Vermont Wetlands Bioassessment Program

An evaluation of the chemical, physical, and biological characteristics of seasonal pools and northern white cedar swamps

Executive Summary

The overall goal of this project has been to combine the expertise of the Vermont Fish and Wildlife Department's Nongame and Natural Heritage Program (VT NNHP) with its background in natural community classification and the Vermont Department of Environmental Conservation (VTDEC) with its background in biocriteria development as promoted by USEPA water programs to: **1) gather and assess chemical, physical, and biological characteristics of seasonal pools and northern white cedar swamps; 2) evaluate assessment methods; and 3) evaluate the feasibility of utilizing these data to develop an ecologically-based classification of reference condition seasonal pools and determine the effects of disturbance on the ecological integrity of seasonal pools and northern white cedar swamps.**

To address these goals, the collaborators conducted chemical, physical, and biological assessments of 28 seasonal pools and 74 northern white cedar swamps within a range of minimally disturbed (reference) and disturbed conditions. Characterization assessments included measures of aquatic macroinvertebrates, amphibians, algae, vascular plants and bryophytes, soils, birds, and landscape condition. This report presents the results of these assessments with analysis and discussion relevant to the overall goals of the project.

Seasonal Pools

The overall goal of this phase of the project has been to investigate the development of a framework from which to assess the ecological condition of seasonal pools in Vermont in a manner consistent with the Vermont Water Quality Standards. Seasonal pools were assessed in order to :1) develop and evaluate standardized protocols for sampling of aquatic macroinvertebrates, amphibians, vegetation, water quality, and other biological and physical characteristics of seasonal pools; 2) assess the natural variability in the biological, chemical, and physical make-up of undisturbed, reference condition seasonal pools; 3) assess the biological, chemical, and physical make-up of disturbed seasonal pools; 4) assess the feasibility of classifying minimally disturbed pools according to biological and/or physical characteristics; and 5) assess the effects of disturbance on ecological integrity and identify biological metrics that reflect ecological integrity.

A total of 28 seasonal pools were assessed during the years 1999 and 2000. The assessed pools included those representative of reference (minimally disturbed) conditions as well as those representing a range of disturbance. Of those 28 pools, 5 were assessed in both years in order to evaluate annual variability. Pools were selected to represent most of the biophysical regions of Vermont as well as a range of disturbance type and intensity. Biological communities assessed included aquatic macroinvertebrates, algae, vegetation, and amphibians. Water chemistry

included earth metals, major anions, color, pH, alkalinity, aluminum, and specific conductance. A number of ecological observations were made at each pool, including pool size, pool depth, in-pool habitat characteristics, and forest type and condition surrounding each pool. All pools were visited a minimum of twice to assess amphibians and aquatic macroinvertebrates (early and late spring), with additional later visits between August and November as necessary to characterize physical and vegetative parameters. Data were analyzed in a variety of ways in an effort to identify ecological indicators of reference condition classification or disturbance gradients.

Methods

Information on the *physical environment* in and surrounding each pool was collected once at each pool and was augmented with additional data collected on each visit. Latitude and longitude, elevation, maximum pool area, maximum water depth, approximate melt-out date, percent leaf litter composition, percent woody debris composition, a description of the surrounding buffer zone, and an estimation of canopy cover at full leaf-out were noted once for each pool. Measurements of percent canopy cover, ambient air temperature, water temperature, pool area and perimeter, and water depth were recorded during each site visit. Water depth continued to be monitored during any additional site visits.

Water samples were collected at each pool during both sampling rounds (provided the pool contained sufficient water during the second visit). Water chemistry included earth metals, major anions, color, pH, alkalinity, aluminum, and specific conductance. Water samples were consistently collected before any other sampling activities occurred in the pool to avoid disrupting the substrate. Water samples were taken from the deepest area of the pool in smaller pools, and several meters in from the edge in larger pools. Sampling precision was quantified by calculating relative percent difference between duplicate analyses. Additionally, designated spike samples were collected from two pools during each round of sampling. Percent recovery values were calculated for all base cations in the spiked samples, and accuracy was expressed by calculating percent bias.

Aquatic macroinvertebrates were sampled by three methods: funnel traps to catch actively swimming invertebrates (beetles, bugs, mosquitoes, crustaceans); D-net scoops to sample benthic invertebrates in the leaf litter and muck (true flies, clams, snails, and aquatic worms); and a qualitative search for any taxa missed using the two previous methods. All samples were picked and sorted in the laboratory, with subsampling of samples with very high abundance. All organisms were identified to the lowest taxonomic level possible.

Algae sampling primarily targeted diatoms, however, filamentous algae were collected when present. An attempt was made to collect both benthic and planktonic diatom samples from each pool during the second round of sampling. Diatoms were identified to the lowest taxonomic level possible. Samples from only 13 of the 28 pools were processed due to resource limitations.

The *amphibian survey* began before the first round of aquatic macroinvertebrate sampling, and continued through the second round of macroinvertebrate sampling. Each pool was visually surveyed for adults, egg masses, and spermatophores. Additionally, physical habitat information was recorded including descriptions of amphibian habitat used, physical characteristics of the pool, water and ambient air temperatures, prevalent weather conditions, and descriptions of the surrounding habitat.

Quantitative vegetation sampling in seasonal pools followed The Nature Conservancy "Quantitative Community Characterization" methodology (Sneddon 1993), except that the plot boundaries varied in size so as to include the entire seasonal pool, as defined by high water marks in the pool's basin. Under this method vegetation cover was estimated by stratum for the following layers: emergent trees, tree canopy, tree subcanopy, tall shrubs, short shrubs, herbaceous, and non-vascular (bryophytes). Species lists were developed for each stratum and percent cover was estimated for each species. Additionally, total canopy closure was estimated for each seasonal pool.

The *natural communities* and any significant human alterations were mapped and described for a 100 m radius around each seasonal pool during the site visit conducted between August and October. The *watershed area* of each seasonal pool was estimated based on topographic information gathered at each site during the natural community mapping process in conjunction with use of topographic maps and digital orthophotos. Field notes were taken describing *geological features* and this information was compared to published maps on Vermont bedrock geology (Doll 1961), surficial geology (Doll 1970), and various county soil surveys produced by the Natural Resources Conservation Service.

A simple process was developed for ranking the *level of human disturbance* in, and directly adjacent to, each seasonal pool in order to allow comparisons between pools. In addition to this disturbance ranking process, each pool was also given overall ranks for "current condition" and "landscape quality".

Biological data were reported as presence/absence and relative abundance of taxa by site and method. Taxa data were reduced to metrics for some analyses. Sampling methods were evaluated to assess efficiency and representativeness. T-tests were used to determine if disturbed pools showed significantly different biological characteristics from reference pools for each of the candidate metrics. The parametric T-test was used where data were normally distributed and the Mann-Whitney-U test was selected if data was non-normal. Two-way indicator species analysis (TWINSPAN) (Hill 1979) was used to cluster seasonal pool sites by similarity of the aquatic macroinvertebrate and vegetation assemblages. Detrended Correspondence Analysis (DCA)(Hill 1979; Hill and Gauch 1980) was used in order to further explore the similarities between pools and to investigate the relationships between plant and macroinvertebrate communities and environmental variables.

