakeshore disturbance was present, boulders were commonly found in the shallows (Figure 38).

The difference between Vermont and the NAP Ecoregion could be due to the marked difference in lake origins. The NAP has many more man-made lakes than Vermont (Figure 8) and many of those have large water level fluctuations, which degrade shallow water habitat. The 2012 NLA quantified the water level fluctuations but the 2007 NLA did not.

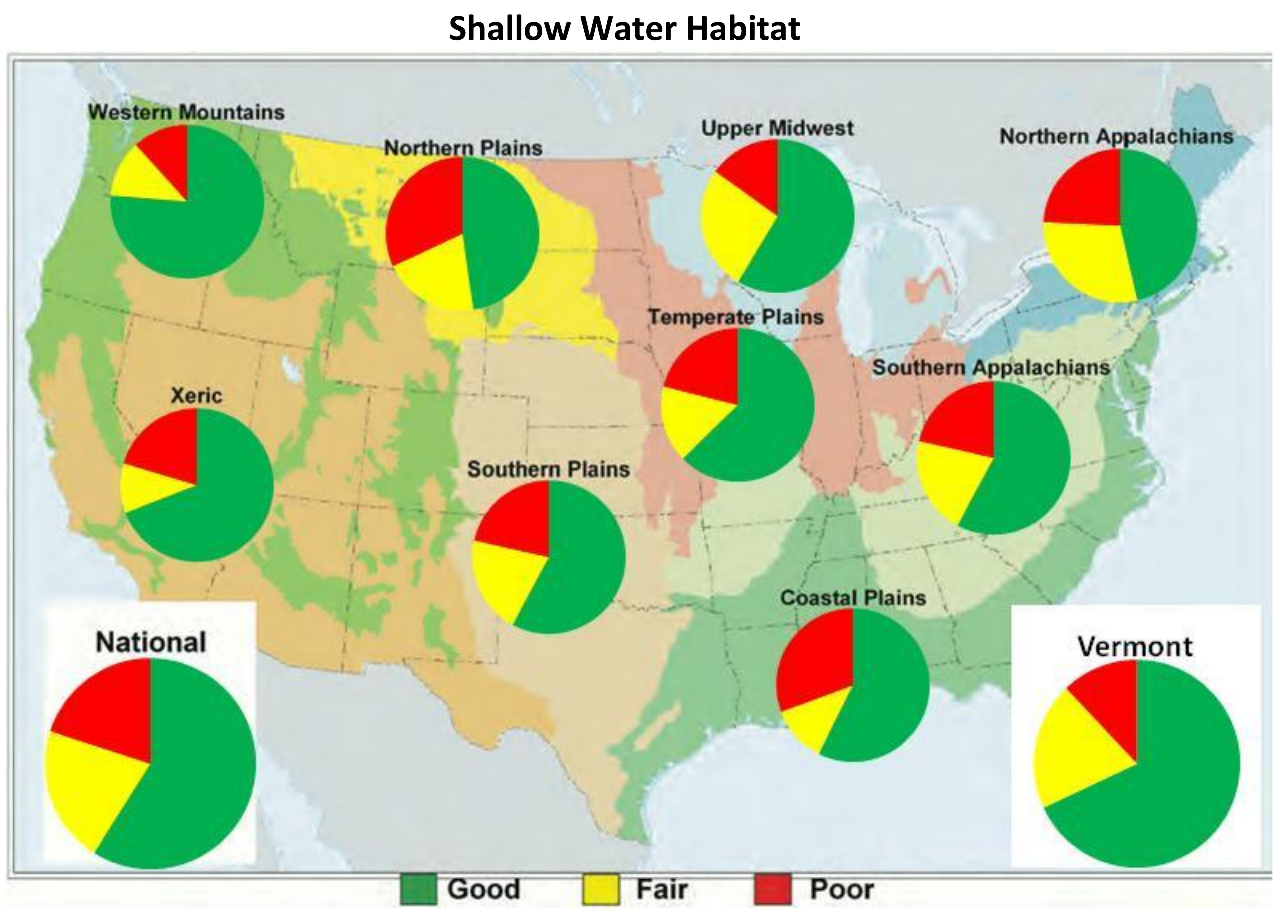


Figure 36. Proportion of lakes in Good, Fair, or Poor condition for Shallow Water Habitat across 9 Ecoregions, the Nation and Vermont.

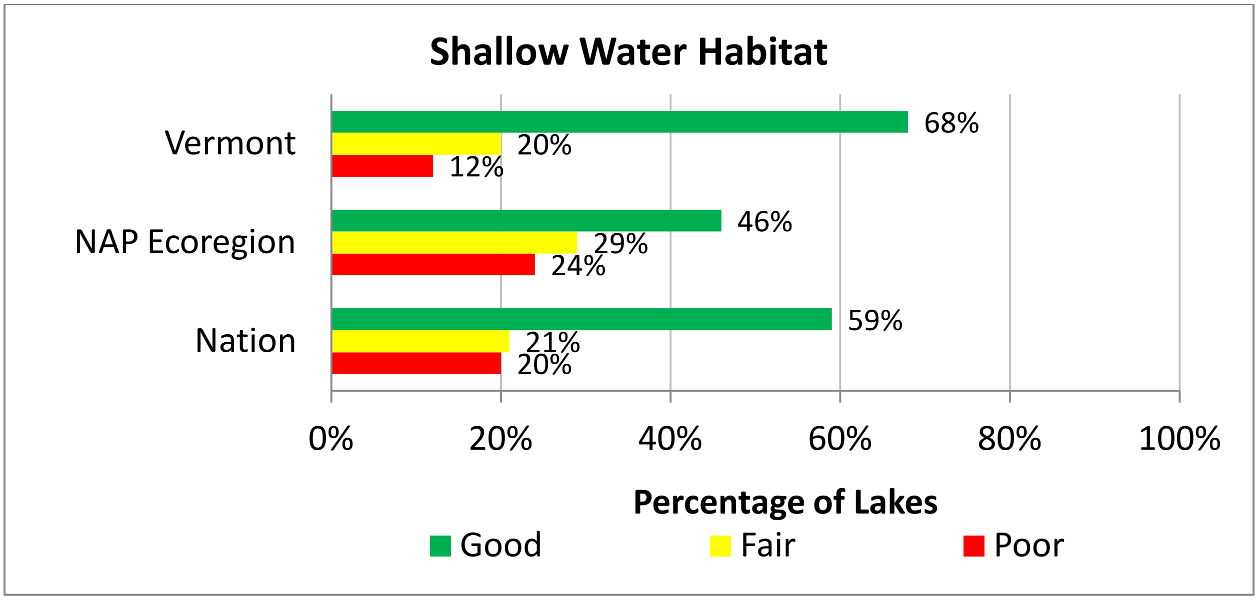


Figure 37. Comparison of lakes in Good, Fair and Poor condition for shallow water habitat for Vermont (lakes >25 acres, excluding Lake Champlain), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

