The 2005 Vermont Acid Lake Biomonitoring Program

VERMONT
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

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Executive Summary

Two Vermont acid-impaired ponds in the Green Mountain National Forest were sampled in the summer of 2005 to assess their current biological condition and compare the results to macroinvertebrate samples collected in the early 1980s. With the implementation of the Clean Air Act of 1990, large reductions in acid causing pollutants have caused an increase in the pH and buffering capacity of many Vermont lakes. While this chemical improvement is well documented in New England, biological recovery has yet to occur in the macroinvertebrate community. There has been no improvement in the acid sensitive orders such as crustaceans (crayfish) or molluscans (snails and clams). This is likely due to on-going declines of base cations; most notably, calcium and magnesium, and an increase in inorganic monomeric aluminum, which is toxic to biota. The greatest impact on the biological composition of the two ponds was the presence or absence of fish. The structure of the aquatic community on the fishless pond was dominated by insects such as beetles and true bugs. On Branch, these insects were kept in check by fish predation and had a less diverse overall macroinvertebrate community.

Introduction

Researchers in the U.S., Canada and Europe have been documenting improvements in the chemical condition of acid sensitive lakes since the late 1990s. This chemical improvement has been predicted as a precursor to improvements in the biological condition. However, no long-term monitoring programs exist to detect these changes and biological data demonstrating improvement on acid lakes is sparse. Researchers have recommended assessments of biological recovery on acid lakes (Driscoll et al. 2001).

Objectives

The objectives of the 2005 acid lake biomonitoring sampling effort were to:

- Characterize and compare the current macroinvertebrate community on two acid lakes
    - Branch Pond, a highly colored, deep pond;
    - Little Pond, a clear, shallow pond
- Compare to historical data and assess if any change has occurred over time.

Background

From 1981 to 1983, macroinvertebrate samples were collected from a total of 36 acid sensitive lakes in the spring, summer and fall by the Vermont Department of Environmental Conservation (Fiske 1987) under the auspices of the Vermont Long-Term Monitoring Program (VLTM) of acid sensitive lakes. In the summer of 2005, the VLTM re-sampled Branch Pond in Sunderland and Little Pond in Woodford. These ponds were selected due to the recent improvements in their pH and alkalinity status, their similar acid sensitivity, and their differences in DOC status and maximum depth. Both ponds are on the State of Vermont’s 303(d) list of impaired waters for 2006.

Branch Pond is a highly colored, dystrophic (>70 Pt-Co, 5-6 mg/L DOC) and deep pond (>10 m) with a population of brook trout and brown bullhead. Little Pond is a clear, oligotrophic (<15 Pt-Co, 1-2 mg/L DOC) and shallow (1 m) fishless pond . Both ponds are in undisturbed watersheds in the southern reaches of the Green Mountain National Forest.

Figures 1-4 provide photos of the two ponds in the summer of 2006.

Figures 1 and 2. Branch Pond: boat access in south bay looking west and north.

Figures 3 and 4. Little Pond: southwest shore and substrate in south bay.

Water Chemistry

Since monitoring began in the early 1980s, pH and alkalinity have increased significantly while, calcium, magnesium and sulfate concentrations have significantly declined (Table). The chemical improvements of pH and alkalinity have been statistically significant but remain low and continue to be critically acidic. Alkalinity and pH levels have not recovered to the degree necessary to expect a biological response (Fiske 1987). The leaching of calcium and magnesium from the watershed soils and in-lake concentrations has thus far limited the potential for biological recovery.

Table 1. Mean water chemistry values of Branch and Little Ponds.

Lake	**Mean pH**		**Mean Alkalinity (mg/L $CaCO_3$)**		**Mean Ca (mg/L)**		**Mean Mg (mg/L)**		**Sulfate (mg/L)**	
	1981-1983*	2003-2005	1981-1983*	2003-2005	1981-1983*	2003-2005	1981-1983*	2003-2005	1981-1983*	2003-2005
Branch	4.64	4.91	-0.77	-0.19	0.93	0.59	0.35	0.21	5.77	2.68
Little	5.16	5.23	-0.09	0.03	1.27	0.82	0.30	0.20	5.81	3.60
Overall Trend**	>		>		<		<		<	

*During 1981-1983, depth integrated samples were collected using the hose method and were analyzed unfiltered. Averages based on unstratified sampling conditions. During 2003-2005, samples were collected at 1 meter with a Kemmerer bottle and were filtered

** Trends based on the Seasonal Kendal Tau analyzed by the EPA lab in Corvallis, OR.

The improvements in alkalinity, pH and sulfate are primarily due to the 50% reduction in the emissions of sulfur dioxides mandated by the 1990 Amendments to the Clean Air Act. Over the same time, concentrations of base cations, in particular calcium and magnesium, have declined (Table 1, Figures 5 and 6). Biologically significant bench marks for healthy aquatic ecosystems are pH > 6.0, ANC > 2.5 mg/L, and calcium > 2.5 mg/L. While pH and alkalinity are slowly increasing towards these levels calcium continues to decline. The availability of calcium is an essential ion for the development and reproduction of zooplankton and certain macroinvertebrates; macroinvertebrate larvae are especially sensitive to low calcium levels. If calcium concentrations are too low, sensitive species will be lacking or absent, even with an increase in pH (Okland and Okland 1980, Fiske 1987).

Figure 5 Branch Pond pH, alkalinity and base cations.

