Wetlands Biological Indicators for New Jersey

Case Study: Forested Riparian Wetlands in the Highlands of New Jersey

Final Report

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Cover photos clockwise from the top include: Cardinal flower (Lobelia cardinalis) observed at the Black River study site; Musconetcong River; Berlese funnel for sample preparation; and Pohatcong site vegetative sampling frame.

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EXECUTIVE SUMMARY

Wetland condition is recognized as an important consideration in reporting on the status of water quality in the state. Biological assessments conducted specifically for wetlands can be used to address wetland quality and condition. Biological assessments document the presence, condition and number and types of organisms such as insects, plants, macroinvertebrates and birds that together can provide direct, accurate information about the health and condition of wetlands. When a system is disturbed or becomes degraded, the biological attributes including taxonomic richness, community and trophic structure and health of the individual organisms change in response to the perturbation. The properties of the system that respond to the disturbance are potential indicators of ecological health and wetland condition.

Biological assessments are currently widely used for the water quality monitoring of lakes, reservoirs, rivers and streams that are reported under the Federal Clean Water Act (CWA), Section 305(b). New Jersey currently incorporates fish and macroinvertebrate indicators as part of the rapid biomonitoring protocol to assess and report on quality of waterways in the state. While emphasis in the past has been on reporting water quality of water bodies including lakes, reservoirs and streams, the US EPA has broadened the scope of what is to be included in the Water Quality Inventory Report to Congress (305(b) Report. By 2014 states are to have programs in place that report on wetland condition and quality under CWA Section 305(b).

To facilitate inclusion of wetlands in water quality reporting, a series of US EPA directives aimed toward enhancing scientific rigor of wetland quality assessment have pushed the development of wetland indices of biotic integrity (IBI) into the forefront for states across the nation. Some states are also exploring the potential for wetland IBIs to serve as useful tools in permitting and mitigation efforts and for establishing legally defensible baseline standards for wetland quality. The US EPA is also developing an approach and methods to help states evaluate and monitor wetland condition. However, any methods, including those developed by EPA, still have to be evaluated to determine if they are appropriate for the region and wetland type.

This project initiated and directed efforts toward the development of wetland biological assessments for the state's wetland resources. These biological assessments will ultimately provide the quantitative data that documents wetland characteristics and provide the framework for the development of a comparatively rapid assessment of wetland condition.

The goals of this research were to build upon various wetland assessment projects conducted by New Jersey and to aid in development of a rapid wetland assessment tool that could work toward fulfilling the EPA mandate. A specific goal of this project was to identify biological indicators that reflect the ecological health and condition of riverine wetlands in the Highlands physiographic region. Longer-term goals are to better understand a) wetland condition and its relationship to water quality and b) to understand how broadly biological indicators can be applied to wetlands that vary in location, type and extent.

The specific objectives included identification and evaluation of existing biological assessments and indicators for different taxonomic groups, including macroinvertebrates, plants, amphibians, fish and birds that are potentially appropriate for the selected wetland class. Based on this assessment, indicators were selected for further evaluation and implementation on a selected wetland class. As this work has implications for policy and management, an important objective was to actively coordinate with existing state regional and EPA efforts to integrate this work. To this end, two advisory groups were established early in the project. An internal NJDEP advisory group and an external advisory group that included State and Federal representatives provided input and guidance at several stages in the development of the project.

IBI Review and Selection

Based on results of the national survey on existing wetland and stream IBIs for different systems and taxonomic groups and in consultation with the advisory groups, two taxonomic groups were selected as the focus of this study: vegetation and macroinvertebrates. These two taxonomic groups have received the most attention in a relatively wide range of systems which provided an experience base to draw from. Also, these two groups may be more closely related to water quality than some of the other taxonomic groups (i.e. birds), but not dependent on seasonal inundation in the case of fish. The macroinvertebrates could potentially link with the State's existing Ambient Biomonitoring Network (NJDEP AMNET, 2005). Finally, it was felt that there was greater likelihood of existing in-house expertise to staff and support these IBIs once they are functional.

Study Location and Sampling Design

The study focused on one physiographic region and within that region a single wetland type. The Highlands physiographic region was selected primarily because of its relative importance for water and natural resources in the State as evidenced by the Highlands Water Protection and Planning Act passed by the State Legislature in 2004 to preserve open space and protect the region's diversity of natural resources and water supply. Riverine wetlands were chosen as the target wetland type as they are numerous in the region, are physically linked to water courses that are reported under Clean Water Act (CWA), Section 305(b)and also provide the opportunity to eventually examine the linkages between wetland quality and the adjacent water quality.

Land cover data was used to define and identify a disturbance gradient based on the extent and degree of altered land within the watershed as well as within proximity of the wetland. Forest and wetland cover were considered to represent intact relatively unaltered land while agriculture and urban land cover represented increasing degrees of alteration. Riverine wetlands were classified according to their score on the disturbance gradient with low scores reflecting a greater degree of altered land in proximity of the wetland as well as within the watershed and high scores reflecting more intact land cover locally and broadly. Ten sites were selected from three categories, high disturbance, intermediate disturbance and less disturbed. The selection process was further constrained by sites located on 3rd through 4th order streams, broadly distributed within the Highlands, and overlapped with current State monitoring locations, particularly those of the Natural Heritage Program and AMNET sites. Vegetation, macroinvertebrate and environmental data were collected from sites during the growing season of 2005.

Vegetation

A number of vegetation metrics were evaluated for their sensitivity on the disturbance gradient. Examination of the disturbance criteria against the metric data themselves found that in general, the vegetation IBIs did follow the gradient. One site that had been identified as moderately disturbed using GIS analyses, was evaluated as the highest quality site with respect to vegetation, suggesting a possible influence of forested buffer in close proximity to the site as a factor in the vegetation community structure. Sensitivity was assessed graphically and metrics that revealed a pattern of increasing or decreasing values along the disturbance gradient were selected for further evaluation and preliminary statistical analyses. The statistical analyses were considered exploratory and preliminary due to the small sample size.

Other Considerations

In addition to vegetation metrics, we examined whether habitat for rare plant and animal species were known through State data sources or encountered in the field. Though there was a trend for more species of interest in less disturbed sites, these results warrant caution because lack of information should not imply the absence of a species.

Numerous other multivariate analyses were conducted; however the results are preliminary due to the small number of sites. The length of intact riparian vegetation parallel to the stream and width of the riparian corridor correlated well with the disturbance gradient ordination, suggesting possible parameters that may co-vary with the disturbance gradient.

Vegetative IBI Development

Seven metrics that demonstrated a notable trend along the disturbance gradient were selected for incorporation into a draft vegetation IBI. These included the sum of tree diameter at breast height, the sum of non-native herbaceous cover, the sum of Roseaceae cover, the sum of native shrub importance values, native genera richness, non-native species richness and a floristic quality assessment index. The draft IBI provided a clear distinction between the three different disturbance categories.

Macroinvertebrates

The initial selection of macroinvertebrates was based on the ability to build upon the relatively large number of existing IBIs for this group. However, much of the existing work is based on aquatic macroinvertebrates and the presence of environmental conditions such as ponds, pooled water or flooding that can provide habitat for invertebrates. The riverine wetlands are not predictably flooded nor do they support extended periods of standing water, thus aquatic insect IBIs were not appropriate. After consultation with entomologists and others familiar with macroinvertebrate community ecology, it was ultimately decided to consider the leaf-litter macroinvertebrate community for biological assessment and potential IBI development. To our knowledge, this is the first time this component of the wetland community has been studied within the context of IBIs.

With limited information available, we had to develop and test sampling protocols. The level of effort necessary to devote to taxonomic identification increased substantially since there was no information available that would allow us to target sensitive groups or species. Taxonomic diversity also increased substantially with upland, aquatic and wetland-specific species in the litter community. As a result of this new approach, information specific to development of a macroinvertebrate IBI for the riverine wetland leaf litter community is slower to acquire. We have enumerated macroinvertebrate abundances and have identified samples to the level of Order and in a few instances to Family. We have examined trends along the disturbance gradient and there are some groups at even this coarse taxonomic resolution that show indications of a pattern. For example, abundances increase as disturbance decreases and some classes and orders show similar patterns though there was no pattern with class or order richness. The taxonomic work continues with this group and results presented in this report are preliminary.

Conclusions and Recommendations

Identification of a disturbance gradient is a critical step in the development of IBIs and our method based on remotely sensed land cover data is one of several approaches often used. Assessment and calibration of the gradient should be an on-going process that includes consideration of differential weighting of local and watershed land cover, incorporation of more up-to-date land cover information as it becomes available and augmentation of remotely sensed data with additional sources of information including ground-based and historical land cover information. For example, additional background information can help elucidate past influences on vegetative cover such as the presence of an even-age stand of trees as was observed at one site in this study. Similarly, forested buffer in proximity to the site (as suggested from one site), rather than overall land use percentages (found in the landscape level analyses from air photos or satellite imagery applied in a Level III approach to assessing wetlands quality), might be considered perhaps as a weighting factor in establishing a disturbance gradient. As new information is incorporated, the disturbance gradient will become more refined and will improve the confidence that it is truly representative of wetland condition. Better information could also provide the opportunity to better distinguish influences of different disturbance vectors on wetland condition.

A total of seven vegetation metrics comprised the preliminary vegetation IBI. The FQAI metric developed for Pennsylvania was incorporated into the IBI in this project and exhibited one of the strongest patterns of sensitivity to the existing disturbance gradient. Since the existing Pennsylvania model demonstrated sensitivity in New Jersey further consideration and adjustment of this model will likely be a fruitful endeavor. The metrics spanned the range of those included in other vegetation IBIs and included metrics that increased along the disturbance gradient as well as metrics that decreased along the gradient. The IBI clearly distinguished sites within the three disturbance categories with limited variation within each category. As more sites are added, a linear regression approach will likely replace the class level and analysis of variance approach used with this limited sample size. The appropriateness of the metrics used here will need to be continually evaluated to see if they are robust between seasons and years. As the information database increases, other metrics may be more representative of wetland condition and thus replace the current ones, but the fact that we obtained a relatively strong pattern with a small sample size and seven metrics lends promise to the ability to develop vegetation IBIs for this particular wetland type in the Highlands.

As more riverine wetland sites are added and seasonal and interannual variability are evaluated, the vegetation IBI model will become more robust. Typically 30 to 40 sites are used in the development of an IBI model. Eventually, the goal will be for sites to span the entire length of the disturbance gradient and encompass a wider range of stream sizes. A continued challenge will be to select sites that will uncouple the longitudinal trend in the Highlands with less disturbed, more intact areas located in the northern portion and more altered land in the southern portion. In this study, our most disturbed sites were also our driest sites. Concerted effort to ensure that a wetness gradient does not confound disturbance will be an important future consideration, particularly for the more disturbed sites.

The macroinvertebrate leaf litter community is resource intensive but has promise for indicator development. Even at coarse taxonomic resolutions, patterns were evident along the disturbance gradient. Continued refinement of the taxonomy will help elucidate trends and identify community and species metrics that are sensitive to the disturbance gradient. Relatively little is known about the wetland leaf litter community and as a consequence this work has the potential to make a significant contribution to our scientific understanding of wetland systems as well as to guide policy and management decisions.

Though progress has been slower than with the vegetation, the rationale for committing resources to the leaf litter macroinvertebrate community has merit in that these communities are likely to be responsive to wetland condition since they are in such intimate contact with the environment. Their relatively short life cycles and quick response to environmental cues were desirable traits for aquatic IBIs and the same argument holds for wetland leaf litter communities. The results that are presented here are preliminary steps in analyzing the leaf litter macroinvertebrate community and will contribute to an increased understanding of the diversity and importance of floodplain wetland forests as well as the continued development of the macroinvertebrate IBI.

As the project moves forward and additional information is gathered, there is a need for a concerted effort to more directly link wetland indices to water quality indices such as chemistry and biological indicators. This will be a nontrivial task as it will require linking two systems that though spatially adjacent necessarily function at different spatial scales within the landscape. However, it is only through collaboration and coordination of parties involved that a long term goal of this project to better understand wetland condition and its relationship to water quality can be achieved.

Wetland resources span a number of resource, policy and jurisdictional interests and as EPA continues to emphasize the incorporation of wetlands into water quality reporting, there is a ongoing need to emphasize coordination and collaboration within and across programs. As this project develops it will benefit from and contribute to programs currently in place within the Bureau of Freshwater and Biological Monitoring. Collaboration will enhance the ability to identify and develop the linkages between the wetland IBIs and the water quality indicators. The baseline data gathered to develop the IBIs and continued monitoring of these reference wetlands will increase our understanding of temporal trends in wetland response to disturbance.

1. INTRODUCTION

Wetlands are one of the few natural resources land types that fall under regulatory jurisdiction. Federal jurisdiction is encompassed within the Clean Water Act and many states have additional programs that strengthen or supplement the Federal regulatory framework. Much of the impetus for this research is the eventual US Environmental Protection Agency (US EPA) mandated requirements that states are to include wetland quality assessments under the CWA Section 305(b) report to Congress.

The series of US EPA directives aimed toward enhancing scientific rigor of wetland quality assessment have pushed the development of wetland indices of biotic integrity (IBI) into the forefront for states across the nation. US EPA's current goal is that all states will have a strong wetlands monitoring protocol in place within the next ten years, which will be used to include wetlands in the Water Quality Inventory Report to Congress (305(b) Report). In addition, some states see the development and implementation of wetland IBIs as a useful tool in permitting and mitigation efforts and for establishing legally defensible baseline standards for wetland quality.

A. Function vs. Quality

Wetlands have often been assessed based on their function. Function generally refers to the services that a wetland performs for the environment such as flood water retention, reducing erosion and sedimentation and improving water quality. Wetland function is generally considered during Section 404 permit actions of the Clean Water Act and is used to determine mitigation or compensatory requirements for permitted actions. Wetland assessment methods used to evaluate function include the Hydrogeomorphic Method (HGM) developed by the Army Corps of Engineers and Wetlands Mitigation Quality Assessment (WMQA) (Balzano, et al 2002) developed by the State of New Jersey to identify indicators of function as examples.

However, wetland function does not necessarily address the condition or quality of the wetland. While wetland function may relate indirectly to wetland quality, indicators of wetland condition are not specifically measured in most functional assessments. In fact, it is possible that a wetland could provide high wetland function and yet be in a degraded ecological state. Ecological health is generally considered a more direct measure of wetland quality or wetland condition. Ecological health is reflected in the types, conditions and numbers of organisms present in the wetland and/or the status of nutrients and contaminants within the wetland. Biological assessments are used to determine the ecological health of a wetland by directly measuring the status of taxonomic groups or nutrients that are closely aligned with the water body (Karr and Dudley 1981). The presence, condition and number of types of organisms such as macroinvertebrates, fish, plants, birds and other organisms provide a relatively accurate indication of the health of the system. When a system is disturbed or becomes degraded, the biological attributes including taxonomic richness, community and trophic structure and health of the individual organisms will change in response to the perturbation. The properties of the system that respond to the disturbance are candidates for serving as indicators for ecological health. Biological assessments are generally comprised of different biological indicators that are determined to provide accurate information about the health of the system. The key to developing a successful biological assessment with indicators is to identify and include metrics that are sensitive to different stressors including chemical, physical and biological alterations (Karr 1999). With an understanding of how the different metrics respond to stressors, it is possible to identify what type of stressor is damaging the biota and how severe the damage is.

B. Framework for wetland assessment

Wetland assessment tools can generally be organized into a three-tiered framework for establishing cost-effective bioassessment. Level I is focused on resource inventories and typically encompasses a broad scale study. This level often consists of analysis of remotely-sensed data, such as aerial photography or various mapped data, in order to predict what stressors might be affecting a wetland from the surrounding landscape. New Jersey has essentially already accomplished this level of assessment through a variety of avenues including the Landscape Project in the Endangered and Nongame Species Program (http://www.nj.gov/dep/fgw/ensp/landscape/index.htm), the mapping of vernal pools using GIS (http://www.dbcrssa.rutgers.edu/ims/vernal) and the land use and land cover maps for the entire state (http://www.nj.gov/dep/gis/download.htm) are additional resources that contribute to the Level I assessment. In many ways New Jersey is ahead of most states with respect to the spatial coverage it currently has that satisfies the intent of the Level I assessment.

Level II (rapid bioassessment) analyses require a field visit to the site of interest, where observations of direct perturbations that might not necessarily show up with remote data are made. In the case of wetlands, this could include diking and draining, selective logging, etc. Based on these observations of perturbation, general plant community characteristics, and apparent influence of surrounding land uses (including buffers), each site can be given a score on the spectrum from relative pristine to highly altered. Groundtruthing of vernal pool sites (identified in the Level I assessment cited above) by DEP staff who examine hydrology to confirm the sites are vernal pools, is an example of a wetland Level II assessment in New Jersey

Finally, the most detailed level of analysis is considered Level III, where a number of specific observations are made about the biological community at that site, typically using quantitative methods (i.e.-plots, transects) paired with select qualitative observations. An IBI is one pertinent result from such an analysis, but Level III also lends itself well to other types of reporting. For wetland functional assessments, the development of an HGM for a particular wetland type is an example of a Level III assessment. This particular project focuses on a Level III assessment. Specifically, the project will initiate and direct efforts toward the development of wetland biological assessments for the state's wetland resources. These biological assessments will ultimately provide the quantitative data that documents wetland characteristics and provide the framework for the development of a comparatively rapid assessment of wetland condition.

Biological assessments are currently widely used for the water quality monitoring of lakes, reservoirs, rivers and streams that are reported under Clean Water Act (CWA), Section 305(b). New Jersey currently incorporates fish and macroinvertebrate indicators as part of the rapid biomonitoring protocol to assess and report on water quality of waterways in the state. While emphasis in the past has been on reporting water quality of water bodies including lakes, reservoirs and streams, by 2014 all states are to have programs in place that report on wetland condition and quality under CWA Section 305(b).