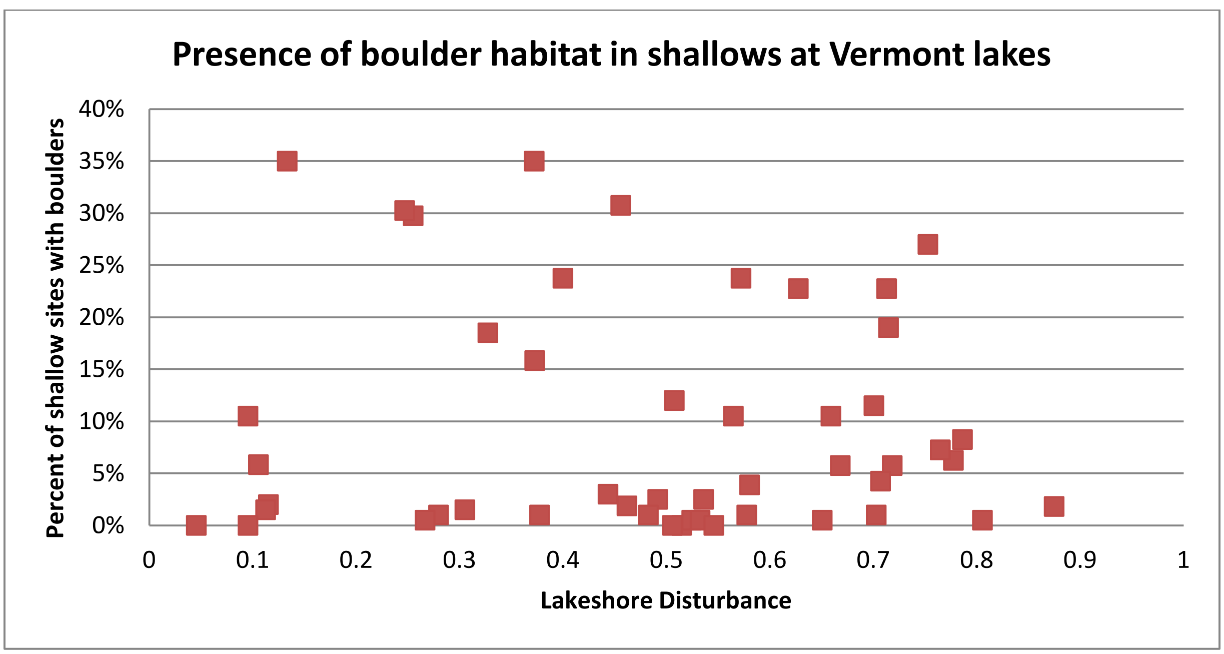
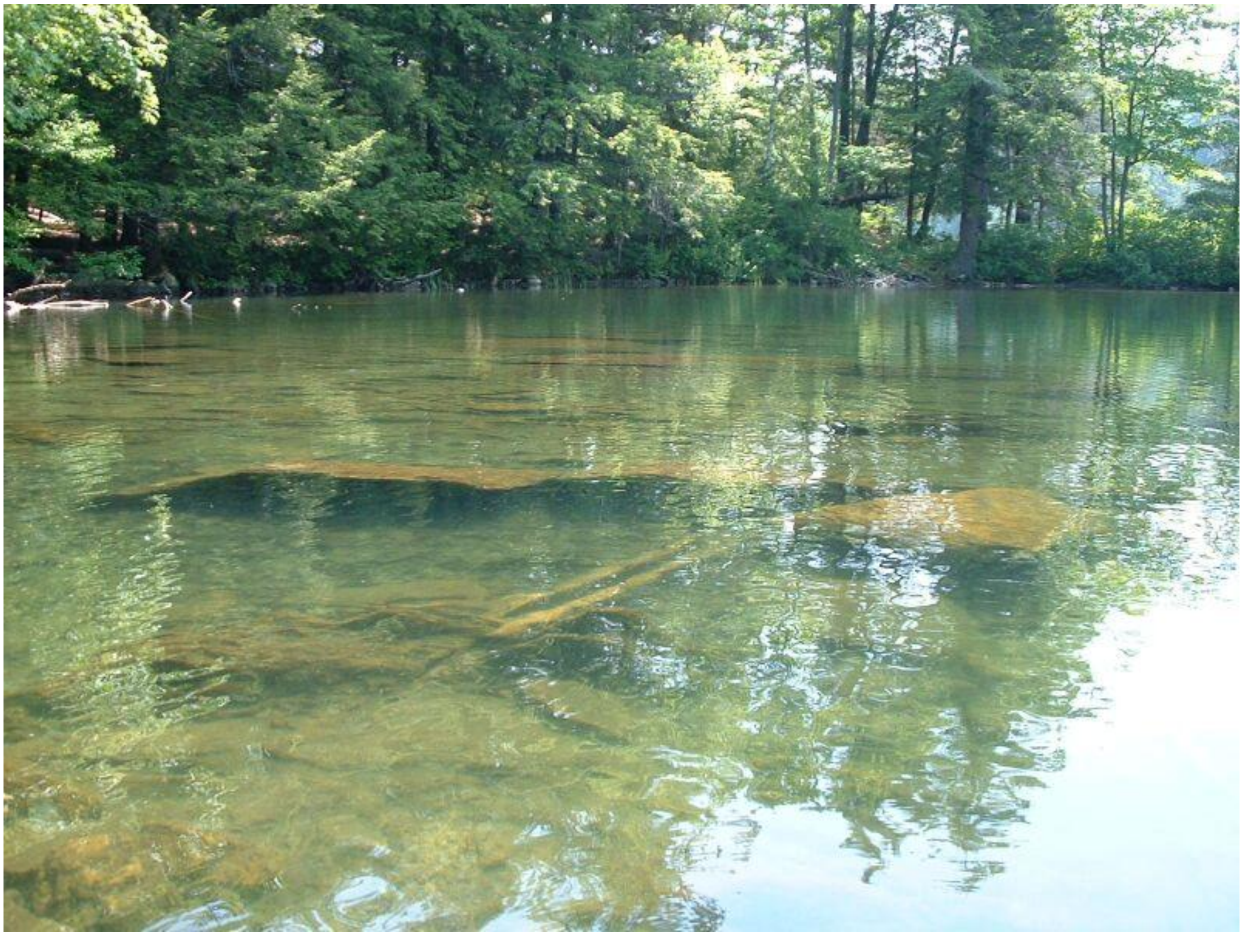


Figure 38. Frequency of occurrence of boulders as part of the shallow water habitat features in Vermont lakes



Spring Lake in Shrewsbury *(VTDEC)*

Physical Habitat Complexity

Physical habitat complexity combines data from the lakeshore and shallow water interface to estimate the amount and variety of all cover types at the water's edge. Results for physical habitat complexity, which is simply the arithmetic mean of the values for lakeshore and shallow water habitat, indicate that 74% of Vermont lakes are in good condition, considerably better than both the Nation and Northern Appalachian Ecoregion (Figure 39 and Figure 40). Yet of all the stressors measured, poor physical habitat complexity is the most widespread stressor to Vermont lakes.

Sixteen percent of Vermont's lakes are in poor condition for physical habitat complexity, which constitutes the largest percentage of lakes in poor condition for any of the stressors measured in this survey. Just because Vermont is doing better than the nation or ecoregion does not mean the degradation of physical habitat complexity is not a serious problem for Vermont lakes. It does mean there is a better opportunity with effective lakeshore stewardship to prevent further degradation of the terrestrial aquatic interface in Vermont than there is at the national or ecoregional scales.