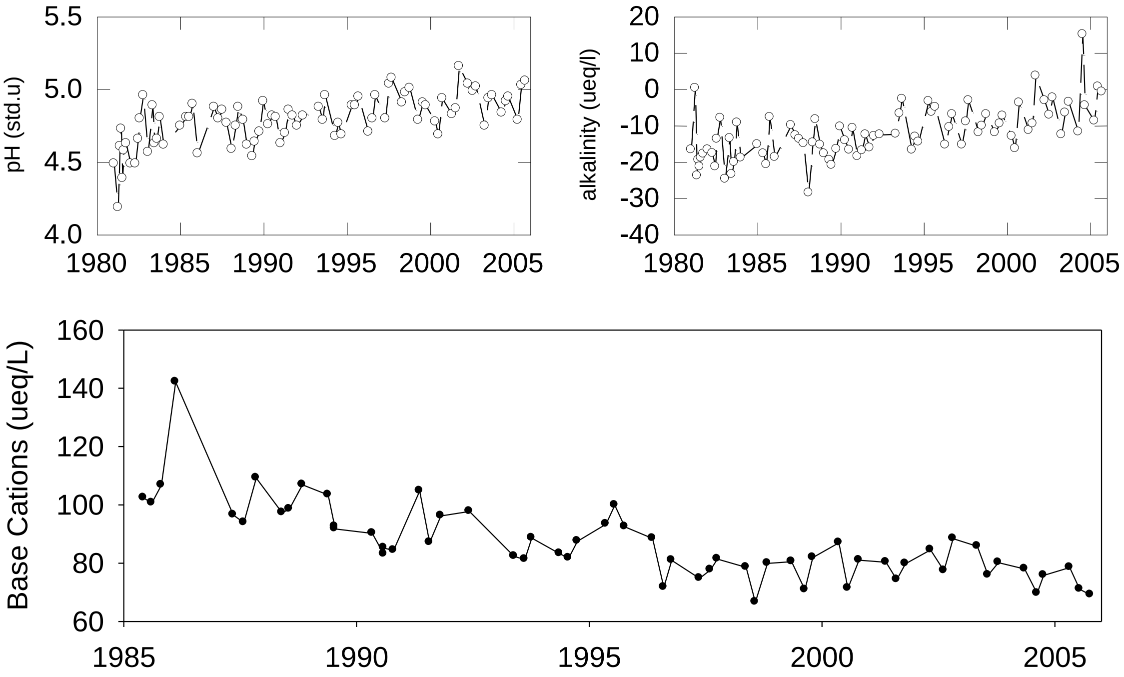
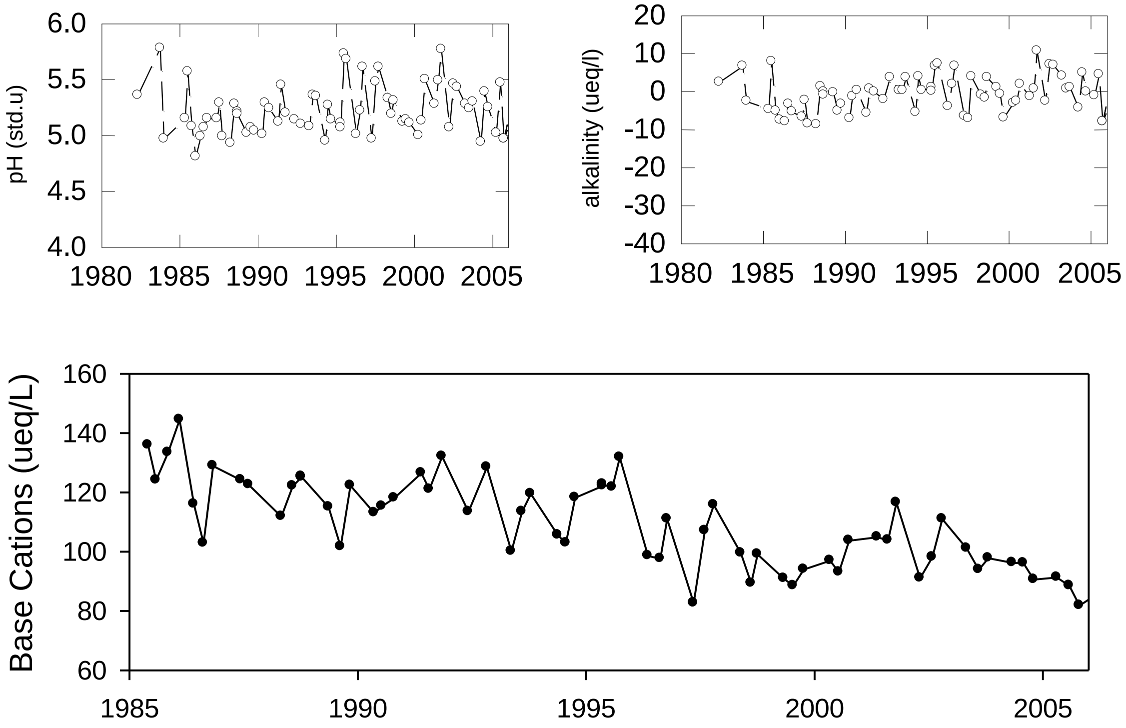


Figure 6. Little Pond pH, alkalinity and base cations.



Methods

The initial macroinvertebrate surveys of Vermont acid sensitive lakes took place from 1981-1983. A qualitative search in the littoral zone was performed for at least 1 hour, at least three times per year in all available habitats. Dredge samples were collected from the sublittoral during the winter at 2 locations on the pond with 3 samples collected from each location. Discrete samples were collected and processed from each habitat. However, the amount of time spent collecting the samples and the season in which the ponds were sampled varied greatly. Sampling was focused on the acid sensitive orders. No standardized method had been established; thus the data from that period are considered qualitative. Seasonally collected data sets from the years 1981-1983 are combined into yearly data sets. This may inflate the overall species richness for these years but it provides the most comprehensive survey of the existing community.

The 1998 and 2005 sampling efforts used a standardized methodology established by the Vermont and New Hampshire Biocriteria Project. The methodology is summarized in the report Development of Biocriteria for Vermont and New Hampshire Lakes (Kamman 2003). The 1998 and 2005 efforts employed this collection method, but in 2005, the profundal zone sampling was eliminated from the effort.

Samples were processed at the VTDEC Biomonitoring Laboratory using standard methods (Section 6.6 of Field Methods Manual, VT Water Quality Division 2006). Samples from the littoral and macrophyte habitats were collected with a kick net for a total of 30 minutes.

Each sublittoral sample represents a composite of three Ekman dredges. As a result, the dredge samples can be viewed quantitatively, while the kick net samples are only semi-quantitative. The 1998 analysis demonstrated that the profundal data was not discriminatory from a lake classification basis; instead, it indicated the presence or absence of oxygen in the deep water. Refer to Table 2 for a summary of the sampling methodology.

Table 2. Summary of sampling methods on Vermont acid lakes.

	Old Method	**New Method**
Years Sampled	1981, 1982, 1983, 1993 (Branch only)	1998 (Branch only), 2005
Seasons sampled	Spring, summer, fall, winter	summer
Location of discrete samples	3 habitats: littoral [composite of silt-muck, sand, gravel-cobble-rock, organic detritus (leaves), logs, submergent and emergent vegetation], sublittoral, profundal.	4 habitats: muddy littoral, macrophytes, rocky/woody littoral, and sublittoral. (Profundal samples eliminated after 1998).
Sampling frequency and method	1981-1983 • 1 hour per season. 1993 • 30 minutes to 4 hours. • Focused on collecting sensitive groups: Crustacea, Mollusca and Ephemeroptera.	~4 hours total. • Rocky Littoral: 30 min/lake (10 min per site at 3 sites). • Muddy Littoral: 6 kick net sweeps at ~3 cm into surficial muds (2 per site, 3 sites/lake). • Macrophytes are composites of 3 net sweeps through a macrophyte bed at each of three sites. Macroinvertebrate densities vary based on vegetation type. • Sublittoral. Composite of 3 Ekman dredges per site. 3 sites/lake.
Equipment used	Ekman dredge (225 sq cm.) and #30 sieve bucket for sublittoral and profundal samples. Kick net for littoral samples.	Ekman dredge (225 sq cm) and #30 sieve bucket for sublittoral and profundal samples. Kick net for littoral and macrophyte samples.
Lab effort	2 bottles/open lake visit, 1 per frozen lake. Complete pick of all taxa from samples.	4 bottles/lake. One quarter of sample picked with a 300 animal minimum.

Results and Discussion

Acidification can affect the macroinvertebrate community in a variety of ways. Richness, density, diversity and community structure tend to be reduced. The EPA document entitled *Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands A Survey of North American Technical Literature (1990-2000)* describes the impacts well:

> "Acidification can alter community structure by (a) being acutely or chronically damaging to tissues of invertebrates – species that easily lose sodium ions when pH is reduced tend to be most sensitive (Steinberg and Wright 1992), (b) altering algal communities and aquatic macrophytes upon which some invertebrates depend for food and shelter, (c) altering predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians, (d) altering the bioavailability of some other potential stressors, such as heavy metals (Brett 1989, Stokes *et al.* 1989, Feldman and Connor 1992, Stephensen *et al.* 1994). The effects of acidity also depend on the seasonal life cycles of macroinvertebrates and water temperature (Pilgrim and Burt 1993). In areas with snow, the greatest acid stress often occurs during snowmelt. Young larvae were more susceptible than older larvae at that time (Gorham and Vodopich 1992). Metals and acidity also can interact to alter the toxicity of either or both (e.g., Havens 1994a)." (USEPA 2001).