Very few states have included wetlands in their reports on the status of water quality within the state. Sampling protocols, assessment criteria and classification have been well developed for water bodies (US EPA 1991, Barbour 1996 and references therein) but approaches to evaluate wetland quality in the context of CWA 305(b) are relatively recent. A few states including Ohio, Pennsylvania, Delaware, Maryland and several New England states have active programs to develop biological assessments that use indicators for biological integrity (IBI) specifically designed for wetlands. EPA recognizes the requirements, challenges and constraints that states' face as they start to integrate wetlands into their water quality monitoring criteria. The EPA is in the process of developing and releasing methods to help states monitor and assess the biological and nutrient condition of wetlands (http://www.epa.gov/waterscience/criteria/wetlands/). Biological indicators that have been or are being developed for wetlands include macroinvertebrates, vegetation, fishes, birds and algae. EPA is also developing a nutrient assessment for wetlands. In the development of the biological assessment for wetlands, the proposed work will draw on the experience, guidelines and recommendations of New Jersey's biological assessment protocols, the EPA, and other states that are making progress in the development of IBIs for wetlands.

C. Goals and Objectives

The goals of this research were to build upon various wetland assessment projects conducted by New Jersey and to aid in development of a rapid wetland assessment tool that can fulfill the EPA mandate. The development of such a tool requires several steps. Prior DEP wetlands assessment research focused more on soil, vegetation and hydrologic parameters of wetland quality and function, with less emphasis on biological endpoints (Hatfield et al. 2004 a and b, Hatfield et al. 2002, Balzano et al. 2002). The work developed in this study began the next phase in looking at biological assessment but was limited in scope to establish the framework and initial steps in the development of a biological indicator that assesses wetland quality. This research effort was further confined to focus on forested riverine wetlands as this is an important wetland type for New Jersey. The specific objectives included:

- Evaluate and identify existing biological assessments and indicators for different taxonomic groups, including macroinvertebrates, plants, amphibians, fish and birds that are potentially appropriate for the wetland class.

- Determine specific modifications and steps necessary to tailor indicators for the wetland class
- Implement and evaluate indicators performance on initial set of reference wetlands
- Coordinate with existing state efforts to integrate this work
- Coordinate with regional and EPA efforts in the development of regional indicators

D. Project coordination

Considering the future implications of how the State incorporates wetland quality assessments into their CWA 305(b) reporting as well as how the State addresses EPA's goals and directives to assessment of wetland quality and function, it was important that representatives from the various State programs who would likely be involved in evaluating wetland quality be involved from the beginning in an advisory capacity. An internal advisory group was established with the anticipation that their involvement would help facilitate an integration of this work into existing programs more efficiently and would potentially position New Jersey to be one of the early states to meet EPA mandates for wetland quality assessment. A list of participants in this advisory capacity is included in Appendix A.

In addition to an internal advisory board, an external advisory board was also established early in the project (Figure 1). The role of the external advisory board was to draw on their experience in biological assessments and the wetland regulatory framework to guide decisions early in the process and to provide critical feedback as the project hit critical milestones in the development of the wetland IBIs. In addition to NJDEP representatives on this board, EPA Region 2 and USGS were active participants (Appendix A).

Finally, it became apparent early in the project that this work complemented on-going work in the New Jersey Natural Heritage Program. A close coordination was established with Kathy Walz and to the extent possible sites were selected that complemented both efforts.

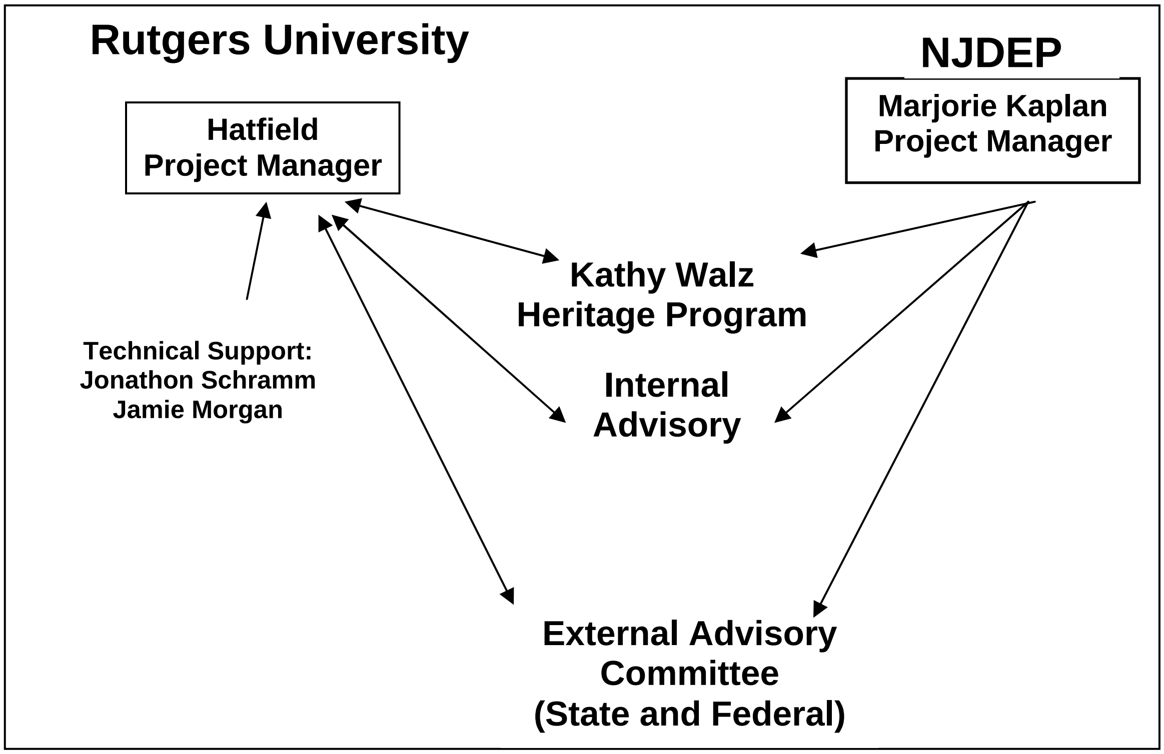


Figure 1: Pilot IBI Project Coordination

II. INDICES OF BIOTIC INTEGRITY

A. Indices of Biotic Integrity as a scientific concept

Among the most sought-after techniques in ecology are those that allow accurate characterization of ecosystem or community health based on a generally applicable survey methodology. Such techniques often rely on patterns within particular taxonomic groupings that seem to hold true across a range of site idiosyncrasies. The overarching goal of such an approach is to quantify how capable a particular site is of "supporting and maintaining a balanced integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the region's natural habitat (Karr and Dudley 1981)." One increasingly common approach of this type is the use of Indices of Biotic Integrity (IBIs).

An IBI attempts to infer the systemic health, and by extension, the relative strength of perturbing stressors thereon, of a biological community based on a series of metrics drawn directly from various aspects of the community. Metrics could include measurements of individual, population, or whole community attributes. While an individual metric, such as total species richness, only deals with one component of the community, by building the index out of multiple metrics, aberrant trends will theoretically be outweighed by other components, thus leading to a balanced and more accurate description of the community's status at any given time.

To date, IBIs are currently developed to be applicable only to one assemblage of species, such as plants, macroinvertebrates, diatoms, and to only one community type at a time. Whatever their applicability, all IBIs depend on "quantitative expectations of what constitutes a community with high biotic integrity in a particular region and habitat type" for each metric (Simon and Lyons, 1995). In this way, IBIs still utilize the wealth of human expertise that exists in many academic and government institutions, and cannot completely substitute for such wisdom. The first description of IBIs as a diagnostic tool was made by Karr (1981), working with fish species in stream communities, and for a number of years most IBI work was done with stream or lake systems in mind. Only in recent years has serious sustained effort been put into developing IBIs that are applicable to wetland communities.

B. Indices of Biotic Integrity in the regulatory framework

Much of the impetus for the development of wetland IBIs comes directly from the desire of governments, both state and federal, to have tools that would allow for relatively rapid and accurate characterizations of a particular site's integrity. This information could inform regulatory assessments, including permitting, mitigation and water quality reporting mandated by the Clean Water Act.

In the case of the present project, we are seeking first to develop a viable Level III IBI for a common wetland type in New Jersey. Once that model has been fine-tuned and shown to be adequately predictive of disturbance intensity at a site, it can inform and facilitate the development of a Level II rapid assessment methodology that will yield similar characterizations to the more detailed IBIs at the majority of sites.

C. Review of existing wetland IBIs

To date, thirteen states have completed at least a preliminary IBI, using 9 different species assemblages taken from 10 different wetland types (Table 1). Although a number of different taxonomic groupings have been tried, the most detailed and numerous studies have been attempted with vascular plants and aquatic macroinvertebrates. In the case of vascular plants, this emphasis is due in large part to the body of work that indicates they are effective synthesizers of the disparate signals and stressors that a given wetland experiences due to their intimate contact with the soil and water, as well as their longevity over time (see review by Carignan and Villard 2002). Macroinvertebrates, particularly in streams, have been shown to be very sensitive to disturbances, both abiotic and biotic, and as such also make excellent indicator organisms (Barbour et al. 1999). Indeed, the State of New Jersey has an extensive Ambient Biomonitoring Network (NJDEP AMNET, 2005) that utilizes benthic macroinvertebrates as part of its water quality monitoring program.

	Depres-sional	Riparian	Seep Slope	Wet Prairie	Vernal Pools	Fens	Bogs	Cedar Swamp	Restored	Fringe Coastal	Total
Amphibians	4	3	1	1	1	2	1	1	1	1	16
Algae/Diatom	3	2		2		1	1			1	10
Breeding Birds	2	1			1	1	1	1		1	8
Fish	2	1	1	1						2	7
Macro-Invertebrates	7	4	1	3	2	1	1	1	1	2	23
Mammals	1			1							2
Vascular Plants	8	5	2	3	2	2	1	1	1	2	27
Zooplankton	1			1							2
Total	28	16	5	12	6	7	5	4	3	9	

Table 1. Wetland IBIs for different wetland types and taxonomic groups.
Highlighted cells show wetland type and taxonomic groups where the majority of the work has occurred.

Another factor playing into the emphasis on both of these taxa is simply that states already have a substantial body of in-house taxonomic expertise with these two assemblages, allowing for less time spent completely adjusting sampling and processing to a new taxonomic group. In terms of wetland type, depressional systems have been examined most frequently. This is probably due to the large size and importance of such systems in the Midwestern and Plains states that have attempted them. In states where depressional wetlands are not as common (due to topography and development), riparian and coastal systems have also been examined. In every case where the intention was to forge a complete IBI (rather than just a pilot study), states have found that multiple field seasons and years have been required in order to build up a large enough sample size to have statistical confidence in their IBI (cf. Ohio EPA; Mack 2001). The typical target number is 50 sites of one wetland type, and at each of those sites two or more assemblages are usually monitored (US EPA, 2004). Naturally it can require very substantial inputs of time and funding to accomplish this level of model robustness.

III. PROJECT DESIGN AND METHODS

A. Physiographic region and study area

When developing any type of assessment approach it is necessary to minimize to the extent possible sources of variability that might confound the ability to extract relevant information. Limiting the geographic setting for the study helps to reduce variability in general abiotic drivers such as climate and geologic setting. For the State of New Jersey, five distinct physiographic regions with similar physical environmental conditions have been identified (Collins and Anderson 1994). To initially minimize variability in this study, we chose to work with just one of the physiographic areas, the Highlands.

The Highlands physiographic region was selected for this study primarily because of its relative importance for water and natural resources in the state. The Highlands Water Protection and Planning Act was passed by the State Legislature in 2004 to preserve open space and protect the region's diversity of natural resources and water supply, which provides drinking water to more than 50 percent of the State's households.

B. Wetland type

Generally, biological indicators and metrics related to biological indicators are system specific. For example, a biological indicator for macroinvertebrates developed for streams may not be appropriate for wetlands. In fact, biological indicators created for one class of wetlands may not be appropriate for different types of wetlands. Although wetlands are similar in many respects, they occur under a wide range of abiotic conditions and vary significantly in their physical, biological, and chemical characteristics. This variability makes it difficult to develop assessment methods that can be applied to multiple wetland types in a practical time frame while still maintaining the ability to detect significant changes in wetland quality. To reduce variability and strengthen model development, we adopted the Hydrogeomorphic Method (HGM) wetland classification system (Brinson 1993, Smith et al. 1995). The HGM classification is based on three hydrologic and geomorphic criteria that play important roles in wetland function: geomorphic setting, water source and transport, and hydrodynamics. Geomorphic setting refers to the topographic position of the wetland within the landscape. Water source refers to the principal source of water flow into the wetland. Hydrodynamics refers to the kinetic energy and direction of water flowing through the wetland (Brinson 1993).

For this study, we selected riverine wetlands for the development of the IBIs. The geomorphic setting of a riverine wetland is that area perpendicular from the stream channel to the edge of the stream's floodplain. The primary water sources for riverine wetlands include overbank flow, precipitation, and subsurface flow. The hydrodynamics of riverine wetlands may be characterized by surface flows across the floodplain. To further reduce the variability within riverine wetlands they were further divided into a riparian forest subclass (Ainslie et al. 1999).

C. Reference wetlands

Reference wetlands are sites selected as representative of the variability that exists among wetlands in a regional subclass. They serve as a standard against which other wetlands can be compared, such as: overall wetland function, or for identifying mitigation or restoration goals, and should represent the continuum existing among natural and degraded wetlands found within a region. The continuum can also be referred to as the disturbance gradient, with sites ranging from those that have minimal disturbance to sites where disturbance is a prominent component of the landscape and the wetland.

In the typical development of an IBI model, thirty to forty reference riparian forests that span the disturbance gradient would be used. In this pilot project where a limited number of sites would form the initial basis for the model development, we placed further constraints on the riparian forested wetland subclass and selected reference sites along the disturbance gradient that were adjacent to 3^{rd} or 4^{th} order streams.

D. Disturbance gradient and site selection

An important initial step in the development of an assessment tool is the delineation of a disturbance gradient. Sites located along this gradient are used as the reference data set for identifying sensitive response variables or metrics to include in the assessment methodology. There are several approaches to identifying a disturbance gradient and for this project we chose a relatively straightforward approach of utilizing land use/land cover data that was categorized based on the extent of human alteration. As resources, we utilized ArcMap GIS software and 1995/97 New Jersey Department of Environmental Protection (NJDEP 2000) land use/ land cover. We used a two step process of ranking land use/land cover based on the degree and magnitude of altered land at two different scales: a) the USGS 14-digit Hydrologic Unit Code (HUC-14) watersheds in the Highlands and b) the 100-year floodplain of the target streams plus a 1 kilometer buffer.

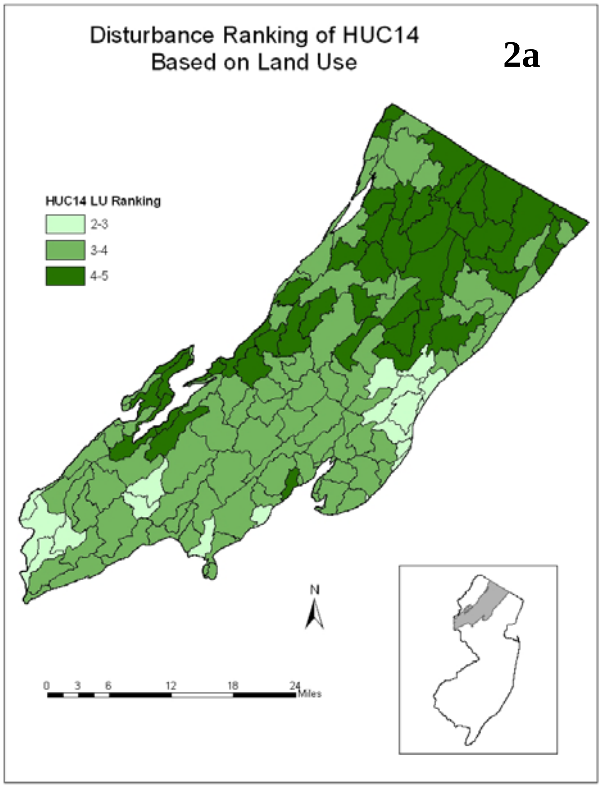
At each of these scales, land cover was categorized according to Anderson's Level I classification system (Anderson et al. 1976) and included forest, wetland, water, agricultural, urban and barren land. To reflect the degree of human alteration, we assigned forest and wetland land cover a score of 5 (least disturbed), barren, agriculture and water was given a score of 3, and urban land cover a score of 1. For each HUC-14, total acreage in each of the land covers was determined, and a final disturbance score determined by summing the products of the proportions of acreage in each category by its corresponding numeric score. Hence, HUC-14's that were dominated by urban lands had a lower overall final score than did agriculture dominated watersheds which in turn had lower scores than forest and wetland dominated watersheds (Figure 2a).

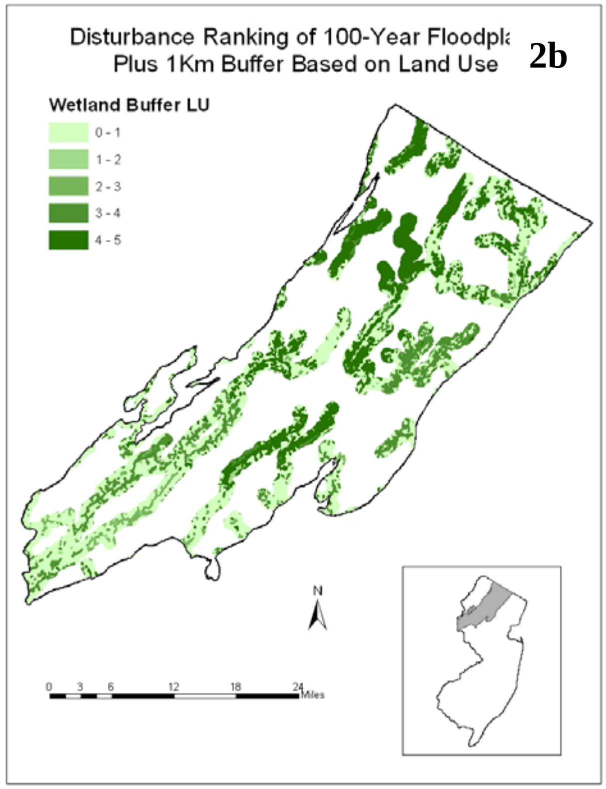
A similar procedure was done for the 1-kilometer buffer and the 100-year floodplain. The proportion of each of the Anderson Level I land cover categories in the buffer were determined and the same land cover ranks as used for the watershed classification were assigned (Figure 2b). The final disturbance score was determined by adding the scores from the watershed-level (HUC14) and local 1 kilometer buffer. Since the initial land cover scores ranged between 1 and 5 for each scale, the final disturbance scores were between 2 and 10 after summation. Thus, scores approaching 10 reflected the HUC14 and local land cover that were heavily dominated by forest and wetland. Areas and their disturbance that were along 3rd and 4th order streams were extracted and served as the study area for selecting sites to sample (Figure 2c).