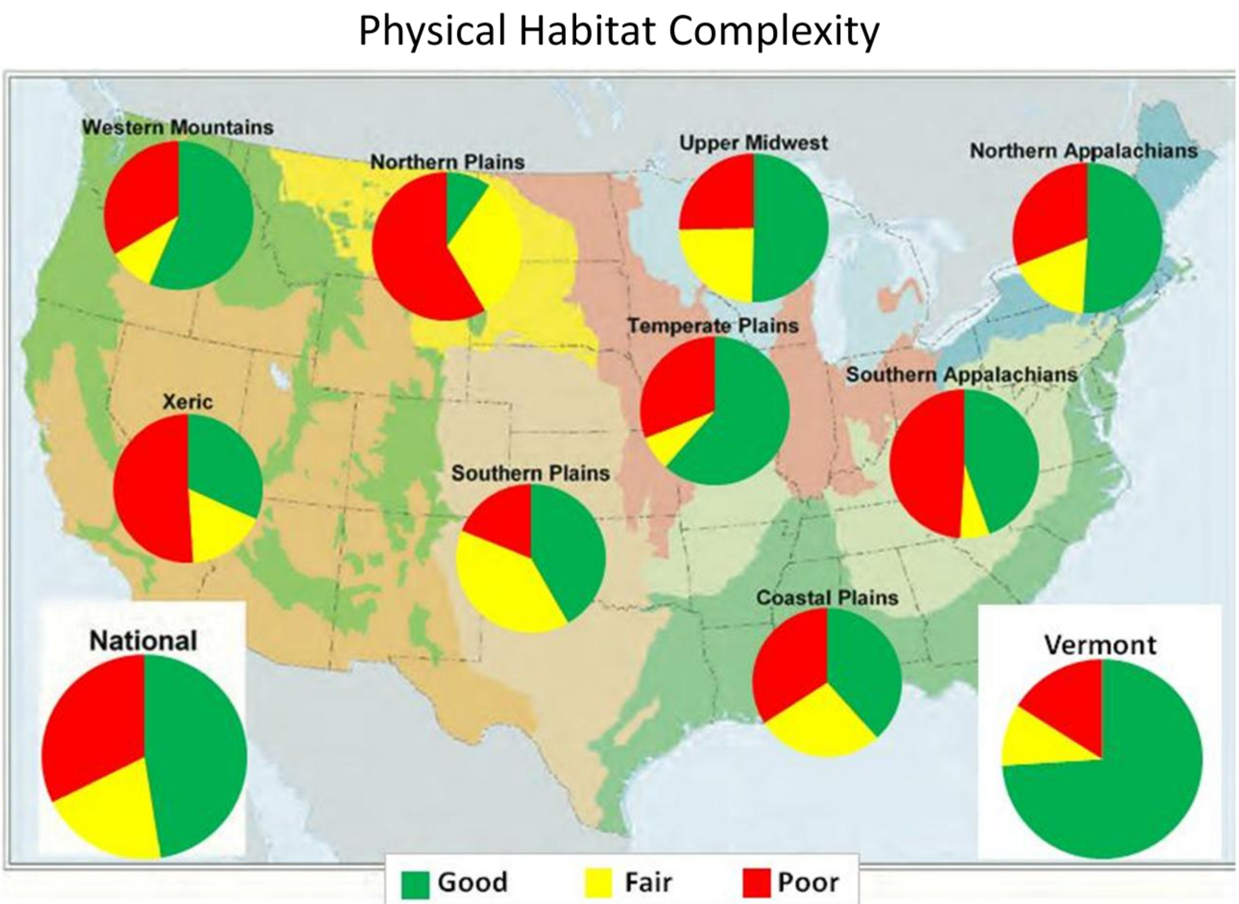


Figure 39. Proportion of lakes in Good, Fair, or Poor condition for Physical Habitat Complexity across 9 Ecoregions, the Nation and Vermont.

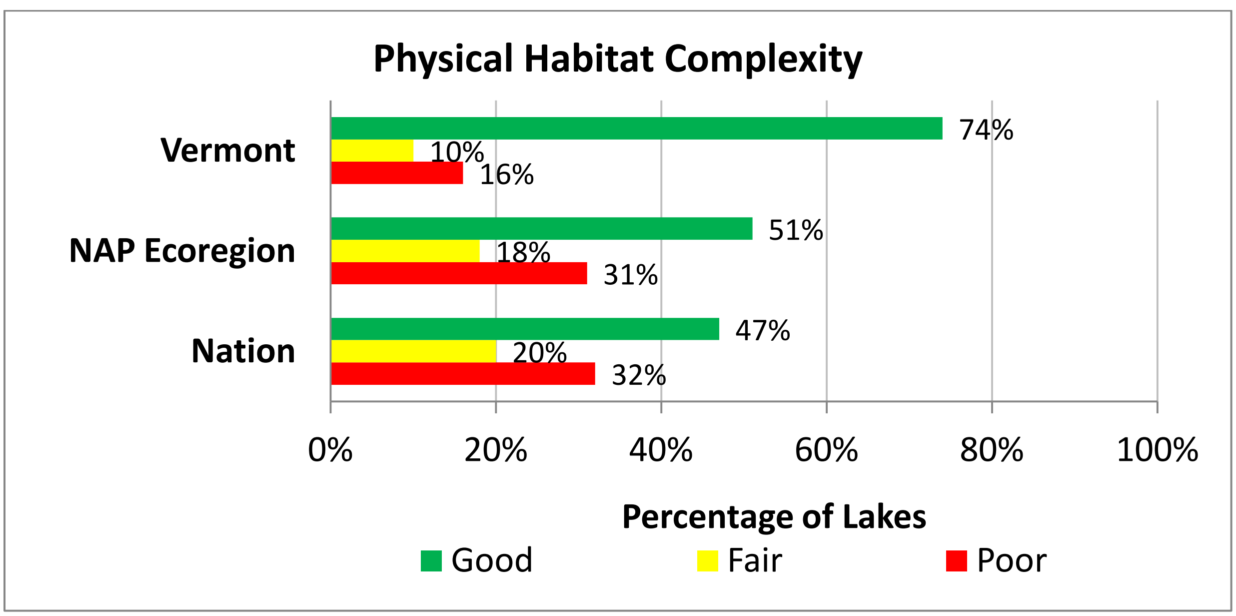


Figure 40. Comparison of lakes in Good, Fair and Poor condition for physical habitat complexity for Vermont (lakes >25 acres, excluding Lake Champlain), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

Macroinvertebrate IBI

Macroinvertebrates were collected at all the physical habitat stations on the Vermont lakes and composited for each lake. The EPA macroinvertebrate index of biological integrity found that Vermont lakes have a greater proportion of lakes in poor condition than five of the nine Ecoregions; the Northern Appalachian, Southern Appalachian, Upper Midwest (even if all the not assessed lakes were rated poor), Southern Plains and Western Mountains (Figure 41).