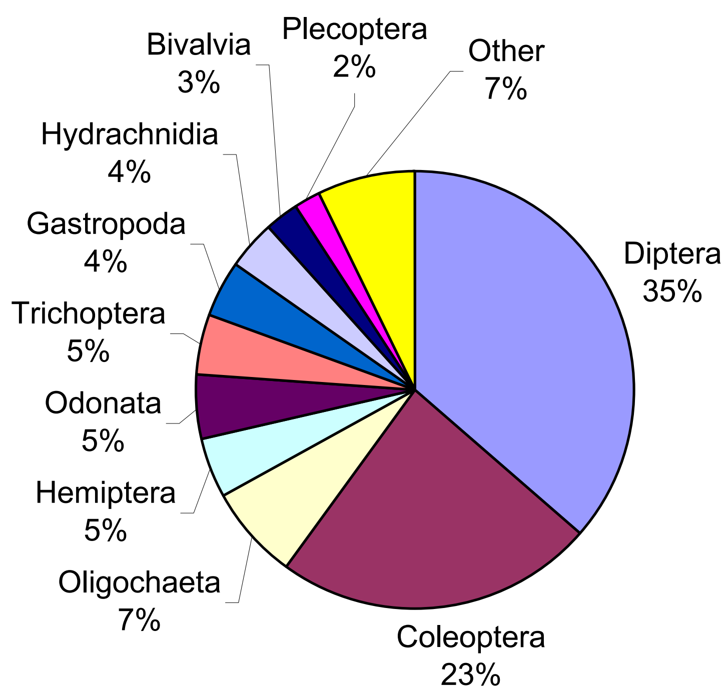
Results and Discussion

The majority of pools were located at mid elevations. Twenty sites were located at an elevation of at least 900 ft. Average elevation for pools sampled was 1196 fet. At 200 ft in elevation, Arms Grant was the only low elevation site (< 500 ft) sampled. The majority (57%) of pools were located within 150 m of other seasonal pools (16 of 28 pools). Only 18% (5 of 28 pools) were located within 150 m of other wetlands. Most of the pools had small watersheds (range of 1,600 m^2 - 12,288 m^2, mean of 5,514 m^2). Only four pools had watersheds greater than 10,000 m^2. The maximum pool water depth recorded in spring was almost 1 meter (0.93 m) at Dorset Pool. The average maximum depth (of springtime measurements) was 0.4 m. The total wetted depth (including pool sediment) was 0.4 m, with a range of 0.2-1.06 m.

The 28 pools were ranked by type and degree of watershed disturbance, with scores from 0-10. Of the disturbance types, logging was rated as the most significant, with 21 of the pools showing some disturbance. Hydrologic alterations and expected effects on water quality were noted at 18 pools. None of the pools were determined to be disturbed by agricultural activities and seven were disturbed by some form of development (roads, trails, buildings, or golf course). Total disturbance rank for the pools ranged from highs of 10 for Carlton Hill (directly adjacent to a gravel road) and 8 for Boyer (surrounding clearcut and skid road at outlet) and Okemo (surrounded by a golf course), to a low of 0 for the two Bald Mountain pools, the two Shaw Mountain pools, and Pine Hill. All five of the latter pools occur in very high quality landscapes with little human disturbance and, by professional judgement, the pools are in very good condition. Reference quality pools were determined to be those with a total disturbance rank of 3 or less and with no individual disturbance type ranked above 2 (moderate).

A total of 358 macroinvertebrate taxa were identified from the 28 pools. Of all the taxa collected, two orders composed the majority of all taxa found in this study: Diptera (35% of total taxa richness) and Coleoptera (23%). All other orders individually composed no more than 7% of total richness. The "Other" category on **Figure E1** includes the following orders: Hirudinea, Lepidoptera, Ephemeroptera, Tricladida, Megaloptera, Anostraca, Isopoda, Neorhabdocoela, Conchostraca. Each of these orders had no more than five taxa from any of the seasonal pools.

Figure E1. Aquatic macroinvertebrate percent taxonomic richness by order. Percentages are based on a comprehensive project taxonomic list from all pools and all sampling methods**.**



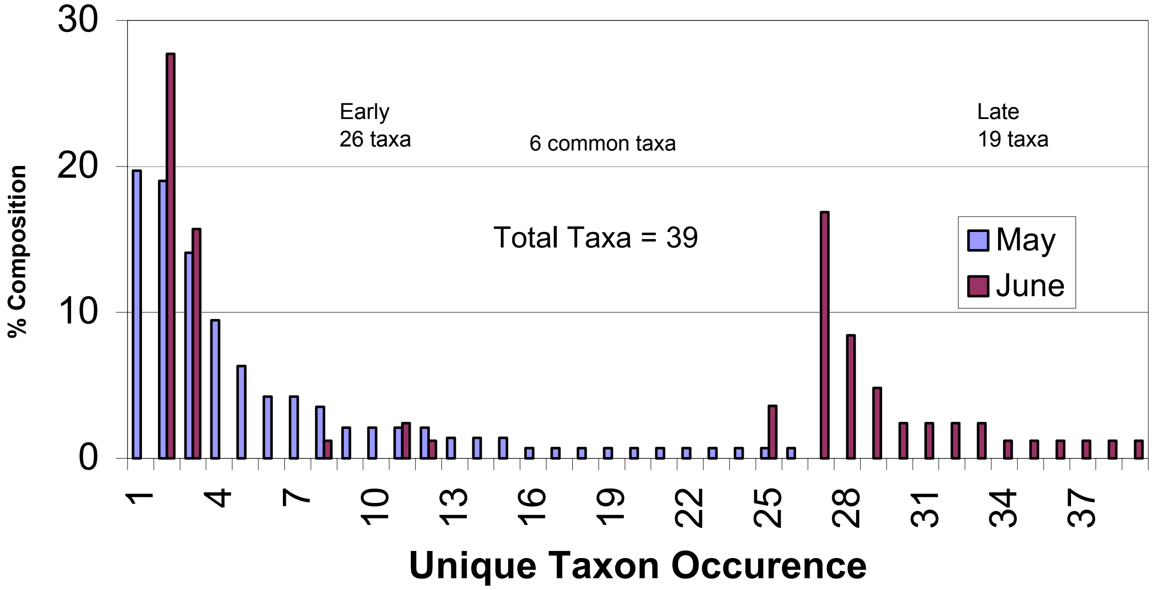
Dipteran larvae had the greatest richness and were often the dominant aquatic insects found in the study pools. Thirteen families of true flies were collected. Thirty-five percent of the taxa collected were from the Family Chironomidae (52 taxa). The six most commonly observed were *Chironomus* sp. (24 pools), *Polypedilium trigonus* (17 pools), *Limnophyes* sp. (15 pools), *Larsia* sp. (14 pools), *Phaenopsectra* sp. (13 pools), and *Pseudosmittia* sp. (13 pools). Members of these genera were often the dominant taxa in the pools. Mosquitoes (Family Culicidae) were ubiquitous, being collected from 27 of the 28 pools. Three genera of Phantom Midges (*Mochlonyx, Chaoborus, Eucorethra*) were collected from the seasonal pools. Beetles were second only to the Diptera (true flies) in terms of pool taxa richness. The Coleoptera were exceptionally diverse and found in all the pools. A total of 74 taxa were collected. The families Curculionidae (weevils) and Staphylinidae (rove beetles) along with the dytiscid genera *Hydroporus* and *Agabus* were not identified to species. Speciation of the adults of these taxa would have increased the beetle richness. Larval keys are not available for most species level identifications. The greatest diversity was in the families Dytiscidae (predaceous diving beetles-37 taxa) and Hydrophilidae (water scavenger beetles-19 taxa). Even lacking larval species-level identifications, these two families accounted for at least 75% of the beetle taxa.