The biometrics of relative abundance (density), species richness, and diversity were used to assess the 2005 results. A complete taxa list for Branch and Little Ponds is presented in Appendix 1. This list includes all the taxa found from 1981 through 2005.

2005 Relative Abundance (Density)

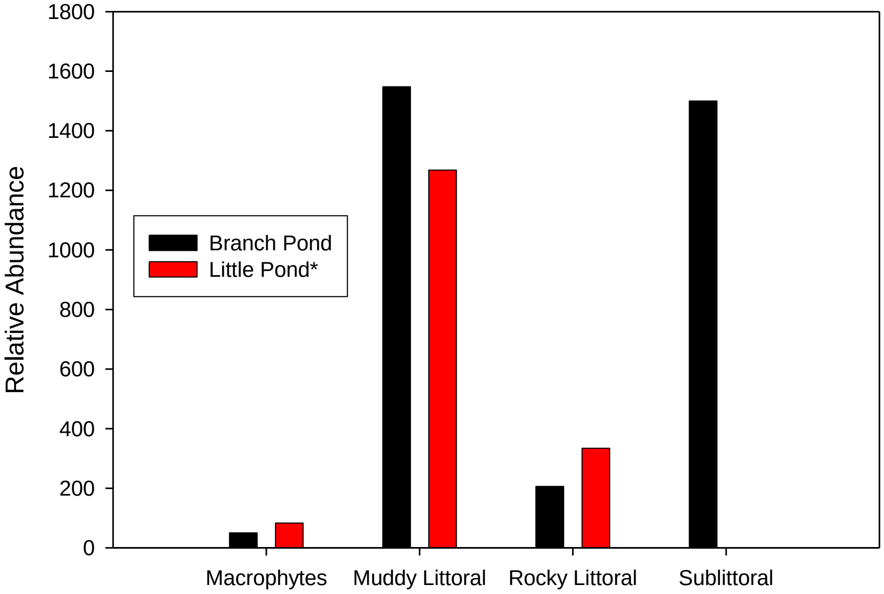
Relative abundance is the total number of organisms present in a sample. Relative abundance values for the sublittoral zone were considered quantitative. The sampling effort represented a discrete area created by the Ekman dredge and included a set number of composites. The abundance values for the remaining lake zones were considered to be semi-quantitative as the sampling area was defined only by the time spent sampling and does not represent a discrete area.

The density of animals was similar for both ponds within a habitat type (Figure 7). The muddy littoral and sublittoral had the greatest density of animals given the sampling method, ranging from 1548 (Branch) to 1268 (Little) in the muddy littoral and 1500/m^2 in the sublittoral of Branch. The rocky littoral zone sample yielded densities of 206 (Branch) and 334 (Little). The macrophyte zone yielded the least number of animals with densities of 50 (Branch) and 83 (Little).

Overall, the macroinvertebrate most commonly encountered macroinvertebrate was the Chironmid *Tanytarsus spp*. Chironomids, especially those in the families Chironominae and Tanypodinae, inhabit lentic warm water systems and have adapted to a large range of aquatic environments, such as low pH and reduced oxygen conditions that other insects cannot. Because they are free swimmers, they do not need the substrate that other groups rely on for shelter and food. As a result, they can thrive in the sublittoral zones of lakes. *Tanytarsus spp.* is characteristic of oligotrophic conditions (Saether 1979) and was found to be the most dominant taxa in the early 1980s survey (Fiske 1987) as well. *Tanytarsus* has a wide tolerance to pH and was present in all habitats on both ponds except the macrophyte and sublittoral zones of Branch (Table 3).

The rocky littoral and the macrophyte zones were the least abundant. The small amount of macroinvertebrates found in the macrophyte samples is due to the lack of diversity in plant structure, species composition and abundance. This zone offers habitat to dragonflies, beetles, true bugs and some chironomids. The rocky littoral did not have high density but did have the highest richness (Figure 8).

Figure 7. Relative abundance (density) of Branch and Little Ponds in 2005.



*Little lacks a sublittoral zone.

Table 3. Relative abundance and percent composition of *Tanytarsus* in 2005.

Lake	**Habitat Zone**	**Relative Abundance (Density)**	**% Composition**
Branch	Rocky Littoral	44.0	21.4
	Muddy Littoral	1026.7	66.3
	Macrophytes	--	--
	Sublittoral	--	--
Little	Rocky Littoral	116.0	34.8
	Muddy Littoral	306.7	24.2
	Macrophytes	2.3	2.8

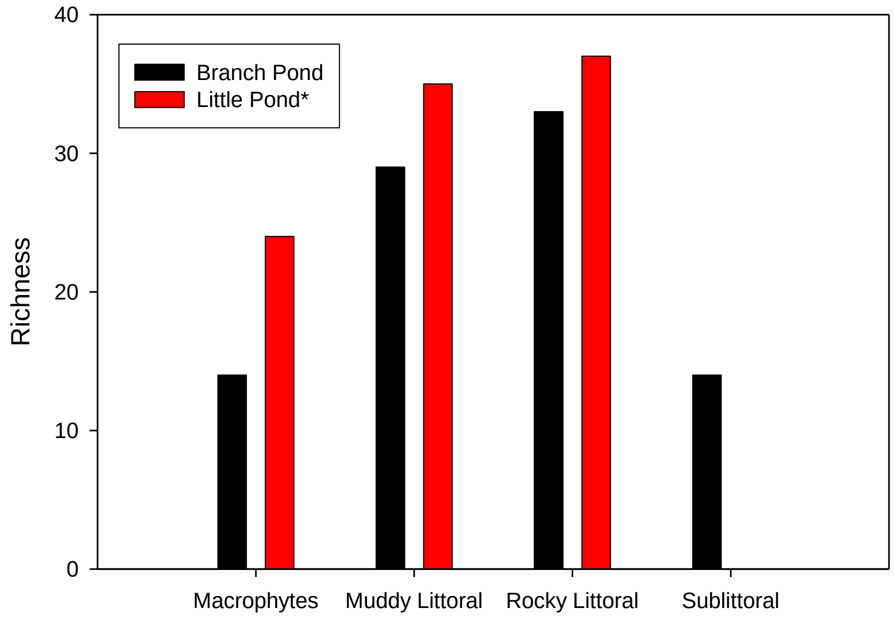
2005 Species Richness by habitat zone

Species richness is the total number of species found in a sample. It is a basic measure of species diversity. Given a relative equivalent sampling effort and processing procedures, richness can be compared between similar habitats types on lakes.

The rocky littoral zone had the greatest species richness of all the lake habitats on both ponds. The chironomids were most diverse, with *Tanytarsus* dominating in both Ponds. Mayflies were present in Branch's littoral zone and there was a greater diversity of caddisflies (5 species present) in this habitat than any other sampled. The muddy littoral was the second most diverse habitat, again dominated by chironomids. The macrophyte community differed greatly from the other habitat zones in that it was dominated by predators, such as the dragonflies and the beetles.

Little Pond had greater species richness across all habitat types despite the lack of a sublittoral zone (see Figure 8). Little Pond had a diverse community of chironomids, beetles, dragonflies and true bugs (Figure 9). Note the absence of mayflies in 2005, a taxa generally considered intolerant to acidic conditions and the presence of sow bugs. Lakes lacking fish in the Ontario had higher macroinvertebrate richness values compared to those with fish present (Mcnicol 1995)

Figure 8. Richness by habitat type on Branch and Little Ponds in 2005



*Little lacks a sublittoral zone.

Branch Pond had the greatest diversity in chironomids, caddisflies, dragonflies, worms and true bugs (Figure 10). Note the absence of leeches and the small number of beetles.