E. Additional considerations

To further refine our site selection process, we utilized several additional selection criteria. Since our sample size would be small this first year (10 sites), we attempted to select sites that were concentrated in specific regions of the disturbance gradient with a goal of three sites in the highly-disturbed range (score < 6.0), four sites in the moderately-disturbed range ($7.0 \leq$ score ≤ 8.0), and three sites in the relatively non-disturbed range (score > 8.6). Accessibility was also a strong consideration with preference given to potential sites that lay on state-, county-, or municipally-owned land. Also, effort was made to identify sites that overlapped with current state monitoring locations, particularly those of the Natural Heritage Program and AMNET sites. Efforts were also made to spread the ten sites out geographically across the Highlands. All potential sites were further examined using the recently available NJDEP 2002 aerial photography (NJDEP iMAP 2004) to confirm whether it did, indeed, appear to be a suitable wetland for this study.

For sites that fit the selection criteria, a site visit was made to insure that the wetland would be useful for the study. The primary reason for site disqualification at this stage was simply inappropriate hydrology, a factor that cannot be accurately assessed at





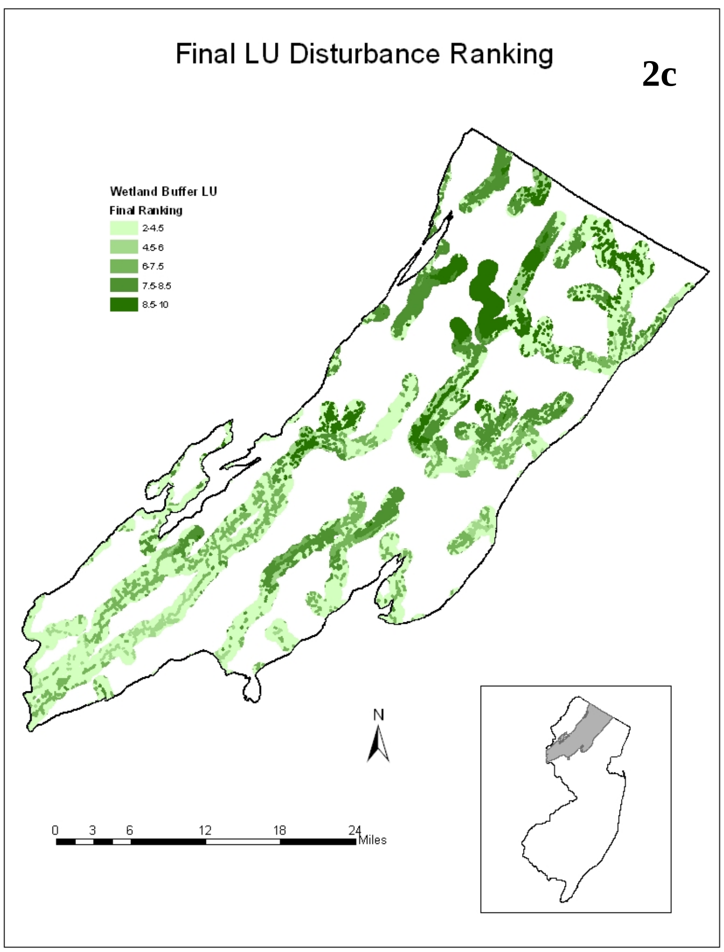


Figure 2. Procedure for establishing the disturbance gradient.

2a) HUC14s were classified according to extent of altered land cover in watershed with scores from 2-5.

2b) Wetland buffer encompassing 100-year floodplain plus 1Km buffer on 3rd and 4th order streams was classified by extent of altered land cover using the same criteria as for HUC14s.

2c) Final disturbance ranking of wetland buffer by combining 2a and 2b.

the level of GIS analysis. Sites that were used had to have a clear hydrologic connection to their associated stream (i.e.- low bank height, channels connected to stream) and often other conditions that indicated recent or frequent flooding (water marks on trunks, stained leaves, wrack lines, etc.). Some usable sites were also disqualified if property access could not be secured from the owners of the site. Finally, if an otherwise suitable wetland was overgrown by dense stands of inhospitable plants, such as *Rosa multiflora*, or had no areas large enough to lay out sampling transects, it was not used.

The results of the national survey on existing wetland and stream IBIs for different systems and taxonomic groups were presented to the project's internal advisory committee. After careful review of available information, all parties concluded that vegetation and macroinvertebrates were likely the most reasonable groups to focus on for IBI development. Several factors influenced this decision including the fact that these groups had received the most attention in a relatively wide range of systems and we could draw upon the experience base from other states. These two groups could also be more closely related to water quality than some of the other taxonomic groups (i.e. birds) but not dependent on seasonal inundation in the case of fish. The macroinvertebrates could potentially link with the State's existing AMNET data set. Finally, it was felt that there was greater likelihood of existing in-house expertise to staff and support these IBIs once they are functional.

Ten sites were selected and surveyed for the pilot study. As previously indicated, select sites that were concentrated in specific regions of the disturbance gradient with three sites in the highly-disturbed range (score < 6.0), four sites in the moderately-disturbed range ($7.0 \leq$ score ≤ 8.0), and three sites in the relatively non-disturbed range (score > 8.6). The sites, their disturbance scores and localities for each are shown in Table 2 and Figure 3. Data for AMNET sites is included in Table 3 and Figure 3. More detailed descriptions for each site including GPS coordinates are included in Appendix B.

Property access permission was obtained from the appropriate parties depending on ownership. The majority of the sites were on public land (8 of the ten sites, Appendix B). We also obtained verbal permission from private land owners to collect field samples for the macroinvertebrate portion of the study and for selective collecting of plant material provided the plant did not have special status (http://www.nj.gov/dep/parksandforests/natural/heritage/textfiles/njplantlist.txt). For public lands we coordinated with the Heritage Program in the Office of Natural Lands Management (ONLM) and followed the same guidelines for collection as for private lands.

Site	Disturbance Score	Stream System	County	Municipality
Phillipsburg	4.80	Lopatcong Creek	Warren	Pohatcong Twp.
High Bridge	5.91	South Branch of the Raritan River	Hunterdon	High Bridge
Whippany	5.96	Whippany River	Morris	Morris Twp.
Pohatcong	7.00	Pohatcong Creek	Warren	Washington Twp.
Lamington	7.02	Lamington River	Hunterdon	Tewksbury Twp.
Black River	7.65	Black River	Morris	Chester Twp.
Musconetcong	8.01	Musconetcong River	Morris	Mt. Olive Twp.
Wawayanda	8.68	Wawayanda Creek	Sussex	Vernon Twp.
Berkshire	8.7	Rockaway River	Morris	Jefferson Twp.
Clinton	9.1	Clinton Brook	Passaic	West Milford

Table 2. The ten forested riparian sites and their disturbance score. The table includes the stream system with which the sites are associated and the counties and municipalities where they are located.

F. Sample design and methods

1. Field

Plot Design

A location for the sampling plots was chosen after surveying the majority of the floodplain riparian wetland, and finding an area where the wetland was intermediate in width (i.e.- stream to upland width), and if possible at least 25 meters wide. Two transects of five 10 x 10m plots were set out running parallel to the flow of the stream (Figure 4). Where possible, one row was located within 5m of the stream bank. In instances where a near-stream transect could not be established adjacent to the stream due to inappropriate vegetation type or floodplain berm (two sites), a transect was established within 35m of the stream. In all instances, the second transect was at least 5m from the start of the transition into upland habitat. The upland transition zone was determined by using a combination of changes in topography accompanied by changes in vegetation from hydrophytic to more mesophytic species. The distance between the two rows varied depending on the overall width of the wetland where the sampling occurred. Distance between transects was recorded on field data sheets.

Site	Name	County	Stream	Impair1	Impair2	NJIS1	Impairment Status
Phillipsburg	AN0053	Warren	Lopatcong Creek	Moderate	None	9	24
Pohatcong	AN0057	Warren	Pohatcong Creek	Moderate	Moderate	21	21
Pohatcong	AN0056	Warren	Brass Castle Creek	None	None	30	30
High Bridge	AN0320	Hunterdon	Willoughby Brook	None	None	30	27
High Bridge	AN0323	Hunterdon	Beaver Brook	None	None	27	30
Lamington	AN0364	Hunterdon	Rockaway Creek	None	None	30	30
Black River	AN0356	Morris	Lamington River	Moderate	Moderate	9	9
Black River	AN0347	Morris	Dawsons Brook	None	None	30	30
Whippany	AN0233	Morris	Whippany River	Moderate	Moderate	21	21
Whippany	AN0234A	Morris	Watnong Brook	Moderate	None	15	24
Musconetcong	AN0063	Morris	Musconetcong River	Moderate	None	18	30
Musconetcong	AN0066	Sussex	Lubbers Run	None	None	27	27
Clinton	AN0261	Passaic	Clinton Brook	Severe	None	3	24
Clinton	AN0262	Passaic	Kanouse Brook	Moderate	None	18	24
Wawayanda	AN0294	Sussex	Wawayanda Creek	None	Moderate	30	21

Table 3. List of AMNET stations that are in close proximity to the study sites

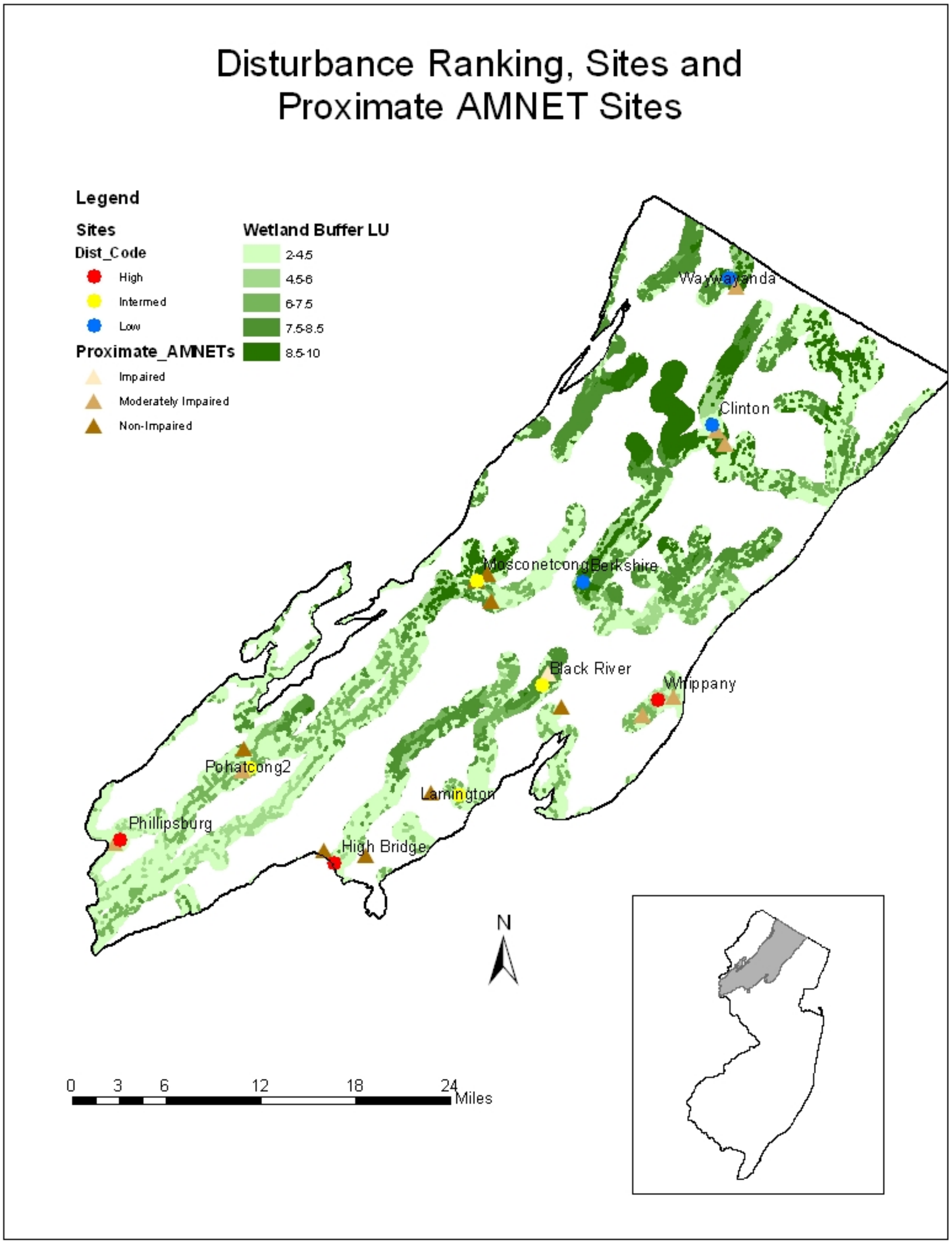


Figure 3. Highlands study area with final disturbance gradient.
The location of study sites are coded by disturbance category and location of AMNET sites in proximity to study sites are coded by impairment score.

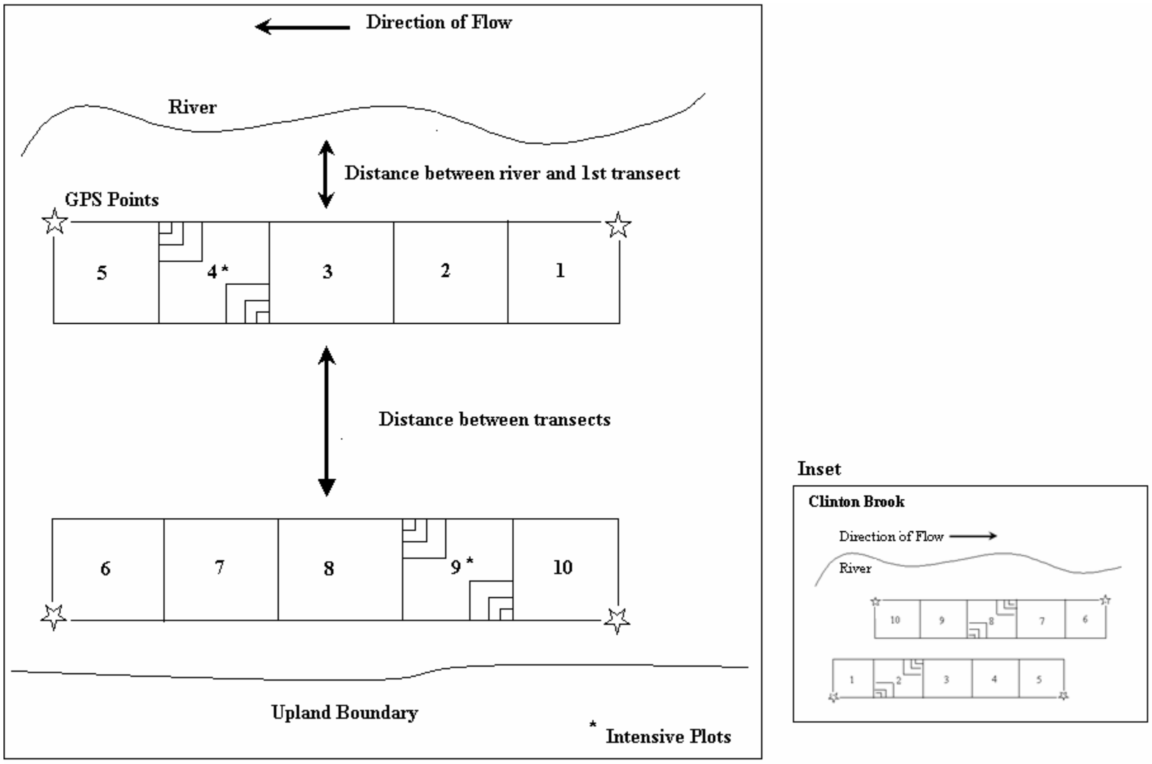


Figure 4. Transects and intensive sampling plot layout.
Distances between transects, river and upland boundary vary depending on site characteristics. The GPS points (as recorded in the site descriptions in Appendix B) are indicated by the stars at the far corners of the end plots. Figure inset: Diagram of plot layout at Clinton Brook. Plots were staggered by 10m to account for an irregular riparian boundary. Note: due to alternate river flow, the numbering of the plots was reversed so that transect 1-5 was heading downstream.

In the ideal scenario, the two transects would be adjacent to each other such that plot 1 lines up with plot 10 (Figure 4). However, in several instances when the irregular boundary of the riparian zone was not wide enough to place them adjacent, the transects were staggered by one plot whereby plot 2 was lined up with plot 10 and plot 1 not paired with a streamside plot and the streamside plot 6 was not lined up with an upland plot (Figure 4 inset). The specific locations of each of the outside corners for each transect were recorded with a real-time differentially corrected global positioning system (GPS) unit.

<u>Vegetation Sampling</u>

Beginning in Plot 1, each 10 x 50m row was walked independently by the different surveyors, who each built a comprehensive species list. Species and tree diameter at breast height (dbh) was recorded for each tree in the two transects. Species identity, shrub area and stem count was recorded for shrubs in the two transects. One of the middle three 10x10m plots within each row was randomly chosen for intensive sampling of the herbaceous layer following Ohio EPA's wetland bioassessment procedures (Mack et. al. 2000, Peet 1988) (Figure 4**)**. The intensive sampling consisted of beginning at opposite corners of the plot with a 0.1m^2 quadrat, and recording species and percent cover for all plants found therein. A 1m^2 quadrat, which encompassed the smaller quadrat sample area, was surveyed for species and percent cover. This procedure was repeated with a 10m^2 (3.2m x 3.2m) quadrat (which encompassed the 0.1m^2 and 1m^2 plots) and finally for the area of the entire plot (10m x 10m). This allowed for assignment of two numbers to each species found within the plot, one being the aggregate cover class, and the other being a number corresponding to the scale at which the species was first noted (with 1 corresponding to 0.1m^2 and 4 to 100m^2).