Three sampling methods were used to assess aquatic macroinvertebrate fauna: traps, D-frame net scoops and qualitative searching. Each sampling method was targeted to sample certain communities. Traps were intended to collect swimming or crawling organisms, scoops collected aquatic macroinvertebrates associated with the leaf litter, bottom substrate and muck, and qualitative samples collected taxa that were not represented or were under-represented with the previous two methods. The majority of taxa encountered in this project were collected at some point in trap samples, although the traps were not always the most efficient method of capturing the taxa encountered. The scoop and qualitative samples supplemented the traps. Overall, traps were the most effective sampling method for collecting total richness of organisms (59%), followed by the scoop method (22%) and the qualitative method (19%)

The trap method collected the greatest taxa richness for the following orders: Coleoptera, Hemiptera, Ephemeroptera (equal with scoop), and Neorhabdocoela, (equal with scoop). The scoop method collected the greatest taxa richness for the following Orders: Diptera, Gastropoda (equal with qualitative), Oligochaeta, Ephemeroptera (equal with traps), Lepidoptera, Megaloptera (equal with qualitative), Neorhabdocoela, (equal with traps). The qualitative method collected the greatest taxa richness for the following Orders: Gastropoda (equal with scoop), Trichoptera, Hydrachnidia, Plecoptera, Odonata and Bivalvia, Megaloptera (equal with scoop).

Most sites were sampled twice during the year for macroinvertebrates: once in early spring and again in late spring/early summer. Observations of the data show that in many cases, there were large differences between the early and late spring samples, particularly in regard to taxa richness and taxa occurrence, as demonstrated in **Figure E2.**

Figure E2. Dartmouth seasonal pool taxa occurrence - early and late qualitative sampling. Of 39 total taxa observed during 2 visits, only 6 were common to both sampling events.



The pattern of taxa occurrence observed in **Figure E2** was common for all sampling methods as well as between replicates for scoops and traps. Temporal variability of taxa occurrence and relative abundance was so extreme that there was often little resemblance in the taxonomic structure of the fauna observed between replicates, between dates, and between years at the same pool regardless of sample method. Populations of many taxa, both dominant (>4%) and rare (<1%), in these seasonal pools were extremely variable and of short duration. The taxa encountered at any specific time will vary greatly depending on temporal variations in factors which favor the initiation of life cycle development, including temperature, snowmelt, and hydrology. The term ephemeral is truly appropriate for invertebrate populations in these pools.

Much of the variability in the occurrence of invertebrate taxa was driven by rare or infrequently encountered taxa. For all methods, the number of taxa encountered was dominated by taxa comprising less than 1% of the overall sample abundance. Taxonomic resolution was high for this project, resulting in extensive species lists. The ecological significance of high taxonomic resolution was not evaluated to any great extent by this project.

The two most common **amphibians** found at the pools were the wood frog (*Rana sylvatica*) and the spotted salamander (*Ambystoma maculatum*). They were found at 27 of 28 sites (96.4%). The least common species was the Jefferson salamander (*Ambystoma jefersonian x laterale*), found at only 25% of the sites (7 of 28). Green frogs (*Rana clamitans*) and eastern newts (*Notophthalmus viridescens*) were found at 54% (15 of 28) and 64% (18 of 28) of the sites respectively.

There was extreme variability in both the **plant species** composition and the overall abundance of plants in the 28 pools visited. Canopy cover from overhanging trees of surrounding upland forests ranged from 5 to 100%, with an average canopy cover of 28%. There was similar variability in rooted herbaceous plant cover in the pools, with cover ranging from 0 to 95% and averaging 28%. A total of 99 species of vascular plants and bryophytes were identified growing within the pools' high water marks. However, species richness was low for all pools, ranging from highs of 25 species at Hughes and 21 species at Arm's Grant and Okemo, to lows of 0 species at Ball Mountain and only 2 species at Bald Mountain South, Iroquois Tannic, MBR Saddle, and Pine Hill. The species that occurred with the greatest frequency in the 28 pools were sensitive fern (*Onoclea sensibilis* - 20 pools), marsh fern (*Thelypteris palustris* - 15 pools), common water-horehound (*Lycopus uniflorus* - 10 pools), and cinnamon fern (*Osmunda cinnamomea*), royal fern (*Osmunda regalis*), and mad-dog skullcap (*Scutellaria lateriflora* - 9 pools). The most frequent tree species in the uplands adjacent to the pools were red maple (*Acer rubrum* - 20 pools), eastern hemlock (*Tsuga canadensis* - 18 pools), sugar maple (*Acer saccharum* - 15 pools), American beech (*Fagus grandifolia* - 15 pools), and white ash (*Fraxinus americana* - 15 pools).

Algae (diatom) data are available only for the thirteen pools sampled in 1999. The most speciose genera were *Pinnularia, Eunotia*, and *Navicula*, accounting for nearly 50 % of the species encountered. *Eunotia* spp. was the only genus that was found in all thirteen pools. This genus was also a dominant component of the diatom flora in several of the pools. The genera *Neidium* and *Tabellaria* were found in only one pool each.

As a first step in **classifying the 28 pools,** Two-Way Indicator Species Analysis (TWINSPAN) was used with a combined dataset of aquatic macroinvertebrates and vegetation. This analysis included all pools, regardless of the level of human disturbance. The intention was to identify types of seasonal pools, recognizing that impaired pools may be identified as a type themselves. Detrended Correspondence Analysis (DCA) was used to ordinate the same combined data set of aquatic macroinvertebrates and vegetation. A secondary matrix of 23 environmental variables was included in the analysis in order to elucidate patterns between the grouping of pools and these variables. The above-described TWINSPAN and DCA analyses were also used on a combined dataset of aquatic macroinvertebrates, vegetation, and amphibians. Very similar results were obtained by adding the five species of amphibians, and no further discussion of this analysis seems warranted. This analysis resulted in the identification of five pools that were considered to be permanent rather than seasonal. These five pools were eliminated from further classification analyses. TWINSPAN and DCA were also run on the aquatic macroinvertebrate and vegetation data for the 23 seasonal pools, excluding the 5 permanent pools. As with the previous analyses, those species that occurred in only one seasonal pool were eliminated; in this case reducing the number of taxa in the analyses to 240.