Just over half, 54%, of the lakes in the NAP ecoregion have macroinvertebrate IBIs in the good range, with the remaining lakes split between fair condition and poor condition (Figure 42). Vermont has the same proportion of lakes with fair macroinvertebrate IBIs as the NAP ecoregion, but 14% more in poor condition.

Macroinvertebrate Index of Biological Integrity

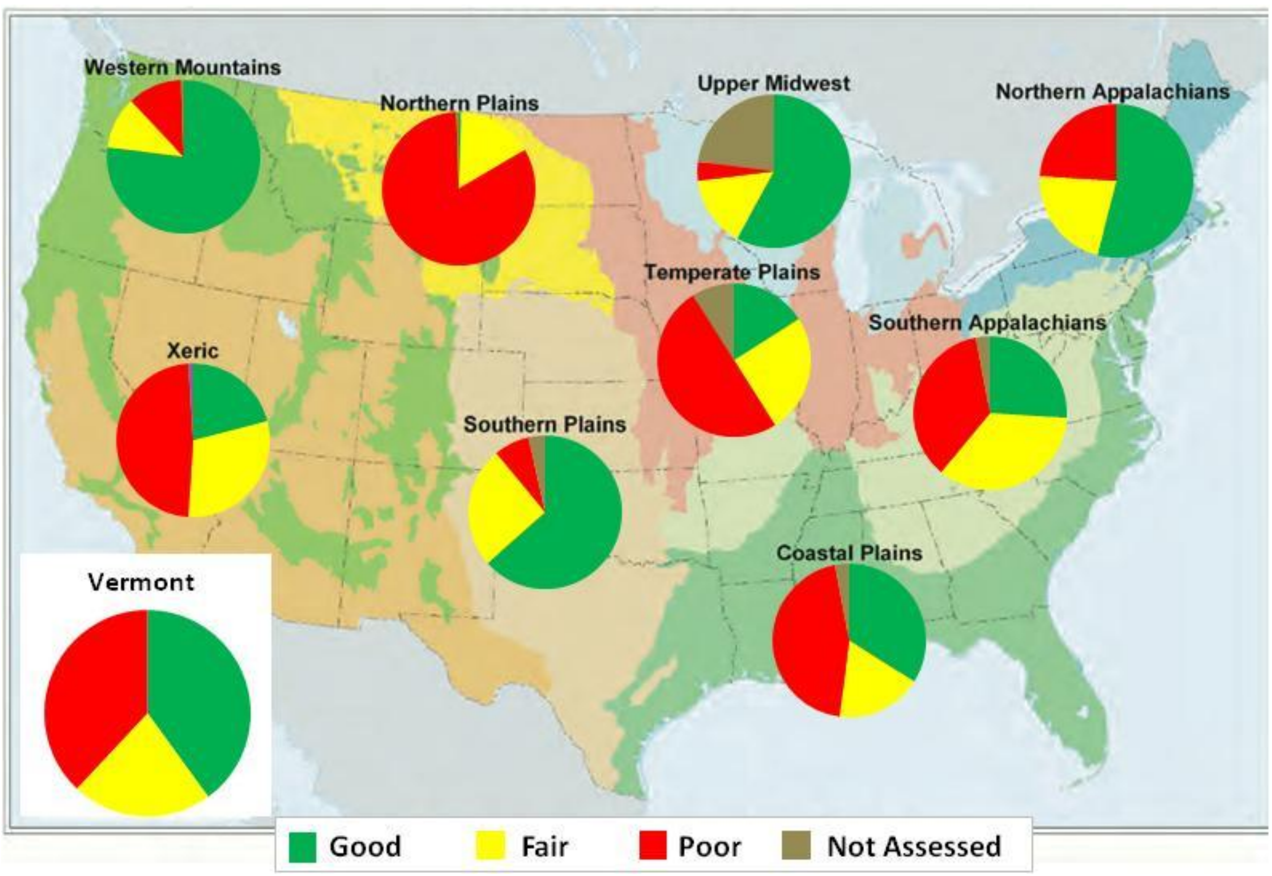


Figure 41. Proportion of lakes in Good, Fair, or Poor condition for Biological Integrity as measured by the Macroinvertebrate Index across 9 Ecoregions and Vermont.

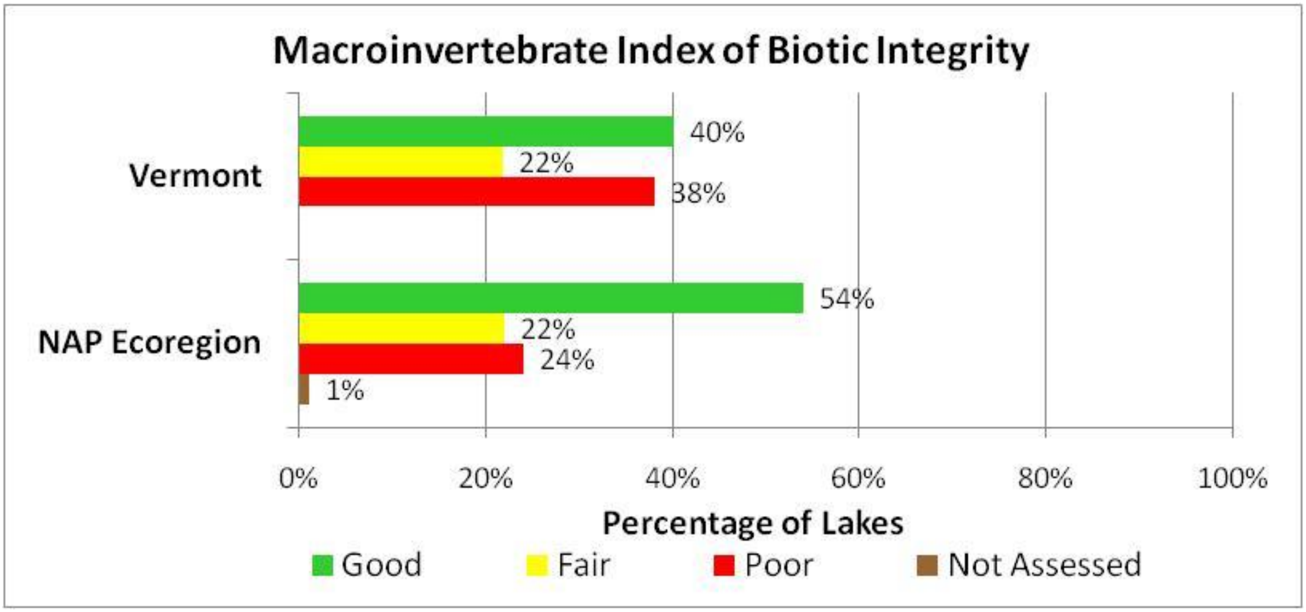


Figure 42. Comparison of lakes in Good, Fair and Poor condition for biotic integrity as measured by macroinvertebrates in Vermont (lakes >25 acres, excluding Lake Champlain), the Northern Appalachian (NAP) Ecoregion (lakes >10 acres) and the Nation (lakes >10 acres).