Figure 9. Little Pond Species Richness. All habitats combined 2005

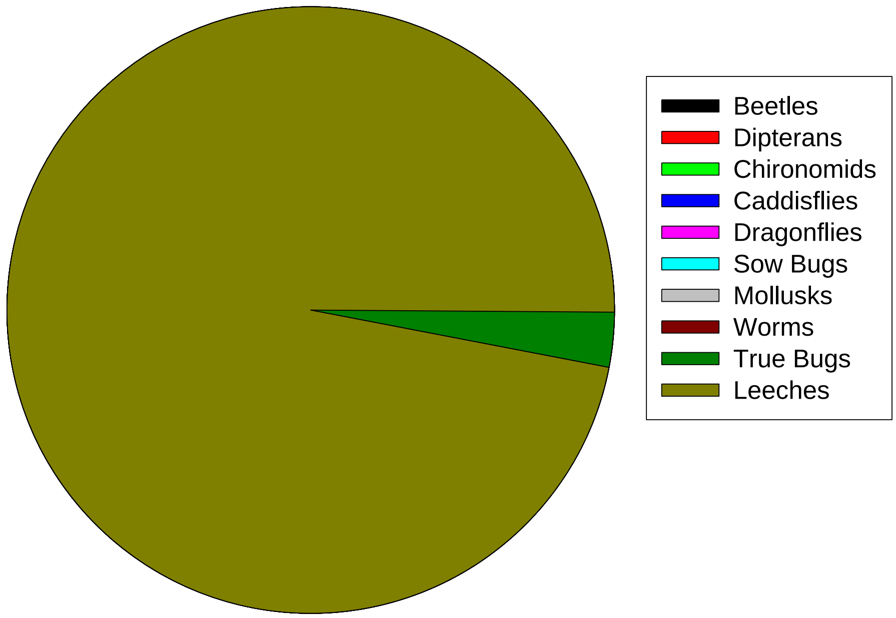
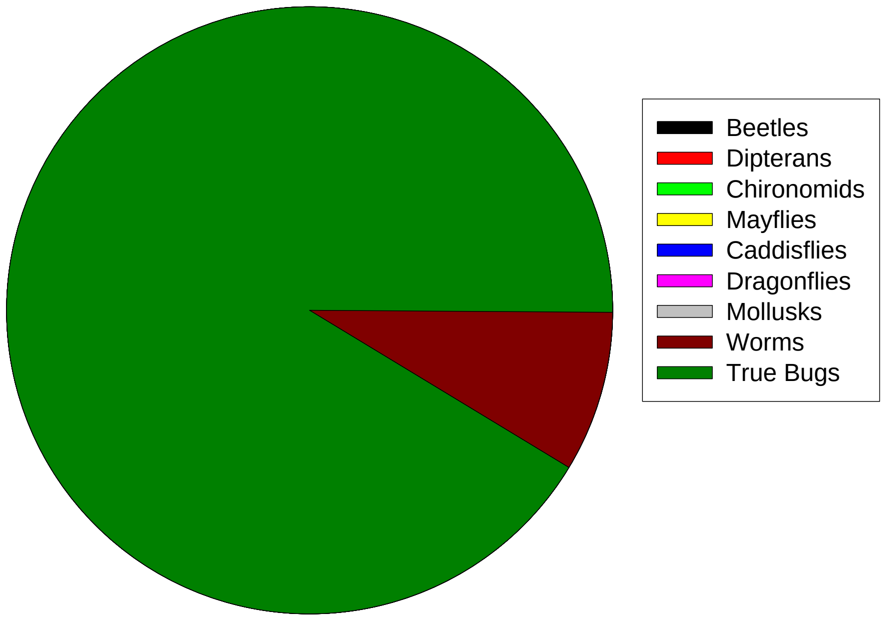


Figure 10. Branch Pond Species Richness. All habitats combined 2005



Overall Species Richness

Chironomids had the greatest diversity, with dragonflies having the second most. Chironomid richness was similar for both ponds with Branch having 26 species and Little with 28. In the Adirondacks, dragonfly richness of common taxa was greater in lakes with fish (Strong and Robinson, 2004). On the two Vermont ponds, the pond without fish (Little) had greater dragonfly diversity (10 species) than Branch, which has insectivorous fish (7 species).

Leeches, which require a pH of at least 5, are abundant in the littoral zone of Little Pond and are absent on Branch Pond. The pH on Little (5.2) is slightly above their tolerance while the pH on Branch is below tolerance (4.9).

The overall richness on Little Pond was greater than Branch Pond. The increased richness was due to a greater diversity of leeches, chironomids and beetles. Branch had only one beetle species collected in 2005, in comparison to 7 in 1981. Little had 13 beetle species in 2005 and 8 in 1981. However, while Branch Pond supports one mayfly species (*Leptophlebia)*, no mayflies were collected on Little Pond in 2005. In each of the prior sampling years, *Leptophlebia* was collected on Little. The lack of mayflies may be due to variability associated with sampling effort or sampling in the summer when lake populations of mayflies are reduced (Burnham et al. 1998). Another possibility is that they are an acid-sensitive species and their absence may be due to a deterioration of the chemical environment.

Chaoborus, a phantom midge, is only present on Branch Pond which is most likely a function of reduced oxygen in the profundal zone. These macroinvertebrates typically inhabit the deepest areas of lakes in order to pursue their selected food. Phantom midges have a diurnal cycle; they travel up and down the water column making use of available oxygen and feeding on zooplankton. They feed during the night when there is a reduced chance of predation and sink into the anaerobic hypolimnion during the daytime to avoid fish.

Species Richness Over Time

Samples collected prior to 1998 were strictly qualitative due to the variable sampling efforts, while the 1998 and 2005 samples were collected with a standardized quantitative method. The 1981 sampling effort was the most thorough of those conducted from 1981-1993 and will be the focus of comparisons over time.

Figure 11 presents species richness of Branch Pond from 1981 to 2005. In 1981, 38 total taxa were found at Branch Pond. In 2005, 56 species were found. Chironomids increased from 12 to 24 taxa. Worms were noted, but not speciated in samples from the 1980s. In 2005, six worm species were identified on Branch.

Figure 11. Branch Pond species richness 1981-2005.