Based on these analyses it can be concluded that variations in aquatic macroinvertebrate and plant species composition are related to variations in environmental characteristics of each pool, especially percent canopy cover, pool perimeter, depth of organic soil, water chemistry, and watershed area. The duration and frequency of seasonal inundation are likely some of the most important environmental variables in determining pool biota, but accurate measurements of these variables would require multiple visits to each pool over several years and was beyond the scope of this project. Other than separating of the permanent pools from the seasonal pools in the analysis of the 28 pools, the DCA ordination shows a continuum in variation between the seasonal pools, with no clear-cut types or classes. Furthermore, it can be concluded that the TWINSPAN and DCA of these datasets cannot be used to distinguish conclusively between undisturbed and highly disturbed seasonal pools, using the disturbance rank as an indictor of disturbance.

The results of the previous analyses indicate that aquatic macroinvertebrates play a greater role in the classification of the pool types than do the vascular plants and bryophytes and amphibians. The development and testing of metrics in later sections of this report, therefore, focus primarily on aquatic macroinvertebrate taxa.

Seventeen invertebrate community metrics were tested for significant differences between reference and disturbed pools. T-tests or Mann Whitney U tests were used to measure significance differences of candidate metrics between the 9 reference pools and the 14 disturbed pools. There were no statistically significant differences ($p<0.05$) in metric values between the reference and the disturbed pool groups.

TWINSPAN was used to classify macroinvertebrate assemblage types. The TWINSPAN included all 23 seasonal pools because no differences in biological metrics could be established between reference and disturbed pools. Two TWINSPANs were conducted on the dataset, differing in the number of taxa included in the analysis. The first analysis included only taxa occurring at two or more sites (resulting in 146 taxa); and the second analysis (82 taxa) included only taxa composing 4% or more of any sample and occurring at two or more sites. Both used presence-absence data. The two TWINSPANs produced similar first-division groupings, as well as indicator and preferential taxa. Only 3 of the 23 pools (Bald Mountain South, Woodstock Inn and Iroquois Tannic) varied in group membership depending on the dataset used. The two first division groups (referred to as negative and positive groups) were made up of 14 pools in the negative group and 9 pools in the positive group for both TWINSPANs.

The two groups of pools identified by the previous analysis were designated as the “Marsh Beetle” group and the “Diving Beetle” group of pools, as indicated by preferential taxa **(Table E1).** In general, the Marsh Beetle pools were characterized as smaller (shorter perimeter and watershed size), with more canopy cover and moderately to mildly acidic conditions. These pools had lower specific conductance, alkalinity, and dissolved calcium and magnesium concentrations. The Diving Beetle pools were generally larger and less acidic with greater specific conductance and alkalinity. Although mean values of some variables significantly differed, all variable values overlapped between the pool types. As a result, no physical descriptor measured here could consistently differentiate between the two pool assemblage types. Despite this, however, a *reasonable* prediction may be inferred on the biological pool type based on a combination of physical and chemical attributes relating to levels of base cations, canopy, and acidity. DCA was performed on the 82 taxa dataset from the 23 seasonal pools. The resulting joint plot shows that assemblages were arrayed in axes 1 and 2 by pH, percent canopy cover, and dissolved potassium concentrations. The plot can be divided down the middle with the left side representing Marsh Beetle pools and the right side, Diving Beetle pools. This is a further indication that aquatic macroinvertebrate community structure is partially driven by pH, percent canopy cover (also related inversely to pool perimeter), and base cations (calcium, magnesium, sodium, and potassium).

Table E1. TWINSPAN groups from the first division of 23 seasonal pools on the 82 taxa dataset of macroinvertebrates collected during 1999-2000. Total watershed disturbance values are given with each pool. Reference pools (total disturbance rating <4) are in italics.

Marsh Beetle Pools	Diving Beetle Pools
MBR-Lake-6	Okemo-8
Iroquois Tannic-5	Irish Hill North-7
MBR-Saddle-4	Irish Hill South-7
Hughes-4	Arms Grant-6
Dana Hill South-4	Woodstock Inn-6
Hampshire Hill-4	Dartmouth-6
Thistle Hill-4	Dorset-5
Sleepers River-1	*Maidstone-3*
Whitcher Mountain-1	*Iroquois Maple-1*
Dana Hill East-1	
Pine Hill-0	
Bald Mountain North-0	
Bald Mountain South-0	
Ball Mountain-0	

The disturbance rankings between the groups were significantly different (p=0.05; t-test) with the Marsh Beetle pools having lower disturbance values - mean of 2.6 vs 5.4 for Diving Beetle pools). This indicates that disturbance (as characterized by the disturbance rating) may have an influence on assemblage composition in addition to some of the measured physical and chemical factors. All 17 candidate biological metrics were tested for significant differences between the two assemblage types. Four differed significantly between groups. These were percent dominance-single taxa (p=0.04; *t*-test), percent dominance-3 taxa (p=0.03), species diversity index (p=0.04), and percent dipterans (p=0.03). It is possible that the division of reference vs. disturbed pools (as determined by disturbance ranking) did not group pools as accurately as did TWINSPAN, which was based on assemblage taxonomic structure. As before, with other variables, there was much overlap in metric value range between the two assemblage types. This indicates that further efforts to identify viable metrics that consistently reflect biological response to disturbance may yet produce positive results.

Biological metrics were not developed for vascular plants and bryophytes as they were for aquatic macroinvertebrates, although it may be worth pursuing this in future studies. At this time there are still some observations to be made about vascular plant species composition in the pools relative to their level of disturbance. Invasive, non-native species are commonly associated with disturbance in wetland and upland natural communities. It is interesting to note that only three non-native species of vascular plants were found in the 28 pools. Although these non-native species clearly occur more frequently in disturbed pools, their presence in a pool is not a definitive indicator of pool disturbance level. Several vascular plant species identified in the study pools are native annuals and perennials that have ruderal life cycle strategies. Ruderal species are typically adapted to stressful environments or those with fluctuating environmental conditions and they commonly have periods of dormancy and then rapid reproduction. Seasonal pools in undisturbed settings are themselves habitats with wildly fluctuating environmental conditions (inundation to dessication) and ruderal species are to be expected here. However, disturbed pools are under additional stresses and appear to harbor either additional ruderal species or the same species in greater abundance than undisturbed pools.

CONCLUSIONS – Seasonal Pools

The following conclusions can be made regarding the objectives for this study of seasonal pools.

1. Methods of sampling aquatic macroinvertebrates in seasonal pools were evaluated in detail. The scoop method was found to be very disruptive to the pools, especially of critical amphibian life stages. This method was also found to be inconsistent in the number of taxa collected and the abundance collected, in part because of accumulation of debris in the scoop. The scoop method was most consistent in sampling taxa associated with the sediment. The trap method was very successful at capturing mobile species, but also collected sediment associated species when placed in close contact with sediments. Trap sampling requires at least two visits to each pool and may capture adult amphibians as well. An interesting finding of the macroinvertebrate sampling was that there is extreme temporal variability in the relative abundance and occurrence of taxa in a pool. This variability was so extreme that there was little resemblance in the composition of macroinvertebrates between sampling replicates, between multiple sample dates over one season, or between years at the same pool, regardless of the sampling method. Methods for sampling vegetation, amphibian populations, and water quality in seasonal pools and other wetland ecosystems were well established prior to this study and were not evaluated in detail for this project.