Sampling for Macroinvertebrates *(VTDEC)*

Aquatic Invasive Species

One important stressor to lakes that was measured but not evaluated as part of the 2007 National Lakes Assessment was the extent of Aquatic Invasive Species (AIS). Because there are so many different species of AIS it is difficult to rank this stressor against the others measured as part of the NLA. One could lump all the AIS together or deal with each species individually. Yet, what is native in one ecoregion or subecoregion, may be a non-native invasive in another. Hence, it is easy to understand why this stressor was not evaluated as part of the National Lakes Assessment.

Because AIS is viewed and managed as a major stressor to Vermont lakes, the Vermont Agency of Natural Resources tracks the distribution of AIS. Five of the major AIS of concern in the state are Eurasian watermilfoil, water chestnut, curly-leaf pondweed, zebra mussels and alewife. While these species were not surveyed during the 2007 and 2008 field visits, it is possible to use existing Vermont ANR data to make inferences about what proportion of Vermont lakes are stressed by one or more of these five AIS. Using the list of NLA lakes >25 acres and ANR's records as to whether one or more of each of the five AIS exist on those lakes, it was possible to apply the NLA weightings. Figure 43 shows that 65% of Vermont lakes are free of all five AIS, while 35% of them have one or more of the five AIS present.

While the 35% gives us an idea of how widespread the presence of these five AIS are across Vermont lakes greater than 25 acres, unfortunately it doesn't tell us how many of those lakes are not stressed by the presence of the AIS (for example, lakes where Eurasian milfoil is present but currently considered controlled due to management) and could be ranked as still in good condition along with the 65% of lakes that have none of the five AIS. It also doesn't tell us what proportion of Vermont lakes are in fair or poor condition due to the invasions of these species. Since we estimate that 65% of Vermont lakes are free of Eurasian watermilfoil, water chestnut, curly-leaf pondweed, zebra mussels and alewife (Figure 43), we can say that at least 65% of Vermont lakes would be considered in good condition for AIS.

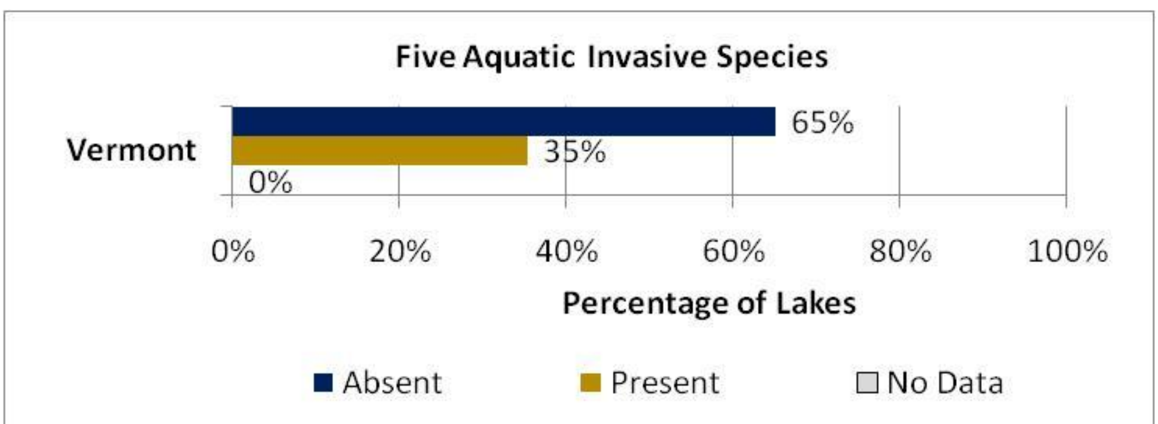


Figure 43. Comparison of lakes with none, or one or more of the five major Aquatic Invasive Species: Eurasian watermilfoil, water chestnut, curly-leaf pondweed, zebra mussel and alewife present for Vermont (lakes >25 acres), using existing 2008 ANR data. Note: This figure does not include data collected during the NLA sampling effort.

Relative Extent of Stressors and Interpretation of Results

Figure 44 shows how widespread the eight main stressors included in the NLA are in the Nation, the Northern Appalachian Ecoregion and Vermont. In each of the graphs, Vermont is designated by the darkest hue, the NAP Ecoregion by the hue used throughout the report and the Nation by the lightest hue. In comparison to the Nation and NAP Ecoregion, Vermont does not have as high a proportion of lakes in the poor category for most of the stressors. Turbidity is the exception, but as mentioned earlier that may be an artifact of the different methods used to measure turbidity in the state and national surveys and will be evaluated in the 2012 survey.

In Vermont, the largest proportion of lakes in poor condition are so for physical habitat complexity (Figure 45). Poor physical habitat complexity affects more than twice the percentage of Vermont lakes that are affected by high levels of phosphorus. Physical habitat complexity is a measure of the condition of the lakeshore and shallow water habitat combined. Natural shorelines are complex, they are made up of wetlands and diverse structured vegetation including vertically stratified layers of groundcover, understory and canopy plant, shrub and tree species. Natural shallow water habitats are complex as well, they are made up of woody snags, emergent, submersed and floating leaved plants, boulders and diverse sediment types. These structurally complex shallow and nearshore environments provide habitat and niches for a wide diversity of both terrestrial and aquatic organisms. Humans tend to simplify this complexity by converting the diverse lakeshore structure to a monoculture of lawn and impervious surfaces. They ‘clean’ up the shallow water environment by removing woody snags and aquatic plants. Often the sediment itself is changed by the importation of sand. All of these activities simplify the physical habitat and result in poor conditions. As the

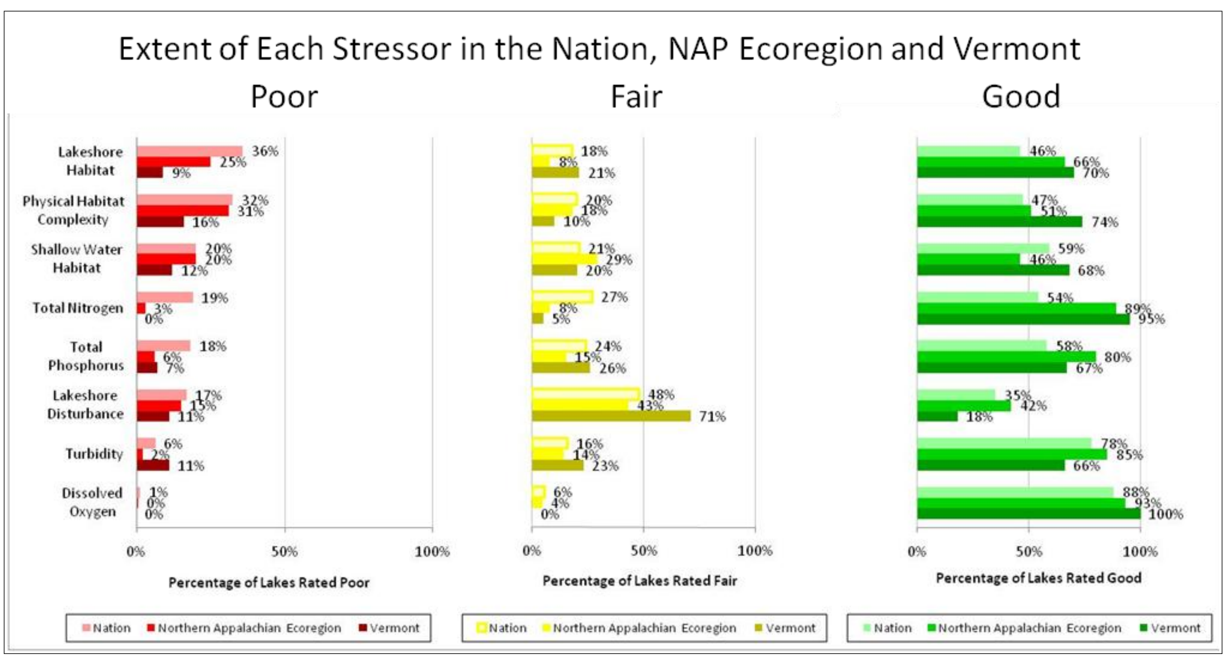


Figure 44. Summary graphs of the percentage of lakes in the Nation, Ecoregion, and Vermont in Poor, Fair or Good condition for each stressor.