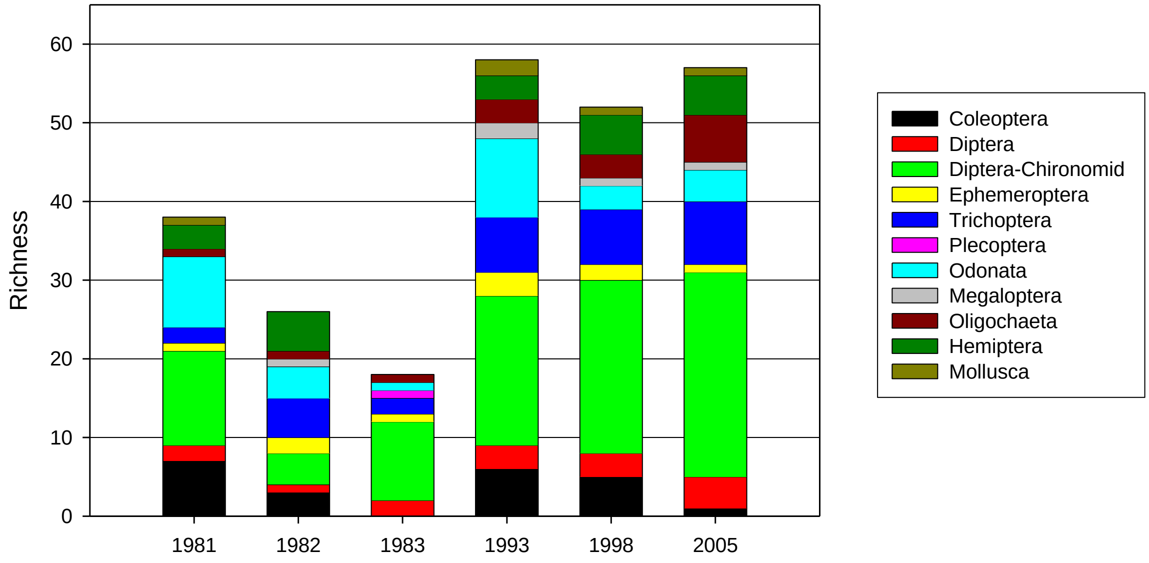
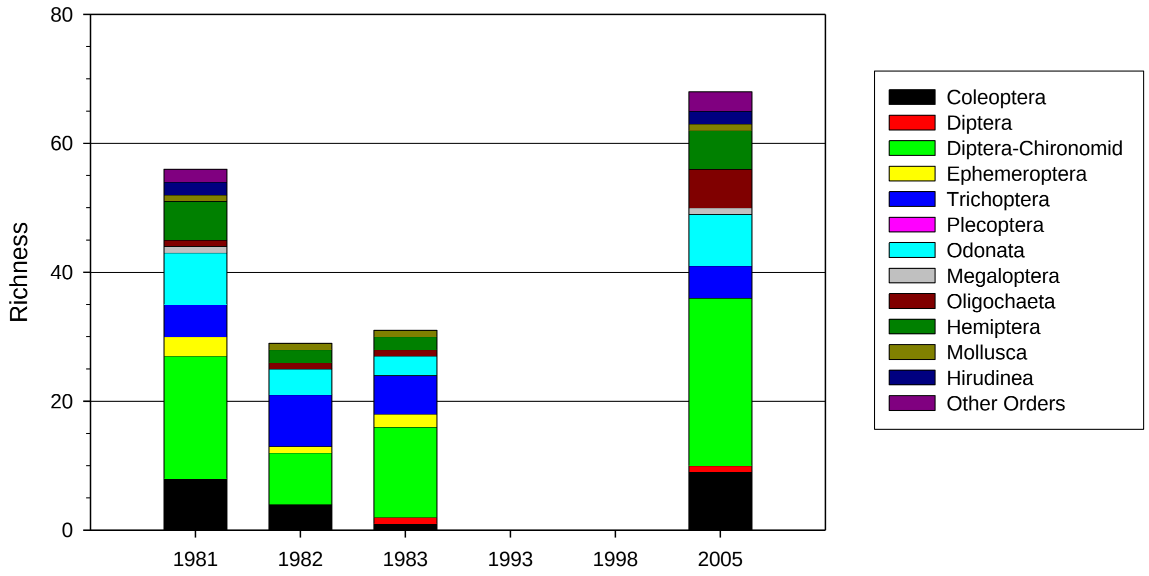


Figure 12 graphs Little Pond's species richness from 1981-2005. In 1981, Little Pond had an overall species richness of 57. In 2005, the richness was 68. Chironomids increased from 19 to 26 different species. No mayflies were found in 2005.

Figure 12. Little Pond Species Richness 1981-2005.
(Sampling did not occur on Little in 1993 and 1998)



Initially, it appears that the total species richness has increased from the early 1980s to 2005 (Figures 11 and 12). On closer examination, the increased richness is most likely a result of two factors; greater taxonomic precision in 2005 vs. 1981 and a slight increase in chironomid richness.

In 1981, 38 taxa were found at Branch Pond. In 2005, 57 taxa were found (Figure 11). However in 1981, worms were only identified to the order level. In comparing the two years using the same level of precision for identifications, species richness is closer: 38 species vs. 51 from 1981 to 2005 (Table 5 and Figure 13). Chronomid richness increased from 12 to 26 over the same time period. The relative percent difference (RPD) between 1981 and 2005 is 29.2%. The RPD between 1981 and 2005 is not considered biologically significant. Variability on stream macroinvertebrate replicate samples deviate as much as 40% (VTWQD 2004).

The situation is similar on Little Pond. In 1981, 57 macroinvertebrate species were identified. In 2005, 68 species were collected. However, 12 identifications were taken to the species-level in 2005 that were only identified to the genus-level in 1981. These more precise identifications are best demonstrated with the worms, chironomids and beetles. Comparing the 1981 to 2005 with the same level of precision the species richness numbers are closer: 57 vs. 62 (Figure 14). Chironomids increased from 19 to 26, but much of that increase was due to the speciation of *Polypedilum* in the 2005 data set. If the same taxonomic precision use in 1981 is applied to the chironomids in 2005, there are only 22 species. The 8.4 % between 1981 and 2005 is not biologically significant.

Table 5. Species richness and relative percent difference using comparable taxonomic hierarchy

Pond	**Species Richness**		**Relative Percent Difference (% RPD)**
	1981	**2005**	
Branch	38	51	29.2
Little	57	62	8.4

Figure 13. Branch Pond species richness using comparable taxonomic hierarchy

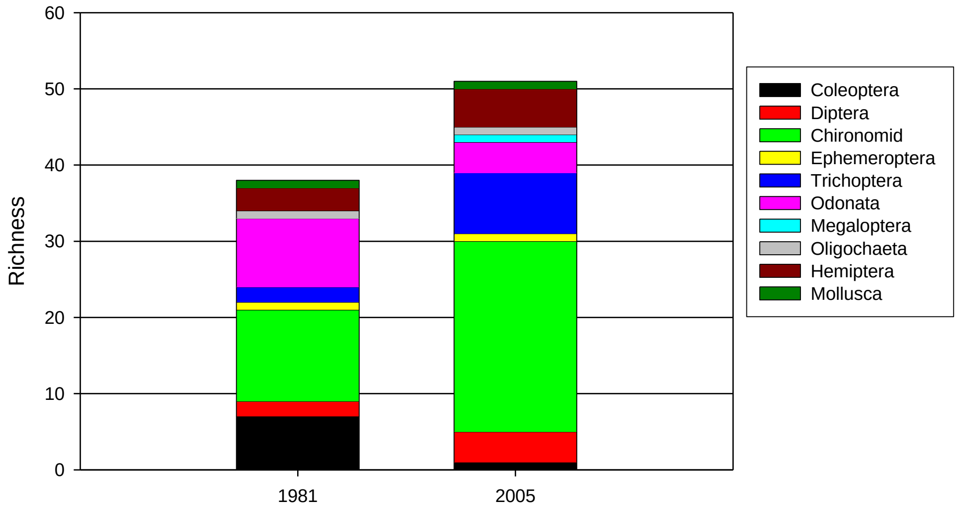
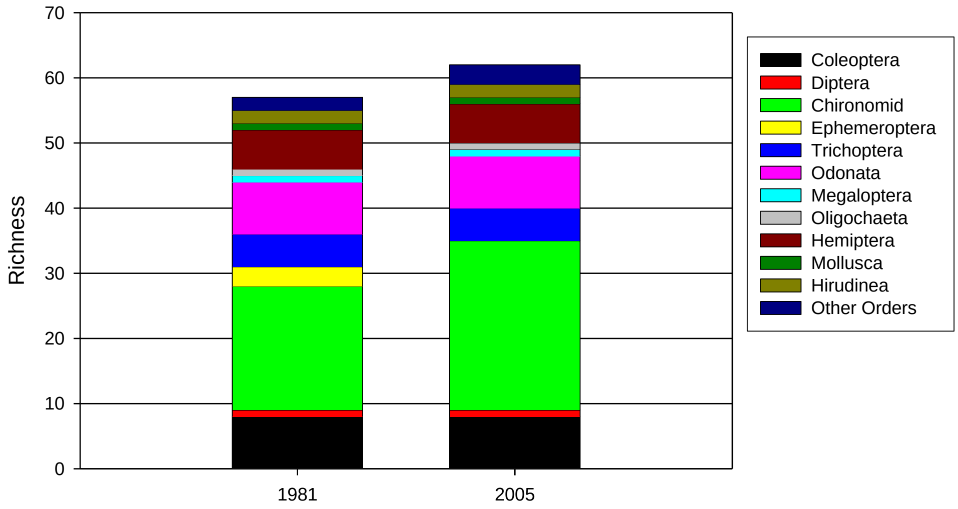