The multi-scaled sampling design was selected to accommodate the complexity of vegetation layers in forested wetlands. Larger woody species (trees and shrubs) are more representatively described by sampling the entire 1000 m^2 area covered by the two plot-transects, while herbaceous species are fairly well-represented by sampling two 100 m^2 areas, one from each transect. In addition, floodplains of very different areas could be sampled using the same basic procedure with the distance between the two transects varying depending on floodplain width.

Common and well documented plant species found in the Highlands region were not collected but rather their presence and appropriate quantitative measures entered on the field data sheets. For unknown plant specimens, the first priority was to provide a valid and accurate identification in the field using field guides. Where identification was not possible or certain and specimens of the plant occurred multiple times (>10 occurrences) throughout the plot and surrounding area, the entire plant including roots was removed, labeled and transported to the lab according to standard operating procedures. For specimens that were rare, digital pictures and drawings were used to try and capture key characteristics for later identification.

Leaf litter macroinvertebrate sampling

The initial motivation for selecting macroinvertebrates as a group was that considerable work had already been done with this particular group in both aquatic and wetland systems and we felt we could build upon that experience base in this project. Initial efforts to implement the macroinvertebrate sampling protocols were unsuccessful. Most states that have a wetland macroinvertebrate IBI have developed it based on ponded water in the wetlands. Due to the nature and hydrology of the riverine forested wetlands in this study, in many instances there is limited or no standing water. What standing water there was, it was only present during a brief time in the early spring. Initial efforts to sample those ponded waters that were present met with limited success. We also did not feel this approach adequately represented the macroinvertebrate community of the riparian system.

We also attempted sampling the soils by taking soil cores and extracting macroinvertebrates. This approach also met with limited success and few macroinvertebrates were found. The mucky soils and high clay content may retard macroinvertebrate colonization of these wetland soils.

After consulting the literature and the staff in Entomology Department at Rutgers, it was decided to develop an approach to sample and characterize the leaf litter (duff layer) macroinvertebrate community. This aspect of the riparian system has not been investigated before and very little known about the leaf litter macroinvertebrate community of riparian forests. Therefore there is not an existing body of literature and experience to draw from specifically for riparian forests. Sampling protocols had to be developed and tested early in the field season. The justification for switching to this sampling approach was presented to the internal advisory committee. It was recognized that this approach would require a more intensive level of effort and would take longer to develop. However, the general consensus was that this approach would more closely approximate wetland condition compared to the other approaches for sampling strategies.

For macroinvertebrate sampling, two 10 x 10m plots were randomly selected from each of the vegetation transects for a total of four plots sampled at the site. The intensive vegetation sample plots were excluded due to disturbance associated with the vegetation sampling. In each of the randomly selected plots, vegetation type, cover and microtopographic variation was evaluated and macroinvertebrate plots were placed so as to represent the heterogeneity within the larger 10 x 10m plot. A total of four $0.50m^2$ macroinvertebrate plots were placed in each larger 10 x 10m plot for a total of 16 macroinvertebrate samples per site.

Within each of the $0.50m^2$ plots, all of the material in the duff layer within the plot was collected. Soil and large plants were not collected. When present, roots were collected but excess vegetative matter was discarded. All rotting log and twig pieces in the square were broken apart and collected. The samples were placed in a loose-weave cotton bag with an identification tag, and kept in the shade until transported to the lab.

Environmental Sampling

To characterize the physical setting and abiotic variables associated with the vegetation and macroinvertebrate communities, several environmental variables were measured. River width was measured at the upstream corners of Plots 1, 3 and 5. The width of the river, the slope of the bank, the bank height, and bank percent cover within a one-meter square plot (rock, vegetation, debris, etc.) were also measured in the same area. The aspect of the riverine wetland parallel and perpendicular to the stream, as well as the slope of the plot with respect to the flow direction of the stream were measured using a compass and a clinometer, respectively. The presence of several indicators of flooding and the furthest distance each indicator was present into the wetland (perpendicular to the river) were measured. These included: wrack lines, water marks, moss lines, buttressing, and water-stained leaves. All information was recorded on field data sheets.

Three measurements were used to determine the wetland extent and continuity of the forest habitat. Measurements that were derived from NJDEP 2004 1-m resolution aerial photos (NJDEP, iMAP 2004) included the length of the intact forested habitat parallel to the stream, and the maximum and minimum widths of the intact forest habitat. The width of the riparian wetland from the upland transect to the river channel was measured and recorded in the field.

A general characterization of the soil (texture and approximate composition) in each of the intensive sample plots was recorded. In addition, midway between the two transects, a soil pit was dug that was deep enough to intersect the B-horizon or a maximum of 60 cm. Depths of soil horizons, hydric conditions and water table depth were included in the soil observations.

A verbal description of the sites' macrotopography and microtopography was recorded to provide a sense of how variable and complex the topography of the site was. Evidence of ditches, small channels, berms or other microtopographic features were described along with their spatial positioning in the wetland. Overall topographic variation of the site and the upland transition zone was qualitatively assessed and recorded on data sheets.

Any man-made or natural disturbance indicators were noted. This included documentation to the nearest visible disturbance. Disturbance included trash, tire tracks, animal browsing, flooding, dams, fallen trees, etc. Also, the land use and land cover adjacent to the transects was documented. This included adjacent forest, agricultural land (pasture or grazing), successional land, or development that bordered the site.

Information on woody debris presence was documented and an approximation of the total percent woody debris cover in each of the two transects was recorded. Both total percent woody debris cover as well as percent cover within different size classes (<1.0cm, between 1.0 and 5.0 cm, and >5.0cm) were collected for the intensive plots.

Using a densiometer, four measurements of canopy cover were taken in each of the ten plots. The observer recorded the canopy measurements from one step in each of the cardinal directions (N, S, E, W) from the center of the plot. A sketch of each site was drawn to depict the general layout of the transects, the shape of the river channel, the orientation and location of any on-site or adjacent disturbance, macro and micro topographic variations, and access to the site. Each site was also photo documented.

2. Laboratory

Plants

Unknown specimens were carefully pressed, labeled and kept in a cool dry place until identification. Efforts to identify the unknown plants were be done by people experienced in plant identification. A complete list of species identified in the ten samples sites is available in Appendix C. Nomenclature was primarily derived from

Gleason and Cronquist (Gleason, 1991), except for *Eurybia divaricata*, *Symphyotrichum lateriflorum*, and *Symphyotrichum novi-belgii*, which were derived from the US Department of Agriculture PLANTS database (USDA 2004). Other plant ID references were The Illustrated Companion to Gleason and Cronquist's Manual (Holmgren 1998), Shrubs and Vines of New Jersey and the Mid-Atlantic States (Martine 2002), Trees of New Jersey and the Mid-Atlantic States (Martine 1998), Newcomb's Wildflower Guide (Newcomb 1977), Freshwater Wetlands: Guide to Common Indicator Plants of the Northeast (Magee 1981), and A Manual of Aquatic Plants (Fasset 1957). Various other sources were used to aid and confirm identifications. Matt Palmer from Rutgers University and Linda Kelly from the Natural Heritage program reviewed all questionable identifications and aided with the unidentified specimens. All unknown plants were identified to the lowest taxonomic level possible, which was to species in most instances, and genus in others. Selected specimens (uncommon or hard to identify) were prepared according to herbarium standards and stored in the Hartman Lab Herbarium collection.

Macroinvertebrates

Once in the lab, the macroinvertebrate litter samples were carefully placed into Berlese funnels. The funnels were constructed of a 70cm tall by 25cm diameter metal cylinder. A screen of mesh size 0.635cm was placed 35cm from the top of the cylinder and a collection funnel was below the screen. Location, time and depth of litter in the funnel were recorded. A 75Watt light bulb was placed over the funnel and a collection jar containing 70% ethyl alcohol was placed under the funnel. The funnels were kept in place and checked at day 3. In samples where the litter was dry, the funnel was dismantled and specimen jars were labeled on the outside and inside and placed in a cool, dark location for later identification. The dry litter was checked for organisms before being discarded. For samples where the litter was deep, the top surface of dry litter was carefully removed exposing the damp litter underneath. Funnels were also checked to ensure they were not clogged. The same procedure was done at day 5. The maximum time that funnels were in place was 7 days. In the event that samples were collected and not placed in the Berlese funnels the same day, they were stored in a cold room and held for a maximum of two days. All marcoinvertebrate samples were preserved in 70% ethyl alcohol and stored in tightly sealed containers in a cool, dark room until identification.

Macroinvertebrate Identification

An initial sort was done on the macroinvertebrate samples to separate the organisms from the organic material. To do the sort, jar contents were placed in an enamel pan and the jar thoroughly washed with 70% ethyl alcohol to remove all contents. Animals including broken parts were removed from organic debris by use of tweezers and eyedroppers. There was no attempt to sort organisms by taxonomic level at this stage of the process. The organisms were placed in a second container of 70% ethyl alcohol and kept in a cool, dark area. This procedure required limited taxonomic expertise and was done with a dissecting microscope.

Once the organisms had been separated from the sediments, they were sorted into taxonomic level groupings. In all instances, every effort was made to sort individual to Class and in most instances Order. This sorting was done by a person who had experience with macroinvertebrate taxon identification using a dissecting scope.

Originally, we wanted to strive for at least Genus level taxonomic resolution in the macroinvertebrate data. However, when the decision was made to sample the leaf litter macroinvertebrate community, there was the accompanying recognition that the taxonomic diversity would dramatically increase due to the complex heterogeneity that characterizes the forested floor of these riverine systems. We expected to encounter species that span the environmental gradient from aquatic to terrestrial. This increase in taxonomic diversity is necessarily accompanied with a need for a wider range of taxonomic expertise that is not readily available. Furthermore, since the focus on leaf litter sampling is relatively recent in the scientific community and this is the first attempt to characterize this component of the system, there was no a priori level of taxonomic classification or taxonomic groups that we could specifically focus on that would provide evidence of wetland condition along a disturbance gradient. Therefore, as a consequence of modifying the approach for developing a macroinvertebrate IBI, there were not sufficient budgetary or taxonomic resources available to take the current project beyond Order in taxonomic resolution.

A reference collection was started for the project and eventually this will require verification by taxonomists with expertise in the different taxonomic groups. The collection consists of specimens of each Class or Order of macroinvertebrate collected for the project.

3. Data Analysis

Following quality control analysis of the data as outlined in the Quality Assurance Project Plan (October, 2004), vegetation data for each site was summarized in a number of ways. A number of ecological community metrics such as Shannon-Weiner diversity, species richness, importance values, and many others were calculated for each site (Appendix D). Each of the metrics was tested for the potential to differentiate the sites along the *a priori* disturbance gradient. *It is important to note that the current data set is in reality too small for the statistical analyses presented in this report and thus results of any statistic should be evaluated with considerable caution. The statistical results are included in this report to provide a preliminary exploration of trends and the strength of those trends. As more sites are added to the data set, the statistical results may change as well as the interpretation. The validity of the statistics and strength of the trends will also increase.*

Percentage and proportion variables were arcsine transformed before statistical analysis. For each metric, statistical tests involved conducting a one-way analysis of variance (ANOVA) of the three disturbance categories (3 highly-disturbed sites, 4 intermediate sites, and 3 relatively undisturbed sites), using the General Linear Model procedure (PROC GLM) due to the unbalanced sample design. Least-Squared-

Difference (LSD) and Tukey's tests for pairwise significance were performed to identify significant differences between disturbance categories. For each metric, equality of variance within the three populations was determined by the Levene's test. Assumptions of normality were tested with a Wilk-Shapiro test on the residual variances from the GLM. For those metrics where normality or equal variance were not present, the data was log transformed to see if there was a better fit to the assumptions of normality before proceeding with the ANOVA. Regression analysis was also performed on each metric and the p-value and r^2 values were noted. Residuals were also tested for normality. SAS v. 9.1 was used for the majority of the statistical analyses. Using final F-statistics and *p*-values from the ANOVAs in conjunction with scatterplot graphing of the sites' scores for each metric, a determination was made whether or not to consider that metric as a candidate for inclusion in the IBI. Due to the small sample size of this study, we set our significance level at $p= 0.15$ versus the normal $p = 0.05$ (the target level when more sites are included in the project). (An alternative to the parametric statistical approach above would have been to take a non-parametric approach and made comparisons based on the ranks of the data between categories using a test such as Kruskal-Wallis on the ranks. Analyses based on rank are not as powerful as parametric statistics and though the sample size was small, in most instances we were able to meet assumptions of parametric statistics. For this phase of the study, we opted for the parametric approach as it provides a roadmap for future analyses. Again, it must be emphasized that the sample size is small and any statistical analyses - parametric or nonparametric - must be reexamined as the number of sites increase.)

In addition to univariate statistics, multivariate statistics were also used to evaluate whether composite measures of the plant community separated sites along the disturbance gradient. As in the parametric statistics, it was recognized that the low sample size compromised the ability to detect trends; thus this approach was more of an exploratory technique that will also gain power as more sites are included. Multivariate analyses, including ordinations and cluster analyses, were done for several metrics including species presence/absence and relative abundances of tree, shrub, and stem species at each of the ten sites using the statistics package, PC-Ord 4 (McCune and Mefford 1999).

IV. IBI DEVELOPMENT

Once the metrics with the strongest statistical pattern were determined, scoring breakpoints for each of these metrics were determined. Since the sample size was small, we adopted a conservative approach for using the data to develop the model. It is of note that this approach will require continued assessment as additional sites are added to the project. Since metrics that form an IBI model have different scales and are in different units, sites are arranged in rank order and assign a scale-less categorical number based on the values of each of the metrics. There are a number of approaches to create the categorical data and for this project we chose to work with the scope of the data for each metric. The range of the data was determined by subtracting the lowest data value from the highest data value and the difference was then divided into three ranges. (It would be possible to augment this approach with a graphical adjustment if the data were clearly non-linear, such as exponential or power functions though we did not follow such a procedure for this report). In all cases, the trisection of the data affiliated with greater disturbance was given a score of '1', the trisection associated with the highest-quality sites earned a '5', and the intervening trisection received a score of '3'. Therefore, for any given metric, whatever range of values a site fell into, it received the corresponding metric score. These scores were then summed for each site, yielding the overall IBI score for that site, and the summed scores were plotted against the disturbance gradient. This distribution was in turn trisected into score ranges representing highly-, moderately-, and lightly-disturbed sites.

V. QUALITY ASSURANCE/QUALITY CONTROL

All aspects of the work were under the direction of the study's project manager, who was responsible for establishing and monitoring the design, implementation and analysis of the project. A graduate assistant served as lead field technician and worked under the direction of the project manager. The lead technician was responsible for coordinating field efforts, training personnel, maintaining the database, and overseeing data validation and quality control. All data was entered by field technicians and independently verified by either the graduate assistant or a secondary lead field technician for both the database of wetland method types and the field data.

All participants in the study were field trained together by the project manager and the graduate assistant for one week before official data collection began. Extensive effort and time was devoted to calibrating all of the technicians so that there was repeatability in their data collection. This calibration focus continued throughout the course of the data collection.

Field sampling and data collection was carried out according to the detailed procedures and sampling protocols developed for different aspects of the project and outlined in the Quality Assurance Project Plan. Data analysis and synthesis of the study were coordinated and conducted by the project director and lead technician. A lead field technician was responsible for ensuring that all the necessary data was collected accurately, completely and in an efficient manner while in the field. All data forms were carefully examined, all samples carefully examined for appropriate identification and labels before leaving the field. All field data was recorded on project specific data forms following sampling protocols.

Lab data including the macroinvertebrate samples and plant identification were attended within the time limits according to sampling protocols. The lead technician was responsible for ensuring that all lab work was complete and legible. Field and lab staff and the lead technician made regular and frequent reports on project status to the project manager.

For data transcription, verification and reporting, all data was entered in the computer onto Excel spreadsheets that were designed for each type of data. For a subset of the data, the site information was entered twice (a total of 4 sites or 40% of the data) and compared for precision in data entry.

All field and lab data sheets were stored in the lab of Dr. Colleen Hatfield, the Rutgers Project Manager and will be turned over to Drs. Jean Marie Hartman and Michael May at the completion of this phase of the project as they transition into managing the next phase of the project. Backups of digital data were made on a regular basis.

VI. VEGETATION IBI

A. Vegetation metrics evaluated

As an initial exploration of the data, a large number of metrics that spanned a wide range of data combinations was explored (Appendix D). Some of this exploration was guided by metrics used in IBI models developed by other states and the US EPA. To weed out excess, redundant and unnecessary metrics, only metrics that showed a definitive, predictable response to disturbance were selected for further study. This process eliminated all but the twenty-seven metrics shown below (Table 4). Many of these metrics have been shown to reflect a disturbance signature in the ecological literature and some version of these metrics have been incorporated into existing IBIs. Therefore these metrics are not unexpected and it is relatively simple to predict how they should respond to a disturbance gradient.

It is important to note that not all twenty-seven of these metrics were ultimately used in the development of the vegetation IBI as they were not all equally informative. Rather the metrics included in the IBI development at this stage of the project were those that showed the strongest pattern. The twenty-seven metrics are listed here to ensure that as additional reference sites are added to the model development process, these metrics should continue to be evaluated as possible and perhaps better candidate metrics for inclusion in the final vegetation IBI model for forested riverine wetlands. It is also warranted to continue to revisit the full list (Appendix D) when a larger dataset is in place as some of these might also show a stronger response pattern.

In the following, we have organized the metrics by general themes which include trends in richness, diversity, density, growth form, ruderal (weedy) species and floristic quality. Since there is considerable overlap in the type of information included in the different metrics, rather than presenting all twenty-seven metrics, we present a representative set of metrics for each theme.