VERMONT DEPARTMENT OF ENVIRONMENTAL CONSERVATION

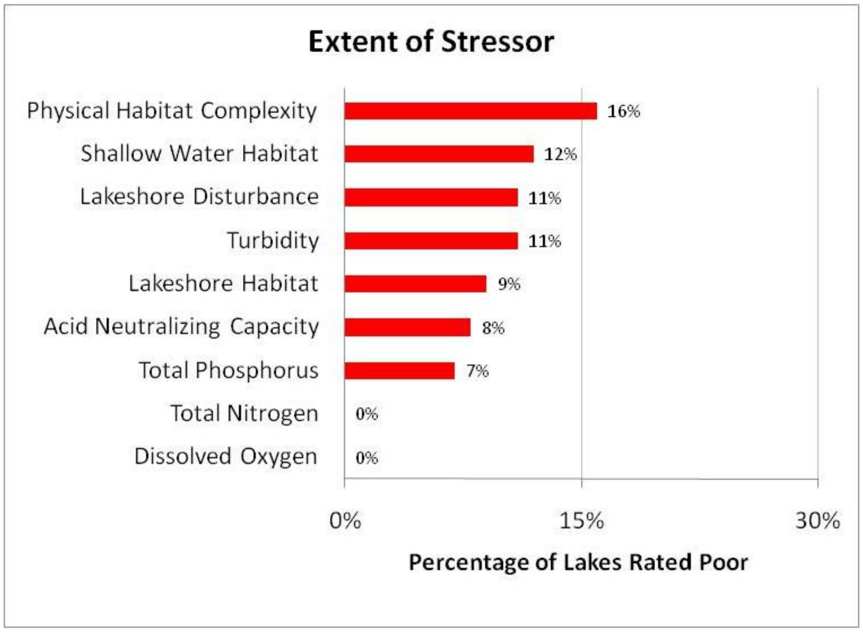


Figure 45. Summary graph comparing the percentage of lakes in Vermont rated poor for each stressor

stressor with the greatest proportion of lakes in poor condition, it is important that Vermont seek ways to protect the existing fair and good physical habitat complexity that exists on the majority of its lakes. To do so will mean changing the way humans simplify this environment. It will mean educating lakeshore residents on the importance of complexity on both the land and in the shallow water and implementing better management practices so that the use of Vermont lakeshores does not result in the degradation of them.

Of particular note in Figure 44 is the preponderance of Vermont lakes in good condition regardless of the stressor type. One hundred percent of Vermont lakes are in good condition for dissolved oxygen in the surface waters. Ninety-five percent of Vermont lakes are in good condition for nitrogen concentrations. Seventy four percent have good physical habitat complexity and sixty-eight percent have good shallow water habitat. Even sixty-seven percent are in good condition for phosphorus concentrations and sixty-six percent are in good condition for turbidity. These are very encouraging findings. It means that Vermont lakes are typically healthy waterbodies. It also means, protecting and maintaining Vermont's high quality waters should be a priority for lake management efforts in the state. For most stressors measured, Vermont lakes are in better condition than the nation.

Lakeshore disturbance is the exception (Figure 48). With only 18% of lakes in good condition, Vermont is lagging behind both the region and the nation. The vast majority of lakes (71%) in the state are in Fair condition. No other stressor puts as great a proportion of lakes in the nation, state or Ecoregion in either the Poor or Fair condition categories. This is a red flag, especially given how well Vermont compared in most other stressor categories. Lakeshore disturbance "reflects direct human alteration of the lakeshore itself. These disturbances can range from minor changes (such as the removal of trees to develop a picnic area) to major alterations (such as the construction of a large lakeshore residential complex complete with concrete retaining walls and artificial beaches). The effects of lakeshore development on the quality of lakes include excess sedimentation, loss of native plant growth, alteration of native plant communities, loss of habitat structure, and modifications to substrate types. These impacts, in turn, can negatively affect fish, wildlife, and other aquatic communities" (USEPA, 2010). In Vermont, lakeshore disturbance was characterized by sea walls, lawns and the placement of buildings and roads within 100' of the lakeshore (Figure 32). Act 250 guidelines set buildings, roads and driveways back 100' and recommend the retention of natural vegetation. However, few lakeshore development projects trigger Act 250. If we focus solely on Vermont's data and not how it compares to the region and nation, but how each of the stressors to Vermont's lakes compare to each other, again lakeshore disturbance stands out (Figure 46). Over 80% of Vermont's lakes are stressed to the fair or poor level by lakeshore disturbance. This stressor affects more than twice the number of lakes as the next most widespread stressor (Turbidity).

The extent of Aquatic Invasive Species (AIS) as a stressor was not evaluated by the NLA. With existing DEC data we estimated that 65% of Vermont lakes are free of eurasian watermilfoil, water chestnut, curly-leaf pondweed, zebra mussels and alewife (Figure 43). So, at least 65% of Vermont lakes would be considered in good condition for AIS. The combination of those five AIS are stressing about the same proportion of lakes as turbidity (66% good condition) or phosphorus (67% good condition) and potentially less if some of the lakes with an AIS species present were considered in good condition because the species is controlled.