Figure 14. Little Pond species richness using comparable taxonomic hierarchy



Functional Feeding Groups in 2005

In addition to taxonomic classification, macroinvertebrates may be categorized by their feeding habits. This categorization addresses how they function and process energy in a waterbody. Scrappers feed on algae covered substrate, predators eat other organisms. Collector-filterers and collector-gatherers feed on fine organic particulate matter that they either collect or filter from the water column. A healthy ecosystem will have representation from a broad spectrum of the feeding groups. Acutely acidified lakes lack entire taxonomic groups and functional feeding groups (Jenkins et al. 2005).

The littoral zone samples were dominated by dipterans, specifically the chironomid *Tanytarsus* which is a collector-filterer. The macrophyte zone was dominated by predators; true bugs on Branch Pond and to a lesser extent, dragonflies on Little Pond. At 98.9% composition, the chironomids at Branch Pond's sublittoral zone had the highest percent composition of any zone for both lakes. Shredders and scrapers were reduced or absent from both ponds. In more buffered lentic habitats, these niches would be filled by snails, mayflies (scrapers) and scuds (shredders). The absence of these groups is an indicator of limited food and diversity resulting from acidification. A list of the dominant feeding groups for the two ponds is presented in Table 4.

Table 4. Dominant order and functional feeding group by habitat zone (2005).

	Rocky Littoral	**Muddy Littoral**	**Macrophytes**	**Sublittoral**
Branch				
Dominant Taxonomic Group (% Composition)	Diptera (84.8%)	Diptera (98.0%)	True Bugs (74.3%)	Diptera (98.9%)
Dominant Feeding Group (% Composition)	Collector-Gatherer (46.9%)	Collector-Filterer (66.5%)	Predators (80.8%)	Collector-Gatherer * (53.4%)
Little				
Dominant Taxonomic Group (% Composition)	Diptera (87.5%)	Diptera (73.3%)	Dragonfly (29.0%)	n/a
Dominant Feeding Group (% Composition)	Collector-Filterer (36.0%)	Collector-Gatherer (42.5%)	Predators (66.1%)	n/a

* Mostly made up of the chironomid *Heterotanytarsus*. The species has not been assigned an official functional feeding group by Merritt and Cummins (2003). Members of the dipteran subfamily Orthocladinae are generally collectors. All other habitat zones dominated by dipterans were comprised of the chironomid *Tanytarsus*, a collector filterer.

Diversity by habitat zone

Diversity is based on the Shannon-Weaver mean diversity index (Shannon and Weaver, 1963). It is a measure of the distribution in abundance between species of the community. Table 5 presents the calculated diversity by lake habitat zone. In comparing the two ponds, Little had greater diversity inclusive of all habitats while Branch had the single most diverse community from the rocky littoral zone. The least diverse community was the macrophyte zone on Branch Pond. The diversity on both ponds was reduced overall due to the low numbers or total absence of acid sensitive species such as mayflies, crustaceans and molluscans (Jenkins 2005).

The rocky littoral zones had the greatest diversity of macroinvertebrates on both ponds. The rocky littoral areas provide the greatest amount of habitat, cover, available oxygen and food for macroinvertebrates. Wave action diffuses oxygen into the surface, while plants and woody debris provide habitat and cover. The low amount of diversity in Branch Pond's macrophyte zone was likely due to the reduced amount of plant growth and plant diversity. This limits the area in which animals could find habitat. The macrophyte beds on Branch Pond were dominated by *Nuphar* (90%) with lesser amounts of *Brassenia* and *Potomageton* (<1%). The macrophyte beds on Little Pond were more diverse with abundant patches of *Ericauolon septangulare* (58%), *Nymphoides cordata* (40%), *Utricularia* (1%) and *Nuphar* (1%).

Table 5. Diversity by habitat zone (2005)

	Habitat Zone	**Diversity**
Branch		
	Rocky Littoral	3.99
	Muddy Littoral	1.98
	Macrophytes	1.92
	Sublittoral	2.57
Little		
	Rocky Littoral	3.76
	Muddy Littoral	3.37
	Macrophytes	3.65
	Sublittoral	n/a

Sensitive Groups: Ephemeroptera, Crustacea and Mollusca

The acid-sensitive groups of macroinvertebrates have declined or shown no improvement over time. In the 1980s, mayflies (Ephemeroptera) were represented by three genera on Little Pond (*Leptophlebia*, *Caenis* and *Ephemerella*). Yet in 2005, no mayflies were found in any habitat. On Branch Pond, three mayfly genera were found in the 1980s: *Eurylophella*, *Arthroplea*, and *Leptophlebia*; in 2005, only *Leptophlebia* was found. *Leptophlebia* has an apparent acid tolerance from VTDEC data. It often can tolerate harsh conditions (vernal pools, low pH streams and lakes) that other mayflies cannot.

Crustaceans were severely limited or absent on both ponds. The absence of amphipods, specifically *Hyallea azteca*, which is ubiquitous in lentic environments, is an indicator of acidification. Isopods (sow bugs) have been found in the muddy littoral of Little Pond while none were found in Branch. These organisms are moderately acid tolerant but their presence is unusual as they have only been found at one other low alkalinity lake in Vermont (Fiske 1987). The absence of crayfish is another indicator of on going acidic conditions.

Mollusca (gastropods and bivalves) richness has declined at Branch Pond over time. This community is the group most at risk from acidification. Two species were collected on Branch Pond in 1981: a snail (*Ferrissia sp.)*. and a fingernail clam, (*Pisidium sp.)*; in 2005, only *Ferrissia* was collected at Branch. *Ferrissia* is called the “fragile ancylid” and is reported in waters down to pH 5.1 with calcium levels of 2.0 mg/L (Jokinen 1992). *Pisidium* is the most common and widespread fingernail clam found in all aquatic habitats. It is thin shelled and has been found in lakes with pH of 5.2 and calcium as low as 0.35 mg/L (Jokinen 1992). These two species are some of the most tolerant of all fresh water mollusks. *Pisidium* is also tolerant of desiccation and have been found in many vernal pools in Vermont (VTDEC data). These mollusca populations are marginal at both ponds. The reduction in mollusca richness on Branch Pond may be due the loss of available calcium. Little Pond's mollusca population has remained consistent. *Pisidium* was found each year it was sampled, from1981 to 2005.

Caddisflies are not generally sensitive to acidification but the communities on Branch and Little have undergone some changes in species abundance. The community on Branch increased from two species in 1981 to eight in 2005 while Little's caddisfly richness remained unchanged over time. The current community, such as *Psitlostomis, Phryganea* and *Rhycaphila*, tend to tolerate a wide range of conditions. In addition to lakes, they have been found in vernal pools, springs, and marshes. They tend to be predaceous or ingest dead and living plant material. The species *Rhyacophila*, found in Little in 1983 and at Branch in 2005, is typically found in flowing waters but is able to survive in the wave zone of lakes. Data from the Adirondacks and Catskills indicates that it is the most acid tolerant caddisfly (Bode 2006). The increase in caddisfly and chironomid richness on Branch Pond was the major difference between samples from the 1980s and 2005.