2. Although the basic environmental conditions in which vernal pools develop are very specific (small basin with a small watershed and a combination of water-accumulation and substrate type that allows for spring and/or fall inundation), the biological and water chemistry characteristics of individual pools vary greatly. The primary environmental gradients associated with the pools studied were percent canopy cover (and the closely related pool perimeter), depth of organic soil, and several water chemistry parameters based on Detrended Correspondence Analyses run on macroinvertebrate and plant composition of pools. Vascular plant and bryophytes were not effective in classifying either reference quality or disturbed seasonal pools sampled in this study. Aquatic macroinvertebrate composition of the pools were used to identify two classes of pools designated as Diving Beetle pools and Marsh Beetle pools. Classification membership was not clearly related to disturbance although there was some indication that factors related to disturbance but not exclusively caused by disturbance (eg percent canopy) may contribute to classification status.

3. The data collected on the presence and absence of amphibians and their egg masses was not useful by itself in classifying pools or as a means of distinguishing between reference and disturbed pools.

4. None of the 17 aquatic macroinvertebrate metrics tested can be recommended for use in measuring biological impacts from human disturbance due to 1) the lack of statistically significant differences in metrics between disturbed pools and reference quality pools, and 2) the lack of structural differences between the disturbed and reference pools as evidenced by a TWINSPAN of all 23 pools.

5. Parametric and non-parametric hypothesis tests contrasting TWINSPAN-defined groups from the total 23-pool dataset showed that one of the two groups had four physical and chemical variables that differed significantly ($p<0.05$, t-test or Mann-Whitney- U test). These were percent canopy cover, pool perimeter, pH, and dissolved magnesium concentration. With additional seasonal pool data, these variables (and possibly elevation) may eventually be used to

differentiate seasonal pools types. The current dataset, however, shows much overlap in all values tested between the two seasonal pool types. As a result, only a modest predictive value can be generated on the parameters that significantly differed between types.

RECOMMENDATIONS – Seasonal Pools

Additional reference-level seasonal pools from as varied locations as possible could be sampled for invertebrates, plants, and amphibians to supplement the dataset. This would assist in the identification of additional reference seasonal pool types. Experience from this project indicates that aquatic macroinvertebrates may be the group that would be most productive to focus on for any future work. Also, more clearly degraded sites should be added to the dataset so that any differences that do exist in metrics between reference and disturbed sites missed during the present evaluation may be identified during a second analysis. Developing additional biological metrics for testing should also be considered.

Seasonal pools are highly significant for the amphibian breeding habitat that they provide. In this study, we identified the presence and absence of all amphibian life stages encountered in each pool. Given the scope of the project, however, it was not possible to evaluate the breeding success of each species at each pool. Although evaluating breeding success of amphibians may be a labor-intensive and time-consuming undertaking, it may also be one of the best measures of ecological integrity of seasonal pools and the surrounding upland forests and should be considered in future studies of this kind.

Variability in the duration and timing of inundation in seasonal pools is clearly a dominant factor determining aquatic macroinvertebrate, amphibian, and plant species composition in a particular pool. Full documentation of pool hydroperiod was beyond the scope of this study, but should be pursued in future studies of this kind. Hydroperiod could be measured by multiple visits to each pool or possibly with the use of remote data loggers.

Northern White Cedar Swamps

The overall goal was to identify specific attributes that can serve as indicators of ecological integrity in northern white cedar swamps.

The specific objectives were to identify assemblages of plants (vascular and bryophytes), species of birds, and assemblages of aquatic macroinvertebrates that may serve as indicators of ecological integrity for northern white cedar swamps.

The selection of northern white cedar swamps as the wetland community for this bioassessment study was based on several factors. The Vermont Fish and Wildlife Department's Nongame and Natural Heritage Program (NNHP) completed a three-year, statewide study of northern white cedar swamps that was funded by the US Environmental Protection Agency (Sorenson et al. 1998). This study provided relatively complete information on the distribution of cedar swamps in Vermont and their vegetational and ecological variability. The vegetation and ecological data collected during this study was easily adapted to examination for bioassessment purposes.

Northern white cedar swamps clearly present a challenge for typically aquatic-based biological assessments in that they often contain almost no standing water at any time of the year. In these wetlands, truly aquatic organisms may be scarce or nonexistent, therefore, focus must be shifted to more terrestrial plant and animal assemblages. As part of this assessment, we evaluated vegetation and breeding bird data that the NNHP gathered in the earlier statewide inventories of northern white cedar swamp sites and augmented these with new data from additional cedar swamps using previously established protocols. We also assessed the feasibility of sampling aquatic macroinvertebrates. In an effort to limit the natural variability between cedar swamp sites, we focused our efforts on the "typical" northern white cedar swamps as described in the NNHP's cedar swamp study (Sorenson et al. 1998) and the Vermont natural community classification (Thompson and Sorenson 2000).

Methods

A total of 36 "typical" northern white cedar swamps were selected for inclusion in this project. These sites were selected from a total of 262 swamps identified by the Vermont Nongame and Natural Heritage Program during a statewide inventory of northern white cedar swamps and red maple-northern white cedar swamps in 1996 and 1997 (Sorenson et al. 1998). Seventy of the highest quality swamps representing the full geographic range of the communities were visited for detailed study and sampling of vegetation and surface water pH and conductivity. The highest quality swamps were identified as those with little or no evident human alteration of the vegetation or hydrology, and with mostly intact, forested, upland buffers. Thirty-two of these sites were selected as "typical" and were included in this project. In addition to the 32 swamps visited for the 1998 study, four additional northern white cedar swamps were selected for the current project. These four sites were selected from the known occurrences as yet unsampled northern white cedar swamps identified during the initial cedar swamp inventory, and included three relatively disturbed examples and one reference quality example of this community type.

Field methods for the four new swamps visited for this study were the same as for the initial NNHP inventory of northern white cedar swamps (Sorenson et al. 1998). They consisted of both general observations of the site and quantitative vegetation sampling. Site observation entailed reconnoitering the swamp, developing a species list of vascular plants and bryophytes, periodically sampling organic soil type and depth with a Dutch auger and/or fiberglass chimney-sweep pole extensions, periodically sampling pH and conductivity of surface water with pocket meters, and noting characteristics of microtopography, hydrology (e.g., active seeps, flowing water) and vegetation patterns, including forest structure and tree diameter.

Quantitative vegetation sampling was conducted during the summer of 1999 and followed The Nature Conservancy "Quantitative Community Characterization" methodology (Sneddon 1993). Sampling as done in selected representative plots. Plots were 200 m^2 (10m x 20m) and boundaries of the plot were located and marked with a 50 m measuring tape and colored flagging. For each plot, vegetation cover was estimated and recorded by stratum for the following layers: emergent trees, tree canopy, small trees, tall shrubs, short shrubs, herbaceous, and non-vascular.