For each metric we include several pieces of information for interpreting trends. The actual value of a metric is presented for each of the ten sites in a line graph to illustrate trends and variability between sites. The x-axis is organized along a disturbance gradient with high disturbance on the left and low disturbance on the right. A box-plot is used to show patterns for the sites when grouped into their a priori assigned disturbance

Metric ID	Description
1E	Total Non-Native Shrub Area
1F	Ratio of Non-Native Shrub Area to Total Shrub Area
1H	Total Non-Native Shrub Stem Density
1I	Ratio of Non-Native Shrub Stem Density to Total Shrub Stem Density
1J	Total Tree dbh
1N	Proportion of Trees <.25 dbh
1P	Proportion of Trees >.25 dbh
1U	Total Non-Native Herbaceous Layer Area Cover (Intensive Plots)
1V	Ratio of Non-Native Herbaceous Layer Area Cover to Total Herbaceous Layer Area Cover
1Y	Roseaceae Area Cover in Intensive Plots
2A	Total Importance Values for Non-Native Shrubs
2B	Total Importance Values for Native Shrubs
2C	Ratio of Non-Native:Native Shrub Importance Values
3A	Proportion of Cover in Native Species (Intensive Plots)
3B	Proportion of Cover in Non-Native Species (Intensive Plots)
3C	Ratio of Native:Non-Native Species (Intensive Plots)
4B	Roseaceae Species Richness (Intensive Plots)
4D	Total Native Genera Richness
4E	Total Native Genera Richness minus upland Genera
4O	Ratio of Woody to Perennial Species Richness
4DD	Cumulative Species Richness
4EE	Cumulative Non-Native Species Richness
4GG	Cumulative Herbaceous Species Richness (Intensive Plots)
6C	Simpson's Index for all Herbaceous Layer Species (Intensive Plots)
6D	Simpson's Index for all Tree Species
6F	Simpson's Index for all Shrubs Species (Area)
7A	Floristic Quality Assessment Index for each site

Table 4. Metrics evaluated further for the vegetation IBI.
Metric index refers to a coding system developed during the initial exploration of the data. Data used just from the intensive vegetation plots at a site are noted in parentheses after the metric description, otherwise data from the two transects are included in the metric.

categories. The box plot includes the 25th and 75th percentile of the data range. Both the median and the mean are presented. Tables of data transformations (if necessary) and univariate statistical results are also presented for each metric. Unless otherwise noted, assumptions of normality and homogeneity of variances were met with either the raw or transformed data (results not shown). Data is considered to meet assumptions of normality when the Wilk-Shapiro p is >0.05. Univariate statistics were evaluated at a p-value =0.15 as noted in the Data Analysis section of Methods. Results of the statistical analysis for each of the twenty-seven variables is presented in Table 5:

Table 5A. Disturbance Metrics		Disturbance Gradient				Wetness Gradient		
Code	Description	Anova p-value	Anova r-square	Regression p-value	Regression r-square	Regression p-value	Regression r-square	Data Type
1E	Total Non-Native Shrub Cover	0.1	0.48	0.02	0.43	<0.01	0.56	NORMAL
1F	Ratio of Non-Native Shrub Cover to Total Shrub Cover	0.03	0.64	<0.01	0.58	0.02	0.45	ARCSIN
1H	Total Non-Native Shrub Stem Density	0.31	0.28	0.13	0.16	0.03	0.41	LOG
1I	Ratio of Non-Native Shrub Stem Density to Total Shrub Stem Density	0.06	0.56	<0.01	0.54	0.04	0.37	ARCSIN
1J	Total Tree dbh	0.02	0.69	<0.01	0.64	0.31	0.02	NORMAL
1N	Proportion of Trees <.25 dbh	0.06	0.56	0.20	0.09	0.45	0.05	ARCSIN
1P	Proportion of Trees >.25 dbh	0.15	0.42	0.29	0.03	0.40	0.02	ARCSIN
1U	Total Non-Native Herbaceous Cover (IP#)	<0.01	0.75	<0.01	0.67	0.28	0.04	LOG
1V	Ratio of Non-Native Herbaceous Layer Cover to Total Herbaceous Layer Cover	**						
1Y	Roseaceae Cover in Intensive Plots	<0.01	0.75	<0.01	0.70	0.18	0.12	LOG
2A	Importance Value (IV) Sum for Non-Native Shrubs	0.03	0.62	0.01	0.64	0.02	0.50	ARCSIN
2B	Importance Value (IV) Sum for Native Shrubs	0.07	0.53	0.02	0.47	0.06	0.31	ARCSIN
2C	Ratio of Non-Native Shrub IV Sum to Native Shrub IV Sum	0.03	0.43	<0.01	0.59	<0.01	0.58	NORMAL
3A	Proportion of Cover in Native Species (IP#)	0.02	0.68	<0.01	0.68	0.02	0.48	ARCSIN
3B	Proportion of Cover in Non-Native Species (IP#)	**						
3C	Ratio of Native to Non-Native Species Cover (IP#)	**						
4B	Roseaceae Species Richness (Intensive Plots)	0.24	0.33	0.20	0.09	0.12	0.18	NORMAL
4D	Total Native Genera Richness	0.06	0.55	0.02	0.44	0.59	0.18	LOG
4E	Total Native Genera Richness Minus Upland Genera	0.02	0.68	<0.01	0.60	0.40	0.02	LOG
4DD	Cumulative Species Richness	0.15	0.42	0.08	0.25	0.45	0.04	NORMAL
4EE	Cumulative Non-Native Species Richness	0.03	0.62	0.01	0.54	0.09	0.23	NORMAL
4GG	Cumulative Herbaceous Species Richness (IP#)	**						
6C	Simpson's Index for all Herbaceous Layer Species (IP#)	0.07	0.54	0.94	0.12	0.21	0.09	ARCSIN
6D	Simpson's Index for all Tree Species	0.42	0.22	0.37	0.01	0.03	0.40	ARCSIN
6F	Simpson's Index for all Shrubs Species (Area)	0.58	0.14	0.62	0.08	0.83	0.12	NORMAL
7A	Floristic Quality Assessment Index	0.01	0.74	<0.01	0.84	0.25	0.16	NORMAL

Table 5B. WETNESS Metrics				Disturbance Gradient		Wetness Gradient		
Code	**Metric Description**			**Regression p-value**	**Regression r-square**	**Regression p-value**	**Regression r-square**	**Data Type**
1W	"Wet" Herb Cover			0.65	0.10	<0.01	0.82	LOG
1X	"Wet" Herb Cover to Total Herb Cover			0.18	0.11	<0.01	0.89	ARCSIN
3D	Cover in "Wet" Species in Intensive Plots			0.19	0.11	<0.01	0.89	ARCSIN
3E	Cover in Non-"Wet" species in Intensive Plots			0.14	0.16	<0.01	0.95	ARCSIN
3F	Ratio of "Wet" to Non-"Wet" Species Cover (IP#)			0.11	0.29	<0.01	0.65	LOG
4J	"Wet" Herb Richness			<0.01	0.61	<0.01	0.60	LOG
4K	"Wet" Tree Richness			0.68	0.02	0.47	0.05	NORMAL

IP# Measurements take the Intensive Plots at a site

** Data did not meet parametric assumptions and statistical analyses not performed

Table 5. Results of statistical analysis for data metrics calculated for the ten sites. Two categories of metrics are presented, those that were predicted to reflect a disturbance signature (Part A) and those predicted to reflect a wetness signature (Part B). Analysis of variance (GLM) results are presented for differences between three disturbance classes (High, Moderate and Low). Analysis of variance was only performed on the disturbance category based on a priori class designations. Two regressions were performed for each metric, one regressing the metric data against the site's disturbance score (Disturbance Gradient) and a second regressing the metric data against the site's wetness score (Wetness Gradient). (See methods and results for details on how the site scores were derived.) All metrics unless otherwise noted approximated assumptions of parametric statistics including normality and homogeneity of variances.

1. Patterns in Species Richness

Sites that experience intermediate levels of disturbance (intensity and frequency of disturbance) often have higher species richness than sites that are repeatedly disturbed or sites that are rarely disturbed (Connell 1977). This pattern has been observed in a variety of systems including plant and animal communities. Considering the history of New Jersey, it is a relatively safe assumption, backed with field observations, that the least disturbed sites in this study have experienced some moderate level of disturbance in the past. As a consequence, we would expect these sites to have relatively higher species richness associated with intermediate levels of disturbance rather than lower species richness indicative of infrequent disturbance. To this end, we examined various forms of richness including genera richness, site species richness and herbaceous layer species richness in the intensive plots.

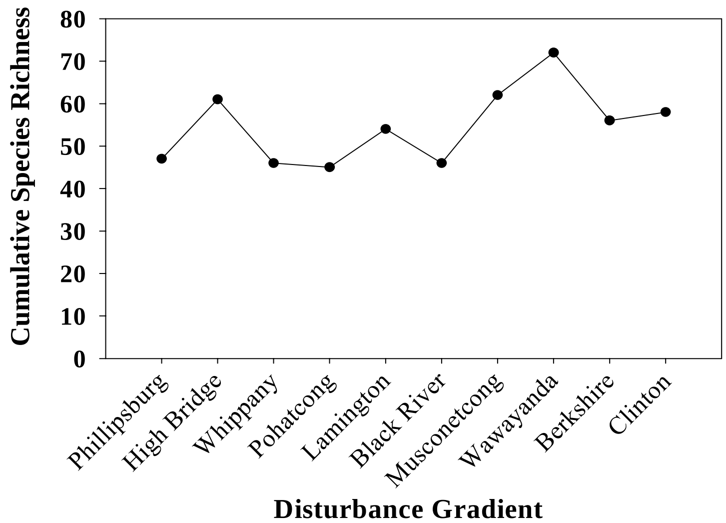
Cumulative Species Richness:

All distinct species encountered in the transects contributed to the cumulative species richness of a site. A list of plant species encountered at all sites is included in Appendix C. There was no trend in species richness across the disturbance gradient (Figure 5a). Though there was a significant increase in richness (r^2=0.25, p = 0.08) with decreasing disturbance, this is primarily due to the high species richness (74 species) at Wawayanda, a low disturbance site, and secondarily at Musconetcong (63 species), a moderately disturbed site. High Bridge, a high disturbance site, was the third highest for species richness at 61 species. Average species richness was similar across the three disturbance categories (Figure 5b).

Non-Native Species Richness:

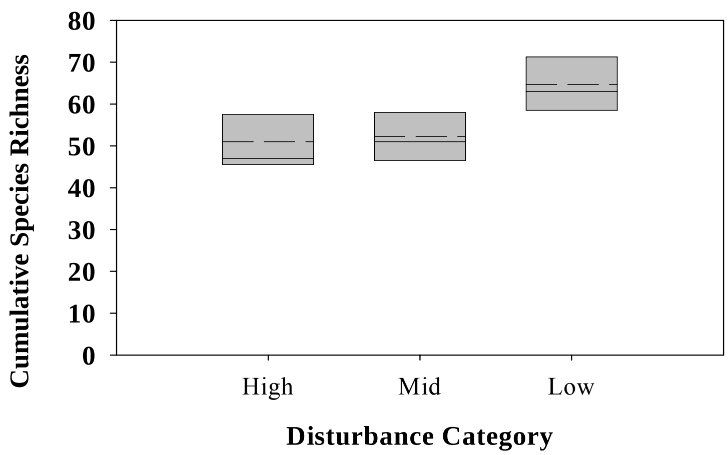
This metric represents the total number of species at a site that are considered non-native . It reflects data collected both in the intensive plots and the transects and each non-native species is only counted once irrespective of how many times it is encountered. There is a notable and significant trend (r^2 = 0.54, p=0.01) whereby non-native species richness tends to decline as site disturbance decreases (Figure 6a). High Bridge had the highest number of non-native species at 14 species followed by Phillipsburg at 11 species. Clinton, the site ranked as least disturbed had 3 non-native species present across the site.

There was also a significant difference between the different disturbance classes (p = 0.03) with the high disturbance class significantly higher than the low disturbance class (Figure 6b). The variability was also considerably higher in the high disturbance class reflecting the relatively lower number of non-native species at Whippany (7 species).



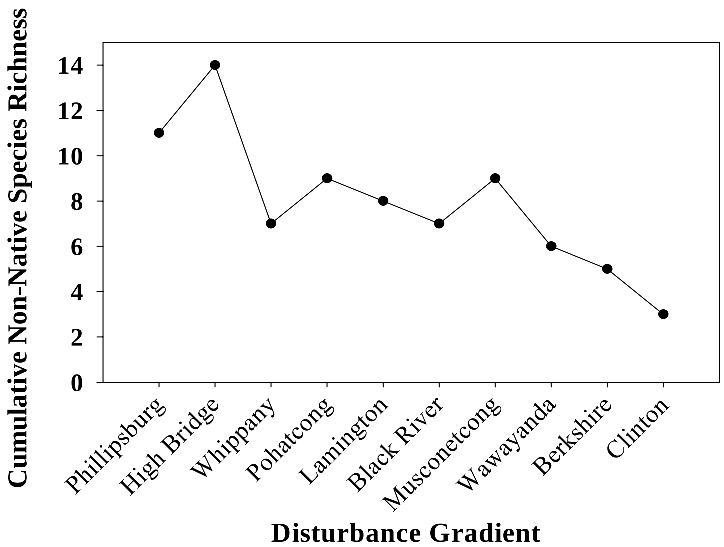
Regression	
R^2	0.25
p	0.08
F	4.0

Figure 5a. Cumulative species richness from transects and intensive plots at a site. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



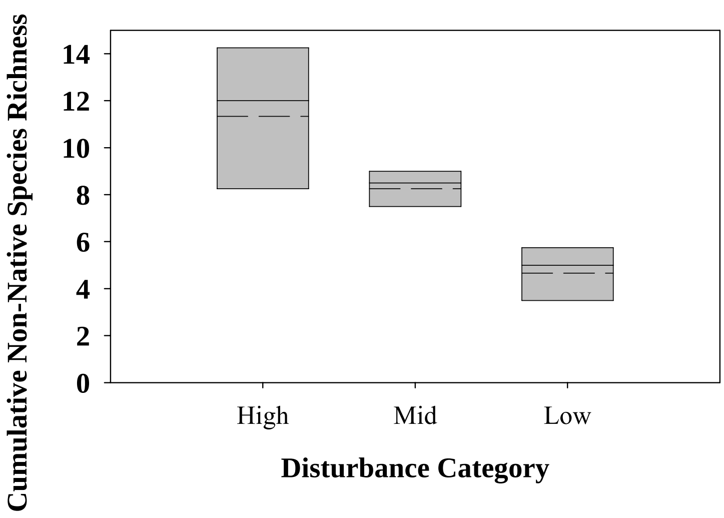
ANOVA	
P	0.15
F	2.51

Figure 5b. Box plots for cumulative species richness by disturbance category. Median (solid), mean (dashed) and 25 and 75 percentiles for cumulative species richness from the transects and intensive plots. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.



Regression	
R^2	0.54
p	0.01
F	12.06

Figure 6a. Cumulative non-native species richness in the transects and intensive plots.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



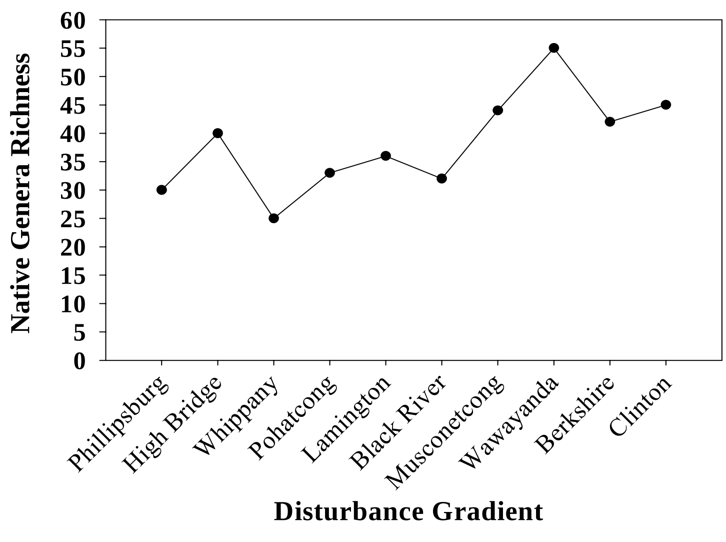
ANOVA	
P	0.03
F	6.70

Figure 6b. Box plots for cumulative non-native species richness by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for non-native species richness in the transects and intensive plots. Sites are grouped into three disturbance categories: high, moderate, and low disturbance.

Native Genera Richness:

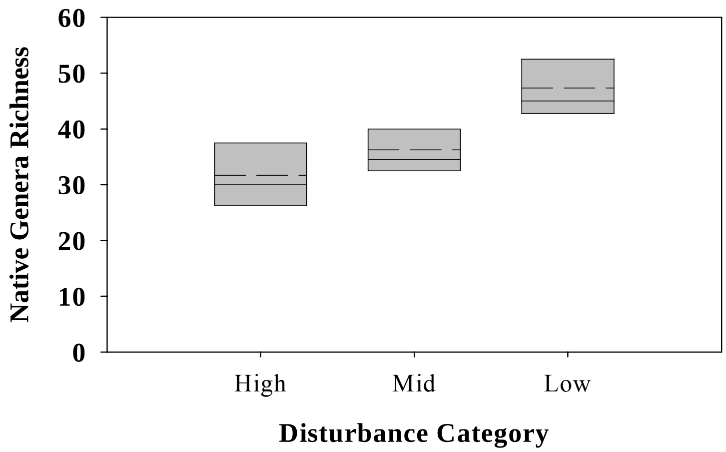
Overall genera richness was modified to consider the number of native genera once the non-native genera were removed. Since some genera contained both native and non-native species, each genera was evaluated and assigned a native or non-native status based on the native and non-native abundance. For example, *Rosa multiflora* always had higher abundance than *Rosa palustris* and therefore *Rosa* was always classified as a non-native genera for purposes of this metric. It is important to note that each genera was evaluated in terms of each site so in some instances a genera may be assigned a native for one site and a non-native for another. For example, the genus *Polygonum* was called a native genera at Berkshire, Black River, and Whippany, because at these sites, the area cover (m^2) of native Polygonum species was more than 50% the total *Polygonum* species cover. In contrast, *Polygonum* was called a non-native genera at High Bridge, Musconetcong and Pohatcong, because at these sites, the area cover (m^2) of non-native *Polygonum* species was more than 50% the total *Polygonum* species cover.