Water Chemistry

The greatest contrast in the water chemistry between Branch and Little Ponds is the amount of dissolved organic carbon (DOC) present. DOC mediates the impacts of the toxic form of aluminum (inorganic monomeric, i.e. IMAL) to biota. As a tannic waterbody, Branch has DOC levels that fluctuate between 6-7 mg/L, with readings as high as 8 mg/L. This high level of DOC may help to offset the negative effects of Branch's IMAL which ranges from 150-200 mg/L. In Adirondack streams, Jenkins et al. (2005) noted that at high aluminum levels (>100 ug/L), 8 mg/L of DOC could reduce fish mortality from 100% to 50%. DOC levels have been increasing on acid lakes in the northeast United States, including Vermont which could aid in the biological recovery of fish populations to acid lakes (USEPA 2003). DOC may be increasing in Vermont acid lakes due to increases in precipitation volume (Figures 15-17) leaching more organics from wetlands and forest soils.

Figures 15 and 16. Branch Pond DOC, 1993-2005. Branch Pond IMAL, 1994-2005.

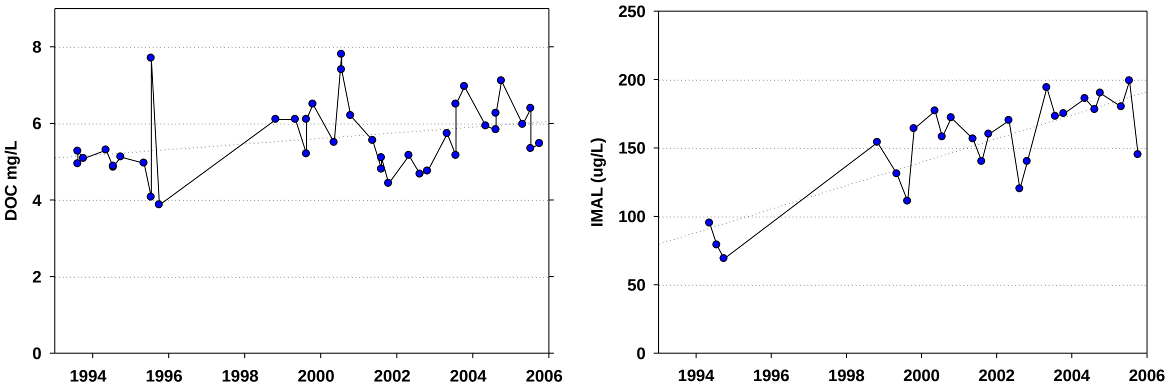
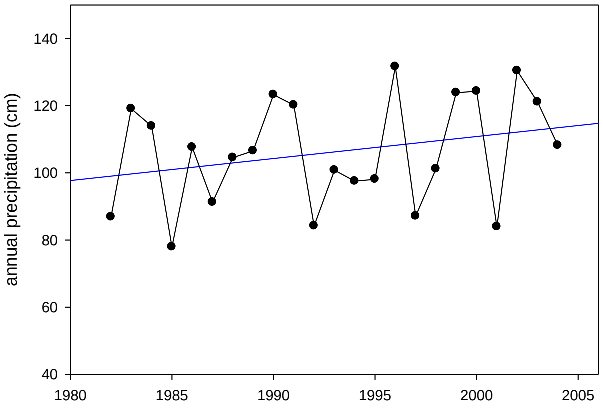


Figure 17. NADP precipitation totals for Bennington, VT, 1980-2004.



Bennington, VT National Atmospheric Deposition Program site has experienced increases in the volume of precipitation since the early 1980s (NADP data, 2006, Lynch 1996), see Figure 17. Driscoll et al. (2003) reported increases in DOC on Adirondack lakes, and increases were greatest at lakes already high in DOC, such as Branch Pond.

Conclusions

The water chemistry of Branch and Little Ponds has significantly changed from 1981-2005 as a result of the 1990 Clean Air Act Amendments. Increases in pH and alkalinity resulted from reductions in the acid pollutant load. Over this same period, the biological community has not significantly improved as demonstrated in the species richness values. This lack of biological improvement is most likely due to the continued decline in available base cations, specifically calcium and magnesium. Earth metals are essential to the development and reproduction of macroinvertebrates, most notably in crustaceans and molluscans. At levels less than 2 mg/L of calcium, biological communities in lakes will continue to be impoverished.

Lake acidification research has documented improvements to the planktonic community on lakes recovering from acidification (Keller et al. 1991). These changes will likely supersede shifts in the macroinvertebrate community. Sampling to assess the planktonic community is recommended.

Recommendations

- Continue to monitor VLTM lakes for macroinvertebrates.
- Collect zooplankton samples from Little Pond and Branch Pond to assess change in the lowest level of the food chain.

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Appendix 1

Macroinvertebrate species list for Branch and Little Ponds, 1981-2005.

Order	**Genera**	**Species**	**Branch**						**Little**			
			1981	**1982**	**1983**	**1993**	**1998**	**2005**	**1981**	**1982**	**1983**	**2005**
Coleoptera	Donacia	sp	X			X	X					X
	Gallerucella	nymphaeae	X (sp)				X					
	Stenelmis	sp										X
	Dineutus	sp	X	X					X	X		
	Dineutus	nigrior					X					
	Gyrinus	sp	X	X					X	X		X
	Gyrinus	pugionis										X
	Gyrinus	pectoralis										X
	Dytiscidae	unid										X
	Agabus	sp							X			X
	Coptotomus	sp				X						X
	Coptotomus	lenticulus										X
	Dytiscus	sp				X						
	Graphoderus	sp	X			X			X			X
	Graphoderus	liberus					X					X
	Hydroporus	sp	X	X		X			X	X	X	X
	Ilybius	angustior							X			
	Rhantus	sp	X									
	Uvarus	sp							X			
	Neoporus	undulatus					X					X
	Haliplus	sp								X		
	Haliplus	canadensis						X				
	Peltodytes	sp				X						
	Tropisternus	sp							X			
Diptera	Ceratopogonidae	unid			X							
	Alluaudomyia	sp						X				
	Bezzia	group	X			X	X	X			X	X
	Ceratopogon	sp				X						
	Probezzia	sp					X					
	Sphaeromias	sp						X				
	Chaoborus	punctipennis	X	X	X	X	X	X				

Order	**Genera**	**Species**	**Branch**						**Little**			
			1981	**1982**	**1983**	**1993**	**1998**	**2005**	**1981**	**1982**	**1983**	**2005**
	Tipulidae	unid							X			
Diptera-Chironomid	Tanypodinae	unid	X						X			
	Orthocladiinae	unid	X									X
	Ablabesmyia	sp	X			X	X	X	X	X	X	X
	Chironomus	sp	X	X	X	X	X	X				X
	Cladotanytarsus	sp									X	
	Clinotanypus	sp			X		X	X	X	X	X	X
	Cladopelma	sp				X		X				X
	Conchapelopia	sp							X			
	Corynoneura	sp				X			X			
	Cricotopus	spa				X		X				X
	Cricotopus	bisinctus							X			
	Cricotopus	intersectus					X					X
	Cricotopus	sylvestris										X
	Cricotopus	tremulus							X			X
	Cryptochironomus	sp			X			X	X	X	X	X
	Dicrotendipes	sp				X	X	X	X			X
	Endochironomus	sp	X			X	X	X	X			X
	Eukiefferiella	sp							X			
	Heterotanytarsus	sp			X	X	X	X		X	X	
	Heterotrissocladius	sp			X	X	X	X		X	X	X
	Hydrobaenus	sp					X					
	Labrundinia	sp										X
	Macropelopia	sp				X						
	Microtendipes	sp									X	
	Natarsia	sp	X					X			X	
	Nilothauma	sp										X
	Nilothauma	baybyii						X				
	Orthocladius	sp	X			X		X				
	Orthocladius	annectans	X									
	Parachironomus	sp					X		X			
	Paracladopelma	sp						X				
	Paratanytarsus	sp										X