A breeding bird census was conducted in each of the six northern white cedar swamps in the spring of 1999. The procedure for this census work was the same that was used for the three other northern white cedar swamps in the 1998 study. This sampling protocol followed that used by the Vermont Institute of Natural Science in their Forest Bird Monitoring Program, which in turn are based on methods developed by the Canadian Wildlife Service in Ontario. Up to five listening stations were established at each of the six swamps. Each site was sampled twice during the breeding season - once during the first ten days of June and again seven to ten days later.

Three sites were visited in early summer to assess the feasibility of sampling aquatic macroinvertebrates for bioassessment and monitoring purposes. Standing or flowing water was not found at either the reference site or at one of the impaired sites. Thus, sampling was not effective. However, there was evidence that suggested the presence of water earlier in the season. The second impaired site contained many braided, slow-flowing channels and some standing water. Three of the channels and a small hollow at the base of a boulder were qualitatively sampled. The samples were preserved in the field, picked and sorted, and identified according to standard protocol.

Physical and chemical data were collected at each quantitative vegetation-sampling plot and recorded on the plot form. This included depth of organic soil, soil profile description, degree of decomposition of organic soil layers by the von Post scale, characterization of soil drainage and soil moisture regime, description of microtopography, and pH and conductivity of surface water.

The process for ranking levels of disturbance in northern white cedar swamps was the same as that used for seasonal pools. Five disturbance types were evaluated for each swamp: logging, hydrologic alteration, water quality alteration, agriculture, and development. Each of these disturbance types was assigned a disturbance severity rank: 0 = None, 1 = Minimal, 2 = Moderate, and 3 = High. A total disturbance rank for each swamp was obtained by adding the severity ranks for each disturbance category. The disturbance categories of logging, agriculture, and development were rated based on the level and abundance of these activities in the swamp and a 150 m buffer surrounding each swamp. The categories of hydrologic alteration and water quality alteration were rated based on a professional judgment assessment of the degree to which any disturbance would be expected to alter the water quality or hydrologic regime of a swamp and were not necessarily based on empirical data.

Several other characteristics of the study swamps were evaluated either during the site visit or during subsequent office review of information. For each swamp, observations of forest structure, evidence of logging or other human disturbance in the swamp, and cores of two or more average sized cedar trees were used as the basis for labeling the swamp as old growth or not. The presence of recent or past beaver activity was also noted during site visits and also during the office review. Only for the 36 swamps that were classified as the "typical" variant and used for the majority of this project, additional information on characteristics of the swamp buffer were generated based on office review.

Two-way indicator species analysis (TWINSPAN) (Hill 1979) was used to cluster the 74 cedar swamp plots based on their vegetation composition. Detrended Correspondence Analysis (DCA)

(Hill 1979; Hill and Gauch 1980) was used in order to further explore the similarities and differences between cedar swamps and to investigate the relationships between plant assemblages and environmental variables. Spearman rank order correlation and Mann-Whitney Rank Sum Test were used to evaluate whether the candidate metrics were significantly different between the reference and disturbed cedar swamps.

Results and Discussion

Saturated soil conditions occur in all cedar swamps that were studied. Organic soil depths range from as little as 20 centimeters at Notch Swamp to as much as 5.5 meters in the deep basin of Mount Sarah Southeast Swamp.

Although pH ranged from 4.7 to 7.7, only three swamps had pH readings under 6.0 (Norton Pond Northwest Arm Swamp, Notch Swamp, and West Mountain Brook Cedar Swamp). All three of these swamps occur in the Northeastern Highlands biophysical region, and specifically, they occur over granitic bedrock that tends to produce more acidic, mineral-poor waters.

Surface water conductivity ranged from 30 to 720 microsiemans (uS) and is weakly and positively correlated with surface water pH ($r=0.434$, $P=0.007$ using Spearman rank order correlation). The extremely high conductivity of 720 uS at Berlin Mall Cedar Swamp is likely a result of stormwater runoff pollution, especially road salt, at this swamp in a highly developed area.

Cedar swamps range from 6 to 165 acres, with a mean of 54 acres.

Total disturbance ranks are given in **Table E2** and ranged from 0 at Bear Mountain Pond, Melvin Hill Swamp, and Roy Mountain Cedar Swamp, to 9 at the highly disturbed Berlin Mall Cedar Swamp and Cemetery Cedar Swamp. For this study, reference quality northern white cedar swamps were considered to be those with a total disturbance ranking of 3 or less and with no individual disturbance type ranked above 2 (moderate severity). A total of 16 of the 36 cedar swamps were considered to be reference quality based on these criteria. Current condition provides an overview of the condition of a swamp at the time of a site assessment and the ranking ranges from natural conditions with little human disturbance to high level of human disturbance. Landscape quality provides a simple assessment of the landscape adjacent to a swamp and ranks the level of human disturbance in this surrounding area. It is interesting to note that current condition and landscape quality are only weakly correlated with each other ($r=0.55$, $P<0.001$). This is likely because it is possible for the interior of a cedar swamp to be in very good condition (good forest structure, development of hummocks and hollows, no exotic species, and no recent logging) and still be in a fragmented landscape (with roads, clearcuts, or development nearby).

Five of the 36 northern white cedar swamps were rated as being "old growth". Although these five sites are mature examples of northern white cedar swamps with old trees, lots of downed and dead wood, and multi-aged canopies, they have all surely seen some disturbance in the past. The "minimum buffer width" and the "percent of wetland buffer greater than 50 m" served as two additional metrics to evaluate the level of disturbance at individual swamps. The minimum buffer width ranged from 0 to 980 m. The percent of wetland buffer greater than 50 m ranged from 15% at Berlin Mall Cedar Swamp to 100% at eleven swamps.

Table E2. Total disturbance ranking and other characteristics of the 36 swamps (38 plots) relating to site disturbance. Reference quality swamps (total disturbance rank of 3 or less) are listed in bold type.