The data shows a gradual and significant (p=0.02) increase in native genera as site disturbance decreases (Figure 7a). In general, one site in each of the three categories had higher genera richness compared to the other sites in that category, which themselves were somewhat similar. Sites with higher general richness within a category included High Bridge in the most disturbed category, Musconetcong in the moderately disturbed category and Wawayanda in the least disturbed category. The least disturbed category was significantly (p = 0.05) different from the other two categories, which were not different from each other (Figure 7b)



Regression	
R^2	0.44
p	0.02
F	8.21

Figure 7a. Native genera richness from the transects and intensive plots. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



ANOVA	
p	0.06
F	4.37

Figure 7b. Box plots for native general richness by disturbance category
Median (solid), mean (dashed) and 25 and 75 percentile for native genera richness in the transects and intensive plots. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

2. Patterns in Diversity Measures

Diversity considers both species richness and species abundance. Unlike species richness, diversity provides a measure of both how many species are present and how evenly the individuals are distributed between the different species. For example, if a few species are dominant (even with high species richness), diversity can be relatively lower compared to where abundances are more evenly distributed among the different species. Similar to the predictions of how patterns of species richness should respond along our disturbance gradient, we would expect higher diversity in the less disturbed sites. Highly disturbed areas are often dominated by a few species that are able to thrive in disturbed areas. Conversely, in low disturbance areas, species that are superior competitors often become the dominant species.

Herbaceous Layer Diversity:

The diversity patterns in the herbaceous layer were examined and there was no consistent trend in diversity along the disturbance gradient (Figure 8a). The herbaceous layer diversity was determined from the intensive plots and included all species that were counted in the herb layer including herbaceous and woody species. This lack of pattern is further augmented by the fact that there was no trend in the herbaceous layer species richness (Figure 8b)

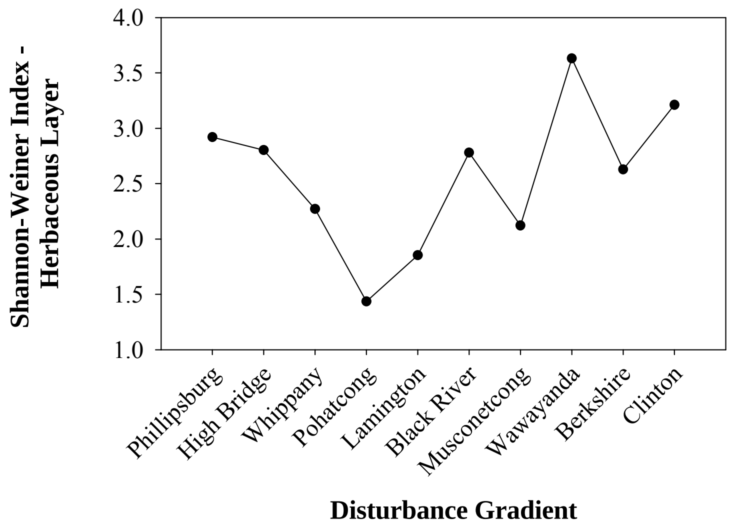


Figure 8a. Diversity in the herbaceous layer in the intensive plots at a site. Herbaceous and woody species are included in the diversity index. y-axis is the Shannon-Weiner Index of diversity and sites are ordered on the x-axis along the land cover disturbance gradient decreasing in disturbance from left to right.

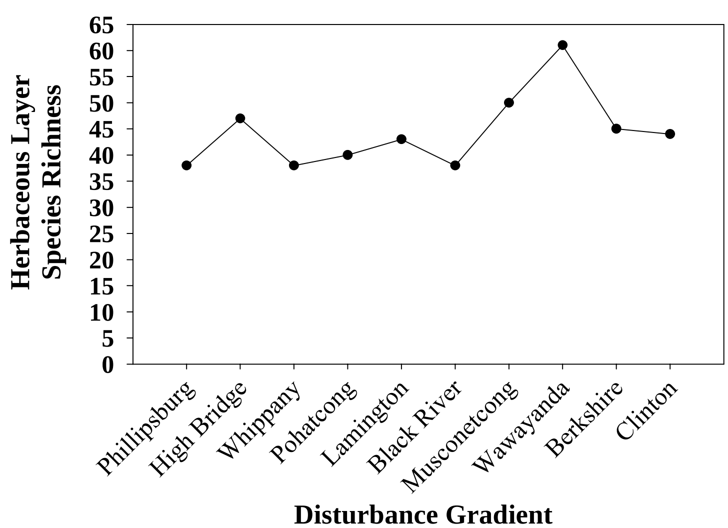


Figure 8b. Species richness in the herbaceous layer of the intensive plots. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

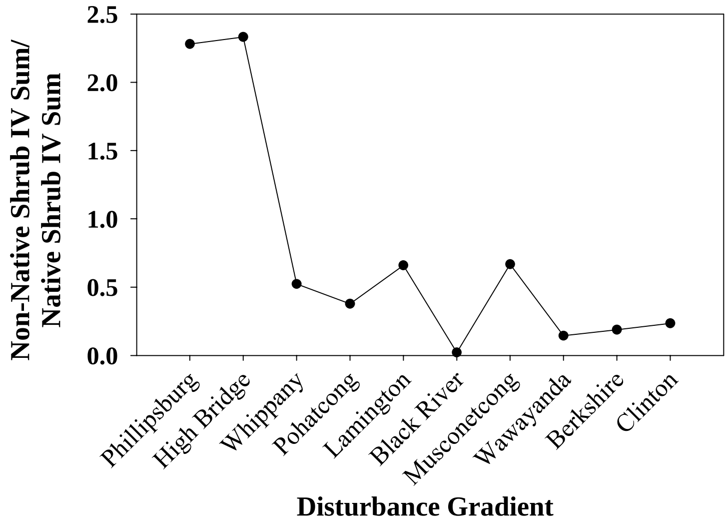
Ratio of Non-Native Shrub Importance Value (IV) to Native Shrub IV:

Importance Values is a metric that is often used in the description of ecological communities. It reflects the relative contribution of a particular species to the entire community. We calculated the Importance Value (IV) for each shrub species at each site using the following equation where i equals an individual species:

$$\text{Shrub IV} = \left(\frac{\text{Species}_i \text{ area } (m^2)}{\text{Total Shrub Area } (m^2)} + \frac{\text{Species}_i \text{ Stems}}{\text{Total Shrub Stems)}} \right) /2$$

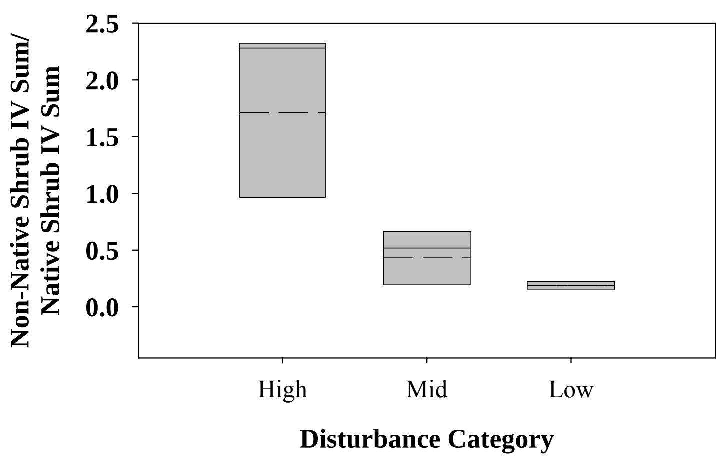
This measure reflects the area covered by a particular shrub species relative to the total shrub area in the two transects at a site combined with the total number of stems of a particular species relative to the total number of shrub stems in the two transects. To derive the metric ratio, the importance values (IV) for non-native shrub species was summed and divided by the sum of importance values for native shrub species.

The majority of the sites had somewhat comparable ratios of non-native shrub to native shrub importance values and the values were moderately low across the disturbance gradients (Figure 9a). The exception to this was for the two sites ranked most disturbed, Phillipsburg and High Bridge. For these two sites, non-native shrubs were a major component of the shrub layer. The Phillipsburg shrub layer was dominated by *Rosa multiflora* (multiflora rosa) with *Ligustrum vulgare* (common privet), *Euonymus alata* (winged burning bush), and *Lonicera morrowii* (Morrow's honeysuckle) while the High Bridge had *Berberis thunbergii* (Japanese barberry), *Rhodotypos scandens* (jetbead) and *Rubus phoenicolasius* (wine raspberry) . The trend in the ratio was significant for the log transformed data with an r^2 of 0.59 but this was primarily driven by the high values for the two most disturbed sites. The ANOVA for differences between the three disturbance categories was also significant at 0.03 (Figure 9b).



Regression	
R^2	0.59
p	<0.01
F	14.05

Figure 9a. The ratio of the sums of non-native shrub importance values to native shrub importance values in site transects.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



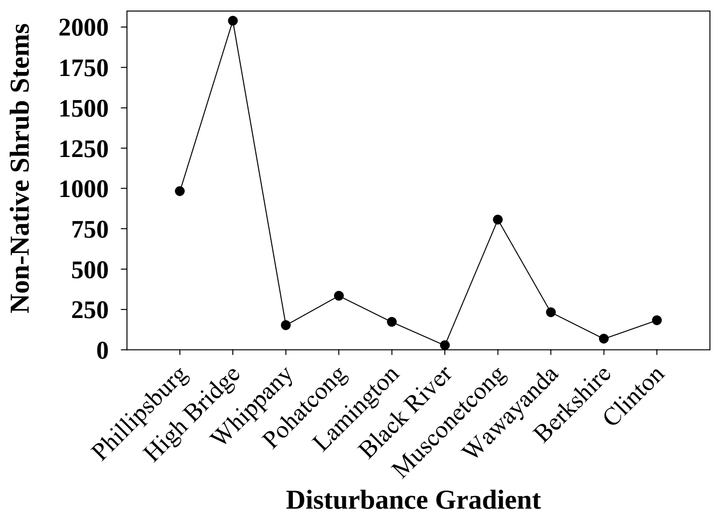
ANOVA	
P	0.03
F	6.01

Figure 9b. Box plot for sums of non-native shrub importance values/native shrub importance values by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for the sum of non-native shrub importance values divided by the sum of native shrub importance values in the transects. Sites are grouped into three disturbance categories: high, moderate, and low disturbance.

3. Patterns in Density

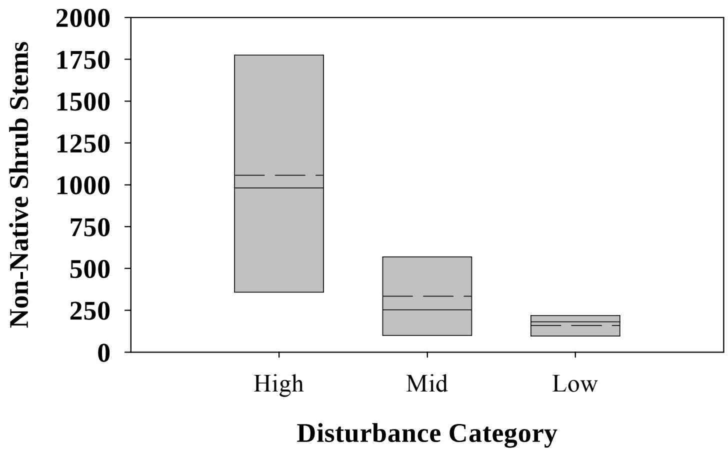
Non-Native Shrub Stem Count:

This metric is a count of the number of non-native stems at a site. Though the information here is a component of the numerator in the above metric, it is included to illustrate the need to understand the nature of the data (Figure 10a). Non-native shrub stems alone do not follow the disturbance gradient and the trend is not strong (r^2=0.16). High Bridge had over 2000 non-native stems, well above other high disturbance sites and Musconetcong was notably higher than other moderate disturbance sites. Disturbance categories were also not significant (p=0.31) and the high variability is noticeable in the high disturbance category (Figure 10b).



Regression	
R^2	0.16
p	0.13
F	2.79

Figure 10a. Count of non-native shrub stems in the transects.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



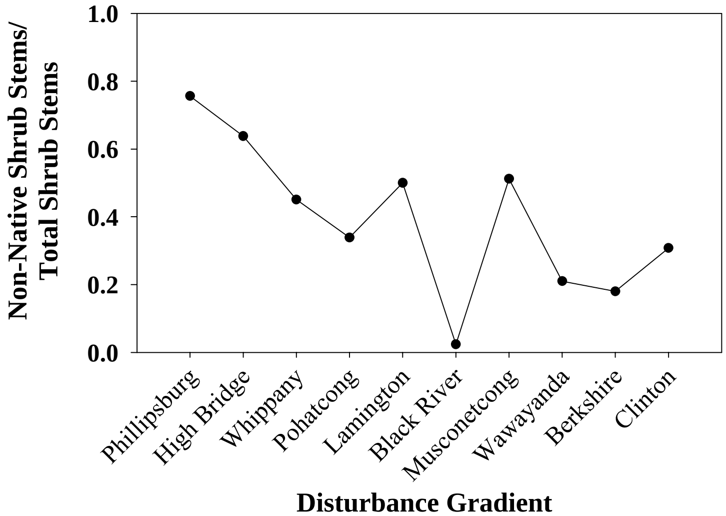
ANOVA	
P	0.31
F	1.38

Figure 10b. Box plot for non-native shrub stems in transects by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for non-native shrub stems in the transects. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

<u>Ratio of Non-Native Shrub Stem Density to Total Shrub Stem Density:</u>

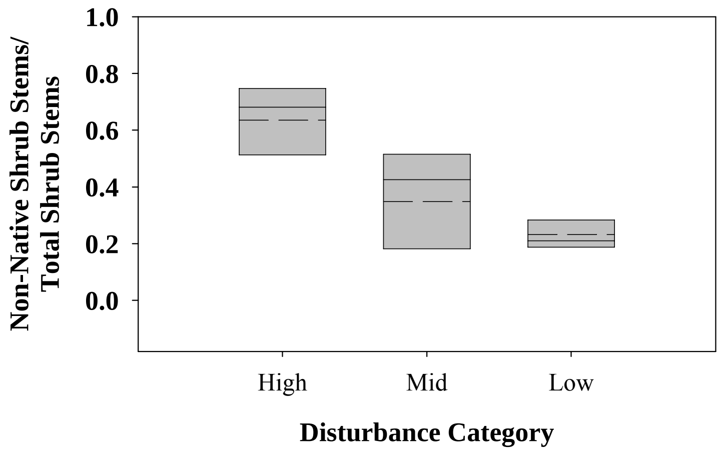
This metric provides another way to examine the relationship between non-native shrubs and the total shrub community. This metric created a proportion between the number of stems for non-native shrubs compared to the number of total shrub stems. Whippany was low compared to the other disturbed sites but there was also a consistent decline in the ratio across the highly disturbed sites (Figure 11a). Two of the moderately disturbed sites (Lamington and Musconetcong) had a higher ratio than Whippany while Black River had few non-native shrub stems in comparison. The trend was statistically significant ($r^2=0.54$, $p<0.01$).

There was less of a distinction between the disturbance categories for the shrub stem count ratio than for the shrub cover but the trend was still significant ($p=0.06$) (Figure 11b). High disturbance sites tended to have more non-native shrub stems relative to the total number of shrub stems compared to the low disturbance sites and the moderately disturbed sites had greater variability between themselves than did the other two groups.



Regression	
R^2	0.54
p	<0.01
F	11.72

Figure 11a. Non-native shrub stems divided by total shrub stems in the transects. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



ANOVA	
P	0.06
F	4.49

Figure 11b. Box plots for the ratio of non-native shrub stems to total shrub stems by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for non-native shrub stems divided by the total number of shrub stems in the transects. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

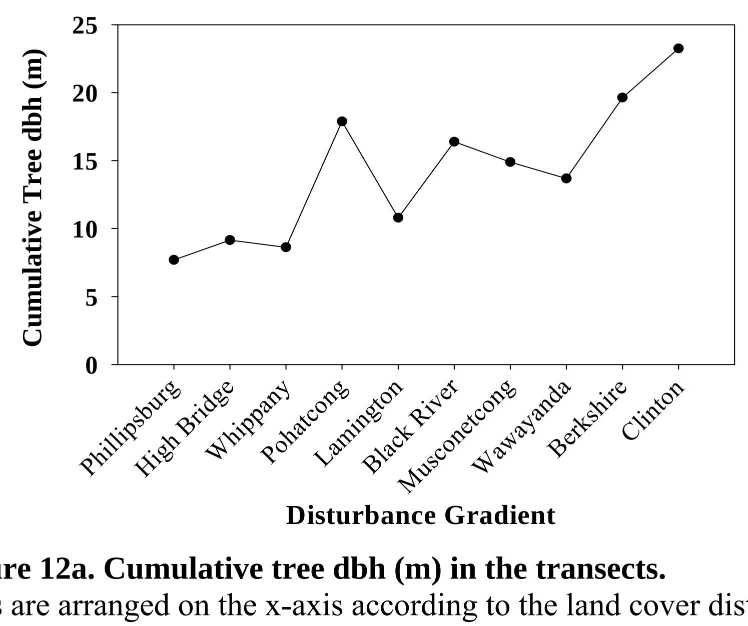
4. Patterns in Growth Forms

Total Tree dbh:

This metric measures the total diameter at breast height for all trees in the site. Sites that have not been disturbed or are subjected to infrequent disturbance should have larger trees. Two formulations of the tree data were examined to see whether they supported this premise: total tree diameter at breast height (dbh) and proportion of trees less than 0.25m dbh.