Order	**Genera**	**Species**	**Branch**						**Little**			
			1981	**1982**	**1983**	**1993**	**1998**	**2005**	**1981**	**1982**	**1983**	**2005**
	Paratendipes	sp							X			
	Phaenopsectra	sp		X			X	X	X			
	Polypedilum	sp	X						X		X	
	Polypedilum	illionoense				X	X					X
	Polypedilum	halterale					X					X
	Polypedilum	tritum						X				X
	Polypedilum	braseniae						X				
	Procladius	sp	X	X	X	X	X	X	X	X	X	X
	Psectrocladius	sp	X		X	X	X	X	X	X	X	X
	Pseudochironomus	sp							X		X	X
	Stenochironomus	sp					X	X				X
	Tanytarsus	sp	X		X	X	X	X	X	X	X	X
	Thienemannemyia	group	X						X			X
	Tribelos	sp	X	X		X	X	X			X	X
	Xenochironomus	sp				X	X	X				X
	Zalutschia	zalutschicola	X		X	X	X	X				
	Zavrelimyia	sp										X
	Pagastiella	sp			X	X	X	X				
	Hyporhygma	quadripunctatum					X	X				
Ephemeroptera	Caenis	sp							X		X	
	Ephemerellidae	unid					X					
	Ephemerella	needhami							X			
	Eurylophella	temporalis		X		X						
	Arthroplea	bipunctata				X						
	Leptophlebiidae	unid				X	X			X		
	Leptophlebia	sp	X	X	X	X		X	X	X	X	
Trichoptera	Oxyethira	sp			X						X	
	Leptoceridae	unid					X					
	Oecetis	sp					X	X				
	Triaenodes	aba					X					
	Limnephilidae	imm	X					X				
	Hydatophylax	argus								X		
	Limnephilus	sp	X	X		X			X	X		

Order	Genera	Species	Branch						Little			
			1981	1982	1983	1993	1998	2005	1981	1982	1983	2005
	Nemotaulius	hostilis		X								
	Platycentropus	sp			X				X	X	X	X
	Platycentropus	radiatus								X		
	Molanna	uniophila				X						
	Molanna	blenda						X				
	Phryganeidae	imm						X			X	
	Agrypnia	improba					X					
	Banksiola	sp							X			
	Banksiola	smithi		X		X			X	X	X	
	Oligostomis	sp					X					
	Phryganea	sp						X				X
	Ptilostomis	sp		X		X	X	X		X		X
	Nyctiophylax	sp				X	X	X				
	Polycentropus	sp	X	X		X			X	X	X	X
	Rhyacophila	acutiloba									X	
	Rhyacophila	carolina group						X				
	Neophylax	sp									X	
	Phylocentropus	sp			X	X	X	X	X	X		X
Plecoptera	Amphinemura	wui			X							
Odonata	Anisoptera	immature	X						X			
	Aeshnidae	immature							X			
	Aeshna	sp				X		X				X
	Aeshna	interrupta	X									
	Aeshna	tuberculifera	X						X		X	
	Aeshna	umbrosa	X							X		
	Aeshna	eremita	X	X				X	X			X
	Boyeria	sp				X		X				X
	Boyeria	vinosa					X					
	Coenagrionidae	unid						X				X
	Chromagrion	sp				X						
	Enallagma	sp				X	X			X		
	Ischnura	sp							X			
	Anomalagrion	sp	X									

Order	**Genera**	**Species**	**Branch**						**Little**			
			1981	**1982**	**1983**	**1993**	**1998**	**2005**	**1981**	**1982**	**1983**	**2005**
	Cordulia	sp				X						
	Cordulia	shurtleffi	X	X					X			
	Lestes	sp	X			X			X			X
	Libellulidae	unid		X		X	X					X
	Erythemis	sp				X						
	Ladona	sp				X	X		X			
	Ladona	julia	X	X				X	X			
	Leucorrhinia	sp				X						
	Leucorrhinia	hudsonica										X
	Leucorrhinia	intacta								X		X
	Libellula	sp				X						
	Nannothemis	bella							X		X	
	Pachydiplax	longipennis	X	X					X	X	X	X
	Libellulidae	Genus A - Immature						X				X
	Libellulidae	Genus B - immature						X				
Megaloptera	Chauliodes	sp				X						
	Sialis	sp		X		X	X	X	X			X
Lepidoptera	Acentria	sp										X
Isopoda	Caecidotea	sp									X	
	Caecidotea	communis							X		X	
	Caecidotea	racovitzai							X	X		X
Gastropoda	Ferrissia	californica				X	X					
	Ferrissia	sp						X				
Bivalvia	Pisidium	sp	X						X	X	X	X
	Pisidium	casertanum				X						
Oligochaeta	Unid		X	X	X				X	X	X	
	Naididae	unid				X						
	Dero	sp					X					
	Pristinella	osborni						X				
	Slavina	appendiculata						X				
	Vejdovskyella	comata					X					
	Tubificidae	unid				X	X					
	Aulodrilus	pigueti						X				X

Order	Genera	Species	Branch						Little			
			1981	1982	1983	1993	1998	2005	1981	1982	1983	2005
	Aulodrilus	paucichaeta										X
	Limnodrilus	hoffmeisteri										X
	Spirosperma	ferox						X				
	Lumbriculidae	unid				X		X				X
	Eclipidrilus	lacustris										X
	Lumbriculus	variegatus						X				X
	Lumbricina	unid										X
Hirudinea	Placobdella	sp							X			X
	Macrobdella	decora							X			X
Neuroptera	Climacia	sp				X						
Hydrachnidia	Limnochares	sp					X					
	Hydrachna	sp					X					
	Hydryphantes	sp										X
	Unionicola	sp					X					
Hemiptera	Corixidae	unid	X	X		X	X	X	X		X	X
	Hesperocorixa	sp				X						
	Palmacorixa	sp					X					
	Palmacorixa	giletti										X
	Palmacorixa	nana						X				
	Sigara	sp						X				
	Sigara	alternata										X
	Trichorixa	sp	X			X			X			
	Belostoma	sp		X								
	Ranatra	sp							X			
	Notonectidae	unid							X			X
	Buenoa	sp		X			X	X	X	X		X
	Buenoa	macrotibialis										X
	Notonecta	sp	X	X		X			X	X	X	X
	Notonecta	undulata						X				X
	Gerris	sp	X	X			X		X			X
	Mesovelia	sp					X					
	Mesovelia	mulsanti						X	X			
	Microvelia	sp				X	X					X

Appendix 2

Vermont LTM study lake physical characteristics.

Lake	**DOC Classification**	**Drainage area (ha)**	**Surface area (ha)**	**Depth (m)**	**Elevation (m)**
Branch	High DOC	101	14	13	802
Little (Woodford)	Low DOC	132	6	3	793