Site Name	Total Disturbance Rank[(1)]	Current Condition[(2)]	Landscape Quality[(2)]	Old Growth	Minimum Buffer Width (m)	Percent Buffer >50m
Albany Cedar Swamp	6	2	3	2	0	60
Bald Hill Swamp	**1**	1	1	2	900	100
Bear Mountain Pond	**0**	1	2	1	670	100
Berlin Mall	9	3	4	2	0	15
Berlin Pond	5	2	3	2	0	50
Black River Swamp	5	3	3	2	0	70
Bliss Pond Cedar Swamp	**1**	2	2	2	75	100
Bruce Pond Cedar Swamp	4	2	2	2	30	85
Calendar Brook WMA Swamp	5	2	3	2	50	80
Cemetery Cedar Swamp	9	2	3	2	0	15
Coles Pond	**1**	1	2	1	50	95
Confluence Basin Swamp	5	2	2	2	0	70
Dutton Brook Swamp	**2**	1	2	2	0	90
East Peacham Swamp	5	2	3	2	0	80
Ewells Mills Swamp	**3**	1	3	2	20	88
Flagg Pond-1	**1**	1	2	2	165	100
Flagg Pond-2	**1**	1	2	2	165	100
Long Pond	**1**	1	2	1	200	100
Maple Hill Swamp	**3**	2	2	2	50	100
Martell Swamp	**3**	2	2	2	0	95
Melvin Hill Swamp	**0**	1	1	1	980	100
Molly's Brook Swamp	7	2	3	2	0	32
Mount Sarah Southeast Swamp	6	3	3	2	0	65
Mud Pond Holland	6	3	3	2	0	75
Newbury Village Land Swamp	**1**	1	2	2	120	100
Norton Pond Northwest Arm Swamp	5	2	2	2	0	45
Notch Swamp	4	2	2	2	0	80
Page Brook Swamp	4	2	2	2	125	100
Pherrins- Clyde River Swamp	6	2	3	2	0	55
Pond Brook Cedars	6	2	3	2	0	40
Roy Mountain Cedar Swamp	**0**	1	1	1	600	100
Sawdust Pond Cedar Swamp	4	2	2	2	0	80
Small Mud Pond Cedar Swamp	5	2	3	2	0	55
Tamarack Brook Flats	4	1	3	2	0	90
Victory WMA North Cedar Swamp	**3**	2	2	2	0	85
West Mountain Brook Cedar Swamp	**3**	2	2	2	0	90
Willoughby River Swamp (LWill)	6	2	3	2	0	60
Willoughby River Swamp (WillR)	6	2	3	2	0	60

(1) Total disturbance rank is the sum of individual swamp ranks for five types of disturbance.
(2) See Table 24 for explanations of Current Condition and Landscape Quality ranking codes

There were 260 distinct species of vascular plants and bryophytes identified in the 38 plots determined to be the "typical" northern white cedar swamp type. Of the 260 species, 201 are vascular plants, 49 are mosses, and 10 are liverworts.

A total of 58 species of birds were recorded at the nine northern white cedar swamps included in the breeding bird surveys. Only White-throated Sparrow occurs at all nine swamps. Three species, Northern Waterthrush, Winter Wren, and Black-capped Chickadee occur at eight of the nine swamps. Six of the 58 species identified appear on the Partners in Flight priority list for the Bird Conservation Region 14, Atlantic Northern Forest (Rosenberg and Dettmers 2002).

Three northern white cedar swamps were visited in early summer (June-July), to assess the feasibility of sampling aquatic macroinvertebrates for bioassessment and monitoring purposes. The very dry weather in 1999 caused the cedar swamps to be even drier than usual at that time of year. It is possible that aquatic micro-habitats in cedar swamps are not available consistently enough to sample for aquatic macroinvertebrates, however our limited sampling efforts did not conclusively elucidate the feasibility of using aquatic macroinvertebrates as biological indicators in cedar swamps.

In order to minimize this between-site natural variability so as to better focus on attributes that reflect anthropogenic disturbance, classification of northern white cedar swamps was undertaken. The first step was to use TwoWay Indicator Species Analysis (TWINSPAN) as a tool to help classify the 74 cedar swamp plots into community types, as was done in the 1998 cedar swamp study. The two-way ordered table resulting from this TWINSPAN identified four main types of cedar swamps that appear to be ecologically meaningful. Detrended Correspondence Analysis (DCA) was used to ordinate 73 of these cedar swamp plots. A secondary matrix of nine environmental variables plus TWINSPAN group indicator was included in the analysis in order to elucidate patterns between the groupings of plots and the environmental variables. Several of the environmental variables were correlated with Axes 1 and 2 of the DCA ordination and help explain variability in cedar swamps. DCA analysis supported the identification of four cedar swamps types, two main community types (NWCS-Typical and NWCS-Red Maple) and two variants (NWCS-Boreal Acidic and NWCS-Sloping Seepage Forest). The results of these classification analyses were used to select the 38 “typical” NWCS plots to be used for the development and testing of biological and physical metrics.

TWINSPAN and DCA were also performed on the this new set of 38 "typical" northern white cedar swamp plots in order to: 1) look for meaningful additional separation of types within this group; 2) check for correlations between DCA axes and environmental variables; and 3) evaluate whether disturbance rankings and biological metrics are correlated with DCA axes. The candidate biological metrics evaluated were: percent cover for the canopy, tall shrub, short shrub, herbaceous, and bryophyte layers; total species richness; vascular plant richness; and bryophyte richness; and number of exotic plant species. Eighteen of these environmental variables, disturbance rankings, and candidate biological metrics were quantitative. Only "old growth" was a categorical variable, as each swamp was assigned a "yes" or "no".

Neither the TWINSPAN nor DCA identified any further meaningful subdivision of the 38 plots. There were only weak correlations between Axes 1 and 2 of the DCA ordination and the 19 environmental variables, disturbance rankings, and candidate biological metrics. These results indicate that, based on the data used, none of the candidate biological metrics and none of the environmental variables are effective in distinguishing between the reference and disturbed northern white cedar swamps (**Table E3**).

Table E3. Results of the *t*-tests (t) and Mann-Whitney rank sum test (M-W) of candidate biological metrics, environmental variables, and disturbance rankings for the 16 reference swamps and 22 disturbed swamps. Means are presented for the t-tests and medians for the Mann-Whitney rank sum tests.

Metric	Reference Swamp Mean or Median	Disturbed Swamp Mean or Median	P-value	Test Used
Bryophyte % cover	85	80	0.712	M-W
Herb % cover	47	41	0.429	t
Short shrub % cover	12	19.5	0.120	t
Tall shrub % cover	2	6	0.267	M-W
Canopy % cover	85	84	0.958	t
Bryophyte richness	9.8	10.6	0.457	t
Vascular plant richness	44	44.5	0.869	t
Total richness	54	55	0.637	t
Exotics	0	0	0.207	M-W
pH	6.67	6.67	0.969	t
Conductivity (μS)	60	105	0.114	M-W
Organic soil depth (meters)	1.7	1.6	0.822	t
Size of swamp (acres)	40	43	0.813	M-W
Total disturbance rank	1	5	<0.001	M-W
Current condition	1	2	<0.001	M-W
Landscape quality	2	3	<0.001	M-W
Minimum buffer width (meters)	97.5	0	<0.001	M-W
% buffer greater than 50 meters	100	62.5	<0.001	M-W

Spearman rank order correlation was used to evaluate the strength of the associations between disturbance rankings, environmental variables, and biological metrics. These results can be separated into correlations relating to level of disturbance and correlations relating to the environmental and biological conditions in swamps. Some of the strongest associations were found between the disturbance rankings, with total disturbance rank, landscape quality, current condition, minimum buffer width, and percent of wetland perimeter with greater than 50 m buffer all highly correlated ($P<0.001$). Conductivity was positively correlated ($R=0.381$, $P=0.019$) with total disturbance rank. This is likely the result of road salts and other stormwater runoff entering disturbed sites such as Berlin Mall Swamp, Pond Brook Cedar Swamp, and East Peacham Swamp. The correlation between conductivity and total disturbance is likely not strong because conductivity is also directly related to the presence of mineral-rich ground water discharge, a characteristic of many cedar swamps, regardless of their level of disturbance.