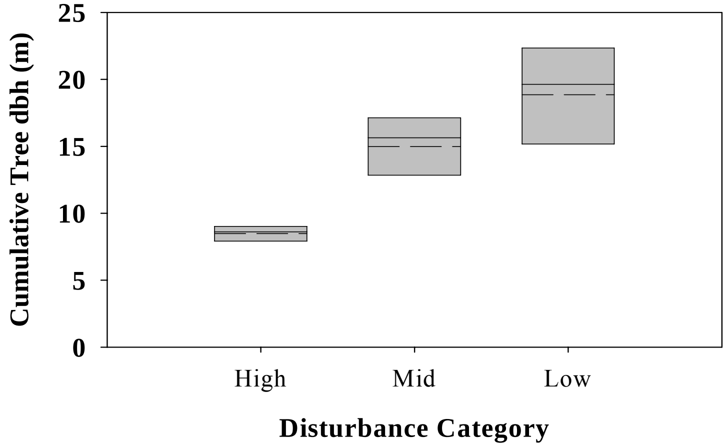
The total tree dbh increased along the disturbance gradient with Phillipsburg having the lowest cumulative tree dbh and Clinton the highest (Figure 12a). The trend is significant and a relatively strong relationship existed across the sites ($r^2 = 0.64$, $p<0.01$). The moderately disturbed category was considerably more variable with Pohatcong having a cumulative dbh approaching that of the least disturbed sites while Lamington had a cumulative dbh that was not much greater than the high disturbance sites. In the least disturbed category, Wawayanda had considerably less cumulative dbh, comparable with the moderate disturbance sites, whereas Clinton and Berkshire were over three times higher than the high disturbance sites.

The high disturbance category was significantly different ($p = 0.02$) from the moderate and least disturbance categories, which were not significantly different from each other (Figure 12b). As noted above, there was greater variability within the moderate and least disturbance categories whereas the sites in the high disturbance category were relatively similar.



Regression	
R^2	0.64
p	<0.01
F	16.8

Figure 12a. Cumulative tree dbh (m) in the transects.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



ANOVA	
P	0.02
F	7.66

Figure 12b. Box plot of cumulative tree dbh by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for cumulative tree dbh (m) in the transects. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

It is important to note that a higher cumulative dbh at less disturbed sites does not imply that the trees are larger at these sites. Rather, the sites with larger trees (High Bridge, Black River and Musconetcong) were not in this category and the less disturbed sites actually tended to have smaller trees (Figure 13)

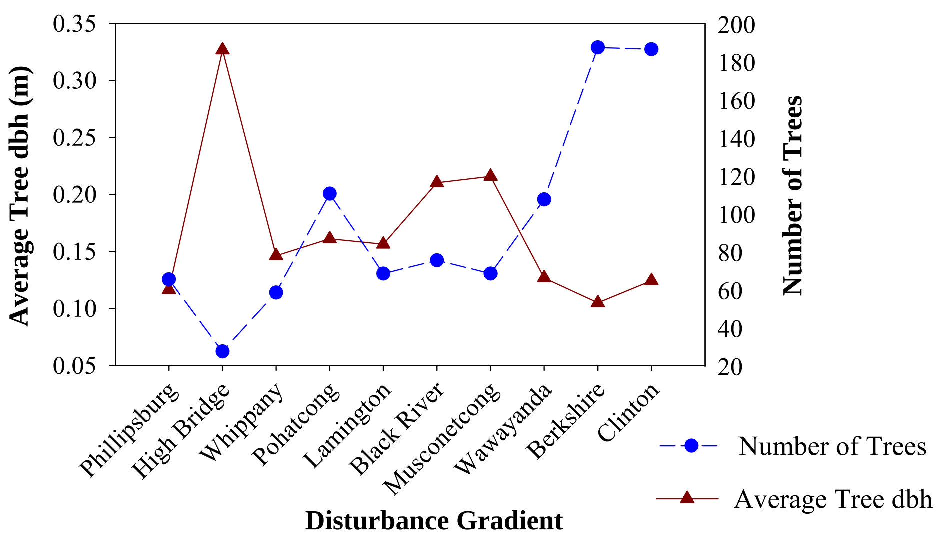
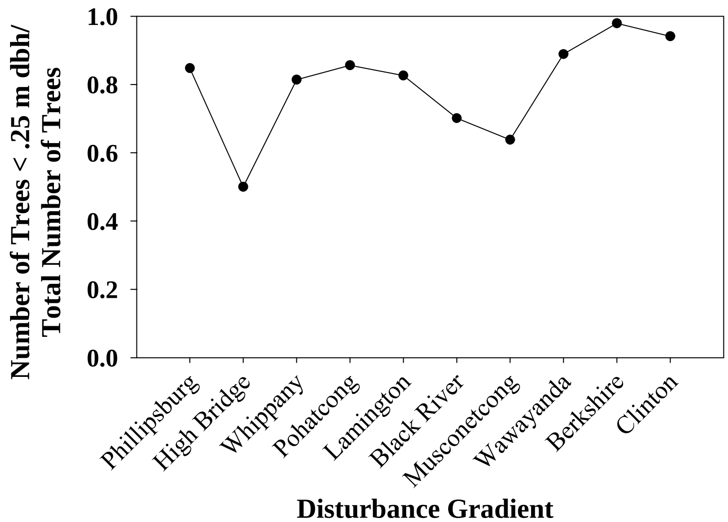


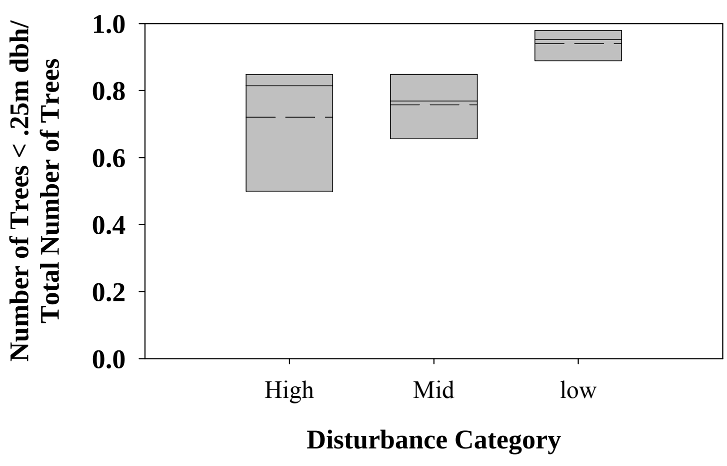
Figure 13. Average tree dbh (m) per site (triangles) and number of individual trees per site (circles).
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

This pattern is evident when we look at the ratio of trees smaller than 0.25m dbh to the total trees at a site (Figure 14a). Higher ratios indicate that most of the trees are smaller and the three less disturbed sites have the highest ratios. The trend along the disturbance gradient is not significant (r^2 = 0.09 and p = 0.20) but when analyzed by disturbance category, the less disturbed sites are significantly different (p = 0.06) from the other two categories (Figure 14b)



Regression	
R^2	0.09
p	0.20
F	1.94

Figure 14a. Ratio of trees <.25m dbh to total number of trees in the transects. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

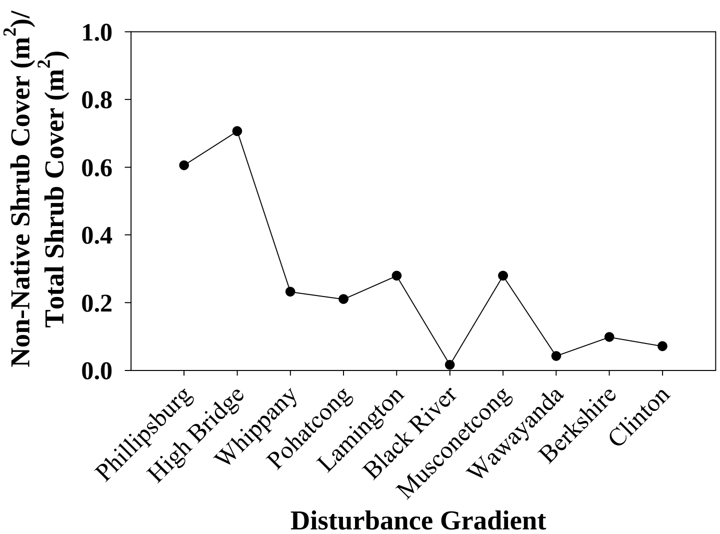


ANOVA	
P	0.06
F	4.4

Figure 14b. Box plot of tress <0.25 dbh divided by total number of trees by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for the number of trees <.25m dbh divided by the total number of trees in the transects. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

Ratio of Non-Native Shrub Cover to Total Shrub Cover:

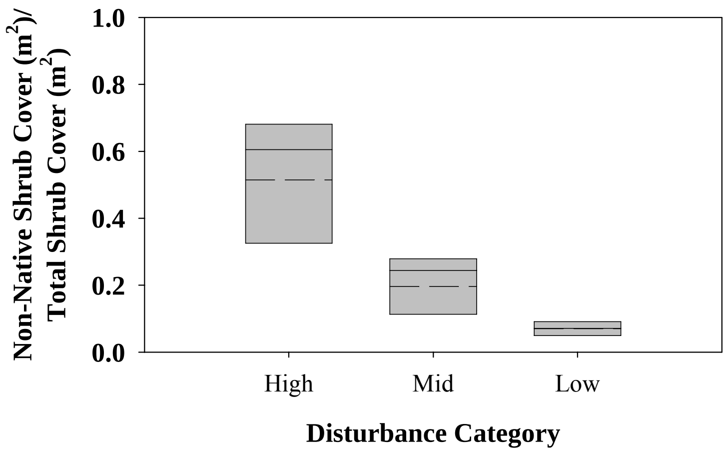
Numerous studies have indicated that with increasing disturbance there is a concomitant increase in non-native species. When we compared the relative proportion of non-native shrub cover to total shrub cover (native and non-native), there was a tendency for the ratio to decrease with decreasingly disturbed sites (Figure 15a). The noticeable exception to this trend was for Black River, a site in the moderate disturbance category. Black River had a very low number of non-native species in comparison to the other species in the moderate disturbance category. Whippany also had a low proportion of non-natives than its fellow highly disturbed sites. Whippany had a very sparse shrub layer and the shrubs that were present tended to be native species. A similar metric of non-native shrub cover rather than the ratio, showed similar patterns with less non-native shrub cover in less disturbed sites (Data not shown).



Regression	
R^2	0.58
p	<0.01
F	13.79

Figure 15a. Ratio of non-native shrub cover (m^2) to total shrub cover (m^2) in the transects.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

There was a statistically significant difference between the proportions of non-native shrub cover to total shrub cover between the disturbance categories (p=0.03). High disturbance sites tended to have more non-native shrub cover relative to the total shrub cover compared to the other two disturbance categories (Figure 15b). There was also greater variability between the disturbed sites (because of Whippany) than the other two categories. The least disturbed sites were quite similar with consistently low non-native shrub cover compared to total shrub cover.



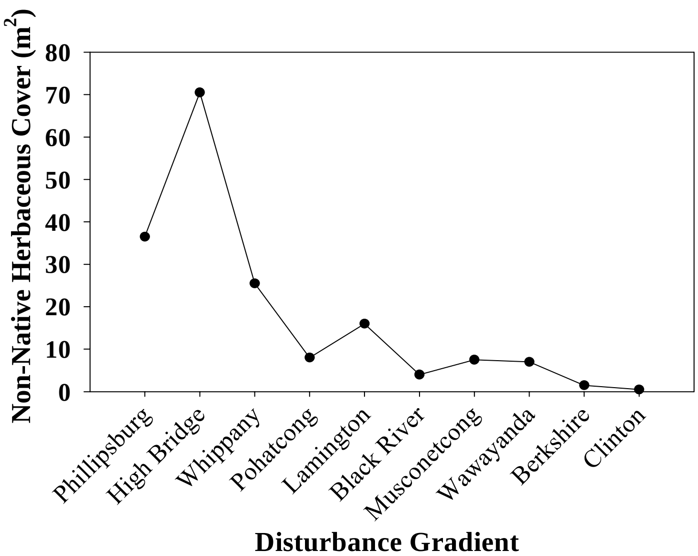
ANOVA	
P	0.03
F	6.32

Figure 15b. Box plot for ratio of non-native shrub cover to total shrub cover by by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for non-native shrub cover (m^2) to total shrub cover (m^2) in the two transects at a site. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

Total Non-Native Species Cover in the Herbaceous Layer:

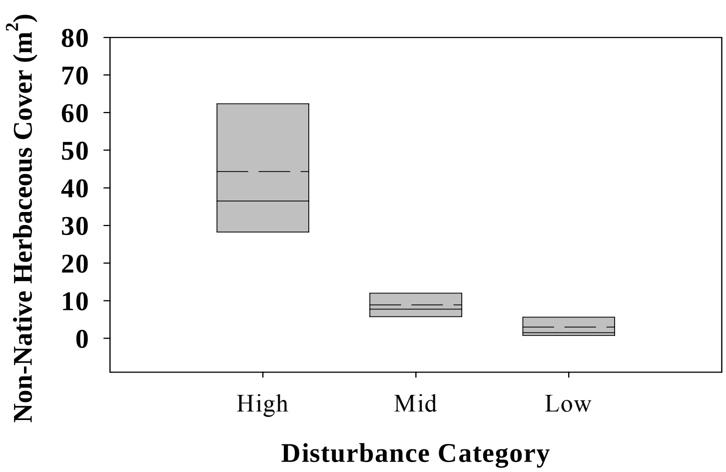
This metric was derived by summing the non-native species cover in the herbaceous layers of the two intensive plots. The extent of non-native species cover increased as sites became more disturbed with disturbed sites notably higher than the other sites (Figure 16a). High Bridge had the highest extent of non-native species cover dominated by two non-natives, *Microstegium vimineum (*Japanese stilt grass) and *Alliaria officinalis* (garlic mustard). The five sites on the right side of the graph were somewhat similar. A log transformation of the data for normality also resulted in a strongly significant trend (r^2=0.67) of increasing non-native species cover with increasing disturbance.

Though there was considerable variability in the high disturbance category, it was significantly different from the other two disturbance categories, which were not different from each other (Figure 16b).



Regression	
R^2	0.67
p	<0.01
F	19.70

Figure 16a. Sum of non-native herbaceous layer cover (m2) in the intensive plots. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



ANOVA	
P	<0.01
F	10.37

Figure 16b. Box plot of non-native herbaceous cover by disturbance category. Median (solid), mean (dashed) and 25 and 75 percentiles for the sum of non-native herbaceous cover (m^2) in the intensive plots. Sites are grouped into three disturbance categories: high, moderate, and low disturbance.

Ratio of Non-Native Herbaceous Cover to Total Herbaceous Cover:

When non-native herbaceous species cover was compared to the total herbaceous cover, the two most disturbed sites, Phillipsburg and High Bridge, had notably higher non-native herbaceous cover comprising the total herb cover (Figure 17a) whereas Whippany was more similar to the remaining sites. In this particular comparison, the low value for Whippany is a reflection of the lack of a well developed herbaceous layer (native or non-native). This metric did not meet the assumptions of normality and is included here to illustrate trends only.

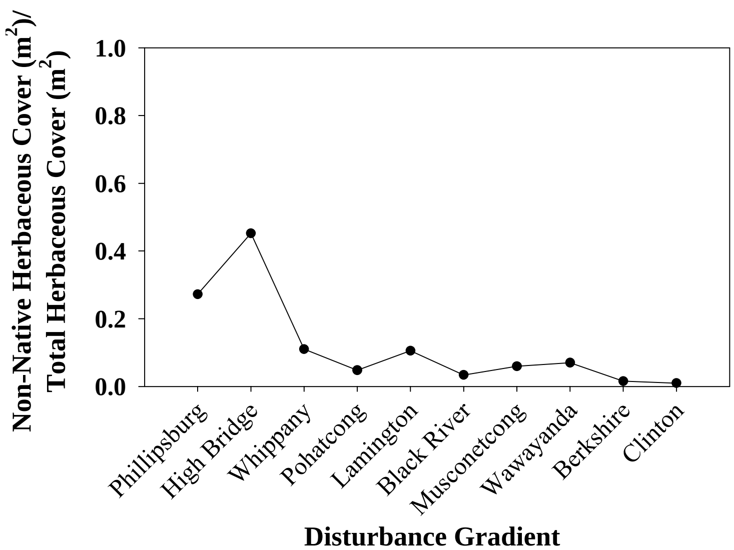


Figure 17a. Ratio of non-native herbaceous cover (m^2) to total herbaceous cover (m^2) in the intensive plots.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

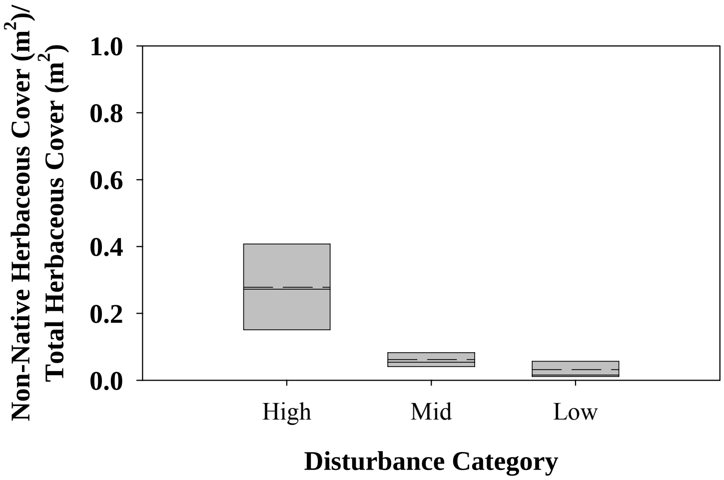


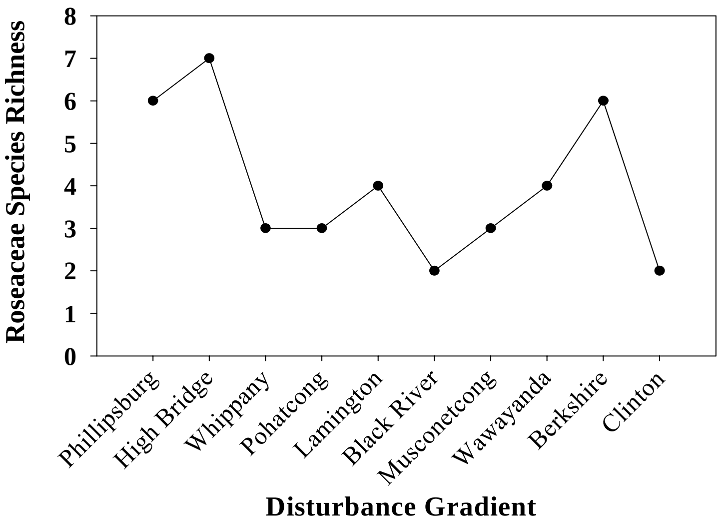
Figure 17b. Box plot of non-native herbaceous cover to total herbaceous cover by disturbance category.
Median (solid), mean (dashed) and 25 and 75 percentiles for non-native herbaceous cover (m^2) divided by total herbaceous cover (m^2) in the intensive plots. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

5. Patterns in Ruderal Species

Many of the species in the family Roseaceae are considered weedy or ruderal species and are indicative of disturbance. To test if Roseaceae followed this pattern we examined both amount of cover of Roseaceae in the intensive plots and the total species richness in the Roseaceae family at the sites.