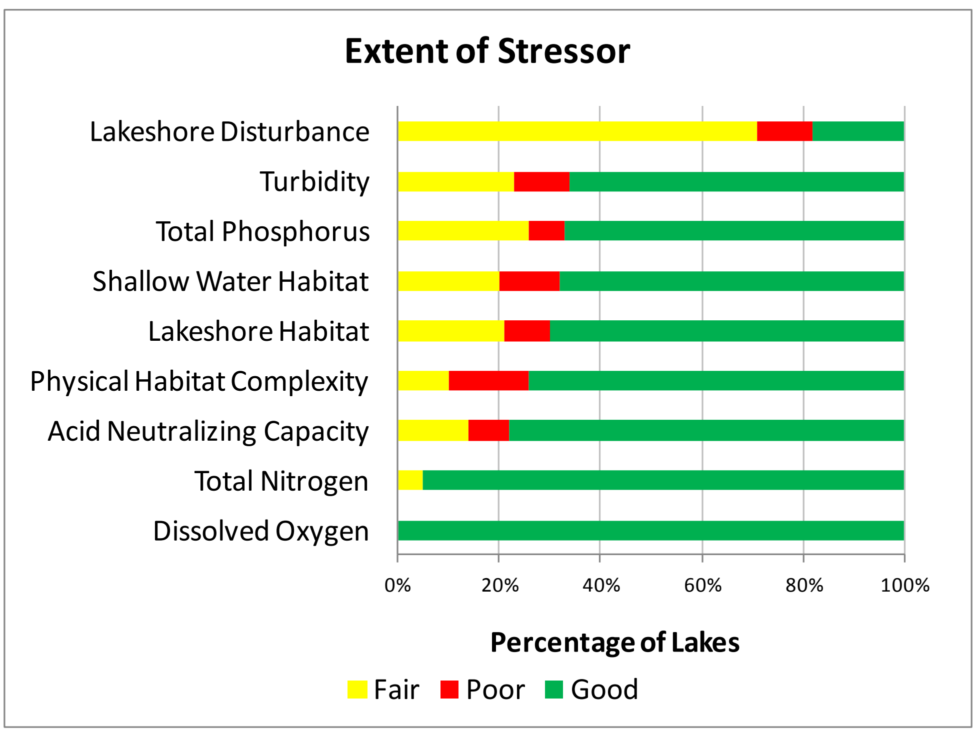


Figure 46. Extent of stressors to Vermont lakes

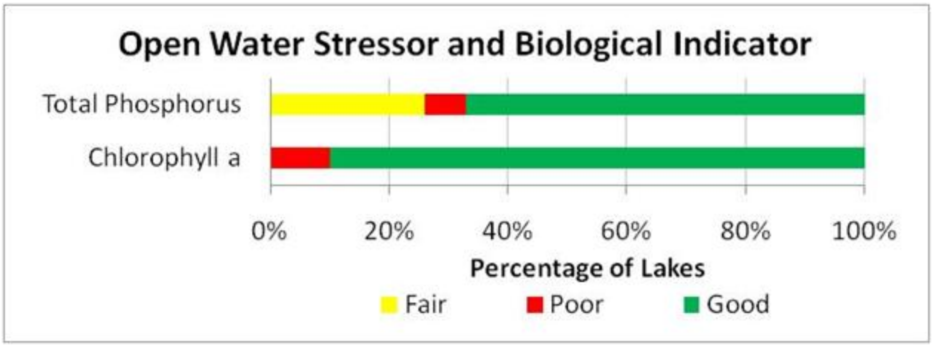


Figure 47. Extent of Vermont lakes stressed by phosphorus and percent with poor or good chlorophyll a concentrations

While Figure 46 focuses on the extent of various stressors to Vermont's lakes, biological organisms are good indicators of how the lake integrates those stressors. Chlorophyll *a* is typically used as a measurement of water column algal (phytoplankton) biomass. Phytoplankton are typically limited by phosphorus. In Figure 47, we see that only 7% of Vermont's lakes have concentrations of phosphorus considered high enough to be poor and that only 10% of Vermont's lakes are in poor condition for Chlorophyll *a*.

Macroinvertebrates are typically used in streams as indicators of ecological health. They respond to multiple stressors, from nutrient enrichment, to degraded habitat, aquatic invasive species and toxic discharges. The macroinvertebrates collected in Vermont appear to be responding to one or a combination of stressors. About the only stressor measured as part of the NLA that is widespread enough to account for the proportion of lakes with fair or poor macroinvertebrate indices of biological integrity is lakeshore disturbance (Figure 48). Recent studies by VTDEC have found that unbuffered lakeshore development affects macroinvertebrates, so it seems likely that macroinvertebrates could be responding to the stress of lakeshore disturbance. In all likelihood, the macroinvertebrates are responding to a combination of both the stressors measured during the NLA and ones not measured. What is most curious about the data is that whatever is stressing lake macroinvertebrates, it is stressing a higher proportion of Vermont lakes than lakes in the NAP Ecoregion (Figure 41).

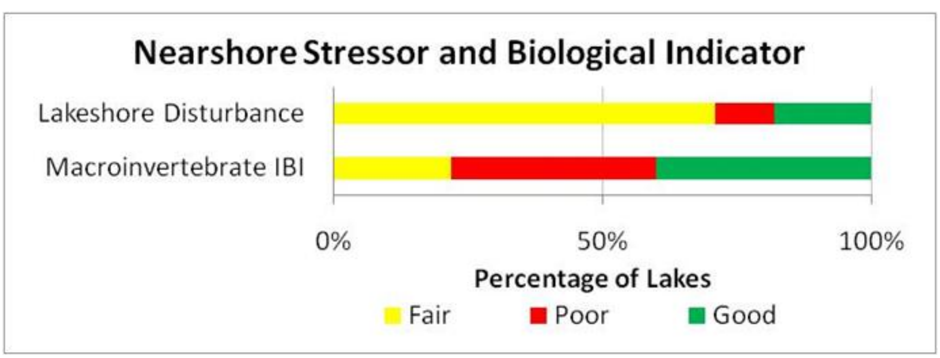


Figure 48. Extent of Vermont lakes stressed by lakeshore disturbance and % with fair or poor macroinvertebrate IBIs

Turtlehead Pond *(VTDEC)*

CONCLUSIONS

While the number of lakes sampled in Vermont was adequate to characterize the condition of Vermont's lakes, the proportions of lakes sampled in each size class did not match the frequency of those lakes on the landscape. This was because the overdraw lakes selected were part of the national survey design and therefore was not a state tailored design, which was done for the 2012 NLA. In the tailored survey design for Vermont, more 10-25 acre lakes were sampled in 2012 to characterize the condition of the most common lake size in the Vermont landscape. Vermont was unable to characterize the condition of these lakes in this report due to the 2007 draw, but using the NLA design still categorizes 93% of the assessed inland lake acreage in Vermont, which constitutes the lakes where management efforts are typically focused. For future national lake assessments, other states with comprehensive data on the size of all their lakes will want to work with EPA to make sure the proportions of lakes within each size class is close to the proportions selected by an overdraw for a state tailored design. This will help ensure each size class is sampled adequately to make correct inferences about the entire suite of lakes in each size class and the overall condition of a state's lakes. In the 2012 NLA, the overdraw selection of lakes for Vermont was adapted to better represent the characteristics of lakes statewide, this will provide a more accurate estimate of condition for the entire population of lakes.

The NLA is designed to get an unbiased, random, single-sample snapshot of a population of lakes, but it is not meant to assess the condition of individual lakes. In the case of trophic state estimates for Vermont lakes, interpretation of the data is subject to the thresholds applied and may not coincide with long-term means for an individual lake at the time of sampling. It is for these reasons individual lake results were not presented.

For the first time, Vermont's participation in the EPA's NLA overdraw allowed for a statistically valid assessment of the condition of its lakes in direct comparison with the region and nation. Vermont now knows how the lakes that comprise the majority of the lake area in the state (lakes >25 acres) compare to the Northern Appalachian Ecoregion and the Nation. With respect to trophic condition as measured by chlorophyll-*a*, Vermont has a preponderance of lakes in what the NLA considered oligotrophic. Vermont had a higher proportion of oligotrophic lakes than the nation and eight of the nine ecoregions. It had a similar proportion of eutrophic lakes to the NAP Ecoregion, but half that of the nation. This finding is consistent with the finding that 95% of Vermont lakes were rated in good condition for nitrogen concentrations and 67% were rated in good condition for phosphorus concentrations. Only 7% of lakes were rated in poor condition for total phosphorus. It is no surprise then that 100% of Vermont's lakes are in good condition for surface dissolved oxygen concentrations. Overall, the water quality of Vermont lakes is at least as good as the region and typically better than the nation.