Although none of the biological metrics evaluated were effective in distinguishing between reference and disturbed cedar swamps, a more qualitative evaluation of the plant species found in cedar swamps relative to their level of disturbance provides some more insight into the ecological integrity of the swamps. Of the 260 species of vascular plants and bryophytes identified in the 38 plots in "typical" northern white cedar swamps, 30 of these species only occurred in reference quality swamps (total disturbance rank of 0 to 3). Similarly, 77 of the 260 species occurred only in disturbed swamps (total disturbance rank 4 to 9), however, we can make no generalizations about these species and their tolerance of disturbance.

Table E4 is an abbreviated list of the bird species identified during the spring breeding bird surveys conducted in nine cedar swamps. A few observations can be made about these bird species relative to the level of disturbance in the nine swamps. There are several species that are present in almost all cedar swamps, regardless of the level of disturbance, including Blue Jay, Veery, Winter Wren, Black-capped Chickadee, and White-throated Sparrow. In contrast, the Song Sparrow occurs only at the most disturbed site, Berlin Mall Swamp, and Swamp Sparrow occurs only at Berlin Mall Swamp and Molly's Brook Swamp. Similarly, Northern Parula occurs in four swamps with disturbance rankings of 1 to 5 and is absent from Molly's Brook and Berlin Mall Swamps.

Table E4. Average number of birds per listening station for nine cedar swamps. Swamps are ordered left to right by increasing total disturbance rank. The species are ordered here by their increasing frequency of occurrence. Partners in Flight priority species are indicated by (PIF).

Site Name (disturbance rank) Species	Bliss Pond (1)	Long Pond (1)	Dutton Brook (2)	Martell Swamp (3)	Victory (3)	Norton Pond (5)	Calendar Brook (5)	Molly's Brook (7)	Berlin Mall (9)	Frequency of Species
Song Sparrow	0	0	0	0	0	0	0	0	1	**0.11**
Swamp Sparrow	0	0	0	0	0	0	0	1	1	**0.22**
Olive-sided Flycatcher (PIF)	0	0.5	0	0.5	0	0.5	0	0	0	**0.33**
Ruby-crowned Kinglet	0	0.5	0	0	0	0.5	2	0	0	**0.33**
Swainson's Thrush	0	2.5	0	0	0	0.5	2.8	0	0	**0.33**
Common Yellowthroat	0	0	0	0	0	1	0	1.5	3	**0.33**
Northern Parula (PIF)	0	0.5	0	1	0	1	3.2	0	0	**0.44**
Canada Warbler (PIF)	0	3	0	2.25	1.3	0.5	0	1	0	**0.55**
Magnolia Warbler	0	1	0	0	0	1.5	2.4	2	1	**0.55**
Brown Creeper	2	0	0.7	0	0	1	0.4	0	1	**0.55**
Yellow-bellied Flycatcher	0	2	0	2.5	2	2	1.6	1	0	**0.66**
Blue Jay	0	0.3	0.3	0.5	0.3	0.75	0.2	0.25	0	**0.77**
Hermit Thrush	1	1	2	2.5	1	0	2	1	0	**0.77**
Veery (PIF)	1	0	0.7	0.5	1.3	1.5	0	0.5	2	**0.77**
Northern Waterthrush	1	3	2	4	2	4	3.6	2	0	**0.88**
Winter Wren	2	4	2	3	0	2.5	5.2	2.5	1	**0.88**
Black-capped Chickadee	2	0	0.3	0.5	0.7	0.75	5.2	0.25	1.5	**0.88**
White-throated Sparrow	2	2	2.7	2.5	1.3	2	1.6	1	1	**1.00**

Determining the level of ecological integrity at a cedar swamp should be based on detailed evaluation of the swamp and the surrounding area and should include an assessment and evaluation of plant species composition, presence of exotic species, animal species using the swamp, community structure, microtopography, natural disturbance regimes, hydrology, water chemistry, soil type, characteristics of the surface watershed, location of ground water recharge areas for the swamp, and many other factors. In many cases it will not be possible to evaluate all of these factors thoroughly given constraints of time and funding for studies. Although the goal of identifying biological metrics that can be used as indicators of ecological integrity has great appeal, given the complexity of forested wetland systems, their relatively robust character, the expected localized influence of disturbance on the flora, and the stepwise loss of animal species, a more general tool for estimating ecological integrity may be more appropriate.

CONCLUSIONS and RECOMMENDATIONS – Northern White Cedar Swamps

1. Aquatic macroinvertebrate sampling occurred too late in the season for two of the three swamps visited for macroinvertebrate sampling. It is imperative to sample these sites during their active hydroperiod. The Martel Swamp has a perennial stream flowing through it and this allowed sampling to occur even in the summer. It is unknown whether the macroinvertebrate biota in this stream reflects conditions in the cedar swamp or more in the stream itself. There was no open water to sample at either the Berlin Mall or the Victory Wildlife Area cedar swamps. Early spring sampling would have been beneficial at these sites to sample hollows and small streams. If aquatic microhabitats (with standing/flowing water) do not consistently occur in cedar swamps, aquatic macroinvertebrates should not be included in bioassessment or monitoring programs for cedar swamps. However, our limited efforts for this project have not conclusively shown that aquatic macroinvertebrates are not useful as biological indicators in these forested wetlands. Sampling needs to occur in the early spring (the same time as seasonal pools) or autumn when the water table is up. Lastly, in order to fully characterize the aquatic insect community, it is important to sample the different habitats, including the pools and riffles of cedar swamp streams and the cedar swamp hollows.
2. Using multivariate analysis techniques and professional judgment, the 70 cedar and hardwood cedar swamps studied in detail were separated into two main natural community types: northern white cedar swamps and red maple-northern white cedar swamps. The cedar swamps were further separated into the "typical" northern white cedar swamp and two variants: northern white cedar sloping seepage forest variant and boreal acidic northern white cedar swamp variant.
3. The 38 plots from 36 "typical" northern white cedar swamps were selected for analysis of disturbance ranking, environmental variables, and biological metrics.
4. None of the candidate biological metrics and none of the environmental variables were effective in distinguishing between the reference and disturbed northern white cedar swamps.
5. Although not identified in any of the quantitative analyses performed, several species of plants and birds can be linked to the level of disturbance in cedar swamps based on their presence and absence in plots and their specific habitat requirements. In general, noticeable changes in the flora of cedar swamps only occurs in those swamps that are highly disturbed to the point that one or more of the environmental variables driving the swamp is altered (such as change in hydrology and loss of canopy cover from logging). Bird species are sensitive to both changes in community structure and to fragmentation of surrounding habitat.
6. Given the complexity of forested wetland systems, their relatively robust character, the expected localized influence of disturbance on the flora, and the stepwise loss of animal species as the surrounding landscape is progressively fragmented, biocriteria may not be the most appropriate means of assessing and monitoring ecological integrity of cedar swamps. Perhaps a better tool for estimating ecological integrity would be a system that incorporate both site-scale measures of ecological integrity as well as landscape-scale measures of ecological integrity, such as the "Element Occurrence Rank" method used by the network of Heritage Programs and NatureServe.