Since Vermont had long term water quality monitoring data on all the 51 NLA lakes, it was possible to apply Vermont's trophic thresholds to the total phosphorus, secchi transparency and chlorophyll-*a* long term data sets. This allows Vermont to characterize all the lakes in the state by its own trophic definition, which finds the majority (60%) of the lakes in the state to be mesotrophic, fourteen percent oligotrophic, nineteen percent eutrophic and eight percent dystrophic.

One confusing finding was the extent of lakes in poor condition for turbidity in Vermont. This was the only stressor where Vermont had a greater proportion of lakes in poor condition than the NAP ecoregion or nation. Since different methods were used to measure turbidity on the 11 core lakes than that used on the 40 overdraw lakes, the 2012 used consistent methods to determine if this finding is correct.

Vermont DEC considers the thresholds used by the NLA to be too liberal and hence under representative of the extent of acid precipitation stress to lakes. The NLA considered ANC equal to or less than 2.5 to be either fair or poor condition. Vermont considers anything less than 2.5 mg/L (50 ueq/L) to be poor condition and has set that as the $[ANC]_{limit}$ in order to protect the most sensitive aquatic biota. The $[ANC]_{limit}$ is the lowest ANC concentration that does not damage selected biota (Henriksen & Posch, 2001). NLA thresholds are too low according to aquatic life uses, which require a minimum of 2.5 mg/L $CaCO_3$ to maintain brook trout populations, an acid tolerant fish. Other studies in North America have chosen ANC values in the range of 40-50 ueq/L (Hindar & Henriksen, 1998) (Dupont, et al., 2002). When applying Vermont thresholds that use only alkalinity (Table 9), the state has a much lower percentage of lakes in good condition (78%) and a relatively high percentage of lakes in poor condition (8%). This is an example of where the thresholds used at the ecoregion and national levels are too low and the Vermont thresholds are more appropriate (Table 10 and Figure 28). It is Vermont DEC's opinion that the Vermont thresholds better represent the condition of the lakes. It is unfortunate that similar thresholds were not applied for the ecoregion and nation. If they had been, this stressor would highlight the fact that while the 1990s amendments to the Clean Air Act have resulted in improvements in lake chemistry, the reductions in emissions have not yet achieved biological recovery in our lakes. Further reductions in Sulfur and Oxides of Nitrogen are still needed.

In Vermont, the largest proportion of lakes in poor condition is for physical habitat complexity. Poor physical habitat complexity affects more than twice the percentage of Vermont lakes that are affected by high levels of phosphorus. Physical habitat complexity is a measure of the condition of the lakeshore and shallow water habitat combined. Natural shorelines are complex, they are made up of wetlands and diverse structured vegetation including vertically stratified layers of groundcover, understory and canopy plant, shrub and tree species. Natural shallow water habitats are complex as well, they are made up of woody snags, emergent, submersed and floating leaved plants, boulders and diverse sediment types. These structurally complex shallow and nearshore environments provide habitat and niches for a wide diversity of both terrestrial and aquatic organisms. Humans tend to simplify this complexity by converting the diverse lakeshore structure to a monoculture of lawn and impervious surfaces. They 'clean' up the shallow water environment by removing woody snags and aquatic plants. Often the sediment itself is changed by the importation of sand. All of these activities simplify the physical habitat and result in poor conditions. As the stressor with the greatest proportion of lakes in poor condition, it is important that Vermont seek ways to protect the existing fair and good physical habitat complexity that exists on the majority of its lakes. To do so will mean changing the way humans simplify this environment. It will mean educating lakeshore residents on the importance of complexity on both the land and in the shallow water and implementing better management practices so that the use of Vermont lakeshores does not result in the degradation of them.

With existing DEC data we estimated that 65% of Vermont lakes are free of Eurasian watermilfoil, water chestnut, curly-leaf pondweed, zebra mussels and alewife (Figure 43). So, at least 65% of Vermont lakes would be considered in good condition for AIS. So, the combination of those five AIS are stressing about the same as proportion of lakes as turbidity (66% good condition) or phosphorus (67% good condition) and potentially less if some of the lakes with an AIS species present could be considered in good condition because the species is controlled.

In Vermont the vast majority of lakes have low concentrations of water column algae as measured by chlorophyll-*a* concentrations. Ninety percent of Vermont lakes are in good condition for chlorophyll-*a*, which is similar to the NAP ecoregion. However, the remaining 10% of lakes were in poor condition. So, when lakes do have high concentrations they are very high. This suggests that the general condition of Vermont lakes is good, but once algal populations find a niche the do very well.

With the exception of chlorophyll *a*, most of the parameters measured and presented in this report give estimates of the extent of stressors affecting Vermont lakes. Whereas, the macroinvertebrate index of biotic integrity is a measure of the response of Vermont lakes to a variety of stressors, some measured by the NLA and some not. The majority of Vermont lakes were ranked as either in fair (22%) or poor (38%) condition by the macroinvertebrate IBI. This finding is alarming, especially considering that a greater proportion of lakes were ranked poor in Vermont than in five of the nine ecoregions across the nation. Because the macroinvertebrate IBI is new, we do not know what the main cause of the degraded nearshore biology in Vermont is, however, it could be related to the lakeshore disturbance findings.

The most worrisome finding in this assessment was that only 18% of Vermont lakes are in good condition for lakeshore disturbance. In this stressor category, Vermont is lagging behind both the region and the nation. The vast majority of lakes (71%) in the state are in Fair condition. No other stressor puts as great a proportion of lakes in the nation, state or Ecoregion in either the Poor or Fair condition categories. This is a red flag, especially given how well Vermont compared in most other stressor categories. Lakeshore disturbance "reflects direct human alteration of the lakeshore itself. These disturbances can range from minor changes (such as the removal of trees to develop a picnic area) to major alterations (such as the construction of a large lakeshore residential complex complete with concrete retaining walls and artificial beaches). The effects of lakeshore development on the quality of lakes include excess sedimentation, loss of native plant growth, alteration of native plant communities, loss of habitat structure, and modifications to substrate types. These impacts, in turn, can negatively affect fish, wildlife, and other aquatic communities" (USEPA, 2010). In Vermont, lakeshore disturbance was characterized by sea walls, lawns and the placement of buildings and roads within 100' of the lakeshore (Figure 32). Act 250 guidelines set buildings, roads and driveways back 100' and recommend the retention of natural vegetation. However, few lakeshore development projects trigger Act 250.

Although most stressors included in the NLA affect lakes in Vermont to a lesser extent than the region or nation, the largest proportion of lakes in poor condition is for physical habitat complexity and should necessitate monitoring and management attention along with turbidity and phosphorus.

Lake Champlain *(Jeff Merrell)*

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Curtis Pond