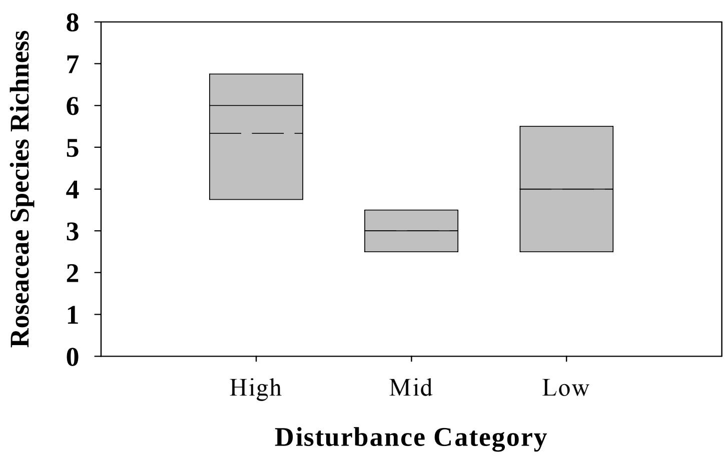
Roseaceae Species Richness:

Measured in the intensive plots at a site, there was considerable variability and no strong pattern of Roseaceae richness across the sites (Figure 18a). High Bridge and Phillipsburg had the greatest richness at 7 and 6 species respectively but Berkshire, a low disturbance site, also had 6 Roseaceae species present. Black River, a moderate disturbance site, and Clinton, a low disturbance site, had the fewest Roseaceae species present at 2 species. The low r^2 of 0.09 reflects the considerable variability in the data and the pattern was not significant between the categories (Figure 18b).



Regression	
R^2	0.09
p	0.20
F	1.93

Figure 18a. Species richness of plants in the Roseaceae family in the intensive plots. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



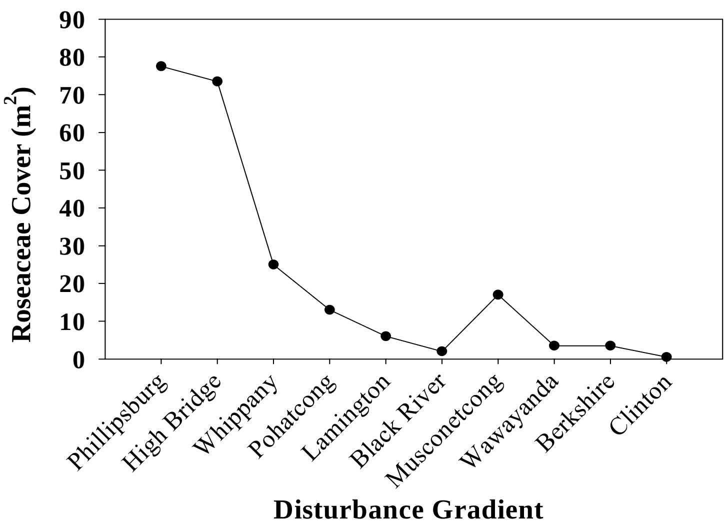
ANOVA	
P	0.24
F	1.75

Figure 18b. Box plot of Roseaceae species richness by disturbance category. Median (solid), mean (dashed) and 25 and 75 percentiles for plants in the Roseaceae family in the intensive plots. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

Roseaceae Cover:

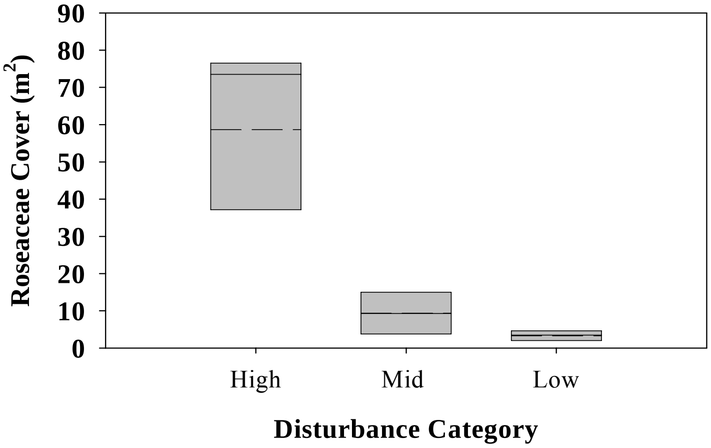
The total cover of Roseaceae in the intensive plots at a site significantly decreased along the disturbance gradient (Figure 19a). Phillipsburg and High Bridge were notably higher than the other sites followed by Whippany (though it was considerably lower that the other two sites in the high disturbance category). With the exception of Musconetcong, the moderate disturbance sites had less than 15 m^2 of Roseaceae cover and the three low disturbance sites were similar and consistently had low coverage of Roseaceae species.

The higher variability in the high disturbance category and the low variability in the low disturbance sites is reflected in the highly significant ANOVA results and in the box plots (Figure 19b). High disturbance sites are significantly different from the other two categories, which themselves are not significantly different.



Regression	
R^2	0.70
p	<0.01
F	21.55

Figure 19a. Cover (m^2) of plants in the Roseaceae family in the intensive plots. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



ANOVA	
P	<0.01
F	10.48

Figure 19b. Box plot of Roseaceae cover by disturbance category. Median (solid), mean (dashed) and 25 and 75 percentiles for plants in the Roseaceae family in the intensive plots. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

Floristic Quality Assessment:

The Floristic Quality Assessment Index, or FQAI, is a quality measure of a site based on the disturbance tolerance of the plants that inhabit it (Swink and Wilhelm, 1994). It is a similar measurement to species richness, but instead each species within the site is weighted based on its tolerance to disturbance. FQAIs have not been developed or used in New Jersey and were used in this pilot IBI project to assess whether this metric might be useful and merit further study and development.

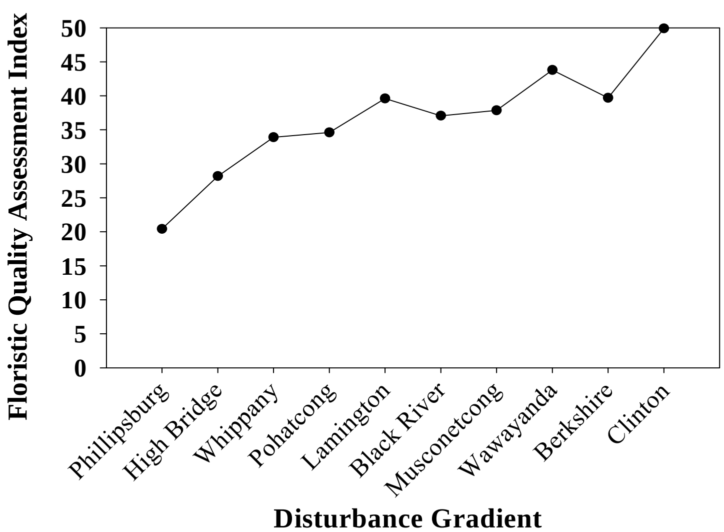
In the development and implementation of a FQAI, each species is weighted by a value called the Coefficient of Conservatism. The Coefficient of Conservatism (CC) for each plant is determined by a panel of botanical experts who are familiar with the flora of the region and have species-specific experience and knowledge of the plant taxa. Collectively the panel works to categorize and assign each species a CC value between 0 and 10. A value between 0-2 indicates the plant has a wide range of ecological tolerances, a value between 3-5 indicates the species has an intermediate range and a value of 6-10 indicates the narrowest range of ecological tolerance. Non-native species receive a value of 0 and therefore do not contribute to the FQAI calculation. The FQAI is calculated based on these CC values and provides a way to rate the sensitivity of the flora at a site and thus give inference to possible disturbance the site may have been subjected to.

Since CC's have not been developed in New Jersey, the CC values used in the FQAI were ones developed for Pennsylvania. It is recognized and emphasized that plant tolerances in Pennsylvania may be quite different than those of New Jersey and therefore this calculation can only be reliable when New Jersey's CC values are established. Nevertheless, since Pennsylvania is the nearest geographic region that has developed CC values, using their CC's provided us with the basis to test the FQAI approach. The Floristic Quality Assessment Index (FQAI) for each site was calculated as:

$$FQAI = \{(c/10)*(\sqrt{N}/\sqrt{N+A})\}*100$$

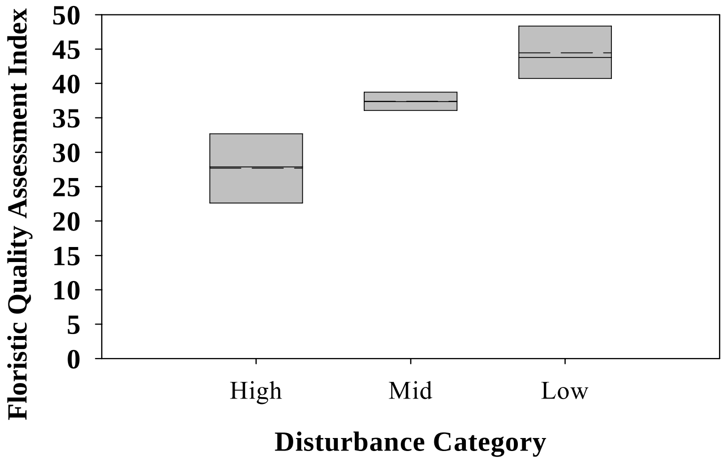
where c equals the average CC value for the site and N and A equal native and non-native species, respectively.

There was a significant ($p = <0.01$) increase in the FQAI as site disturbance decreased (Figure 20a). There was a sharp increase within the highly disturbed sites, a leveling off and similar values for the moderately disturbed sites and a slight increase for the least disturbed sites. The low and moderately disturbed sites were both significantly different from the high disturbance sites ($p = 0.02$) and there was also a distinct trend of increasing FQAI's across the three disturbance categories (Figure 20b).



Regression	
R^2	0.84
p	<0.01
F	50.55

Figure 20a. Floristic Quality Assessment Index for the sites.
The FQAI was derived using Coefficients of Conservatism for native species at each site. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.



ANOVA	
P	0.01
F	9.81

Figure20b. Box plot of Floristic Quality Assessment Index by disturbance category. Median (solid), mean (dashed) and 25 and 75 percentiles for Floristic Quality Assessment Index derived from cumulative site species. Sites are grouped into three disturbance categories: High, Moderate, and Low disturbance.

B. Examination of the disturbance criteria

There are a number of ways that have been used to derive a disturbance gradient and there is no consensus as to the best appoach. This lack of consensus is reflection of the difficulty in determining the ‘appropriate’ or true disturbance gradient. Disturbance is complex and encompasses natural and anthropogenic factors that vary in time and space. The disturbance gradient used in the above analysis was derived from land cover/land use in the watershed and in proximity of the 100-year floodplain. It is an approach that has been used in a number of studies but that does not necessarily mean that it should be readily adopted for this study. As a preliminary step to test the integrity of this gradient, we took twenty-four of the twenty-seven metrics in Table 4 (eliminating three that were duplicate metrics when reversed). Ideally, this approach should be done for all of the metrics that are included in Appendix C but resources precluded their inclusion in this report). However, irrespective of the trends observed along the GIS-derived disturbance gradient, each of these metrics or derivations thereof have theoretical and empirical support as to how they should respond along a disturbance gradient and we drew on this body of knowledge to examine the merit of the GIS-derived disturbance gradient.

For each of these twenty-four metrics, sites were ordered and numbered one through ten based on their relative scores in each metric. The order of the ranking was based on the hypothesized trends for how the metrics should respond to a disturbance gradient with 10 assigned to reflect low disturbance and 1 to reflect high disturbance. This allowed a new site ordering based on the strength of the trends for each individual metric as opposed to forcing the metric data into the proposed disturbance gradient derived through the GIS analysis. When the rankings for each site were totaled across all of the metrics, less disturbed sites should have a higher total score. The rankings were summed and averaged across the different metrics for each site. This average value for each site represented the average location of where the site occurred along the ten-site disturbance gradient (Table 6).

Site Order In Metric Derived Gradient	**Disturbance Score**	**Site Order in GIS Derived Gradient**	**GIS Score**
Phillipsburg	2.54	Phillipsburg	4.80
High Bridge	3.58	High Bridge	5.91
Pohatcong	4.13	Whippany	5.96
Whippany	4.5	Pohatcong	7.00
Lamington	5.29	Lamington	7.02
Musconetcong	5.33	Black River	7.65
Berkshire	7.04	Musconetcong	8.01
Wawayanda	7.33	Wawayanda	8.68
Clinton	7.63	Berkshire	8.7
Black River	7.63	Clinton	9.1

Table 6. Comparison site positions with two disturbance gradients. The metric-derived gradient was obtained by arranging sites according to their quantitative value for each metric and ranking them from 1 to 10 based on their hypothetical response to disturbance. High scoring sites should be relatively less disturbed than low scoring sites. Disturbance Score represents the average of each sites' rank across twenty-four metrics. The GIS derived ordering of sites along the disturbance gradient was dependent on the ranked land cover categories in the HUC14 subwatersheds and that rank added to land cover categories in the 100-year floodplain plus a 1Km buffer. In this scenario, altered lands were ranked lower than intact lands such as forest and wetland land cover categories. See Methods for a detailed description of the methodology. Note that the disturbance scores between the two methods are not directly comparable since they are not scaled the same but rather are included for reference.

The most marked change in the ordering of the sites from the proposed, GIS-derived disturbance gradient to the metric-derived one was that Black River moved from its place in the moderately disturbed site grouping in the GIS disturbance order, to tying with Clinton as most pristine at the ninth/tenth place in the order (the ratio of non-native shrub stems to total shrub stems is used to illustrate this point, Figure 21). Black River had very low non-native species abundance and a notably large forested buffer in close proximity compared to the other sites. It's GIS disturbance score was primarily determined by the watershed land cover (3.5 out of 5.0) and secondarily by the wetland buffer land cover (4.2 out of 5.0).

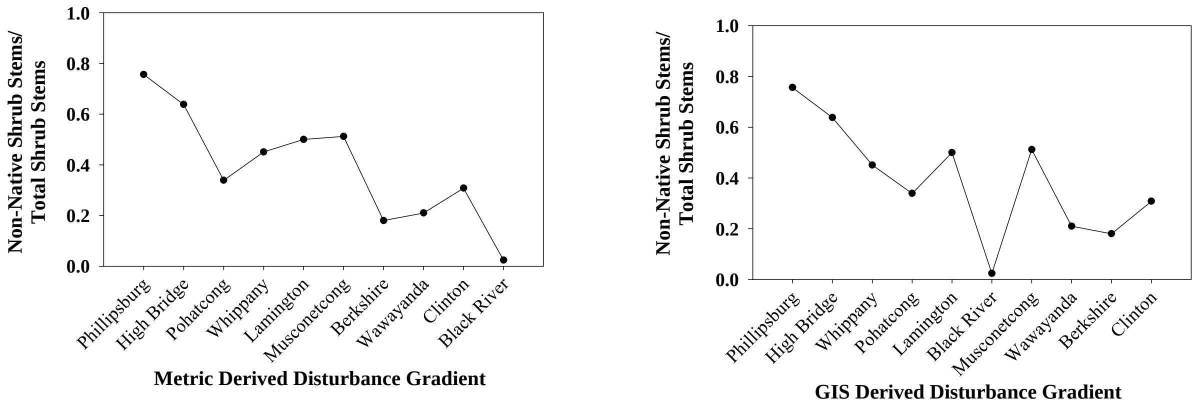


Figure 21. Comparison of a metric on two disturbance gradients.
The ratio of non-native shrub stems to total shrub stems on the metric derived disturbance gradient (left panel) and on the GIS derived disturbance gradient (right panel).

Though there is some shuffling between Berkshire and Wawayanda, the three least disturbed sites follow after Black River in the metric-derived disturbance gradient (Table 6). Phillipsburg and High Bridge also stay in their relative ranked order for the disturbed sites. With Black River removed, Musconetcong and Lamington were positioned next to each other. The other reordering occurred with Whippany and Pohatcong where Pohatcong has a slightly stronger metric disturbance signature than Whippany. The particular metrics where Pohatcong ranked higher than Whippany included a less even distribution of abundances between species, greater non-native species richness, and less overall tree dbh. Pohatcong also had the lowest cumulative species richness and was the least even in the herb and shrub layer across the sites. These metrics were low due to the fact that the herbaceous layer was dominated by skunk cabbage (*Symplocarpus foetidus*) and the shrub layer was dominated by spice bush (*Lindera benzoin*). It was only second to Berkshire in lack of tree diversity with *Acer rubrum* dominating the tree canopy. In contrast, Whippany had a sparser but larger and more diverse canopy.

There was some shifting of sites between the two different approaches but only one site, Black River, changed markedly. This exercise does not support or refute the GIS-derived disturbance gradient and as previously mentioned, examination of the full suite of metrics (Appendix C) would augment this approach. The conclusion section of this report includes a discussion of the challenges in determining and validating a disturbance gradient and it is important to note that since a fundamental premise of approaches such as the IBI model development are based on a priori disturbance gradients, concerted and continued efforts are necessary in evaluating and re-evaluating the rationale and appropriateness of how the disturbance gradient is defined.

C. Assessment of wetness gradient as complicating factor

If sites became increasingly wet along the disturbance gradient, the metrics that show a response to the disturbance gradient could in fact be responding to the wetness gradient or a combination of the wetness gradient and the disturbance gradient. Metrics included in the plant IBI need to be independent of any underlying gradient such as wetness, so we evaluated whether there was a relationship between the disturbance gradient and a wetness gradient. To do this, we examined an additional suite of metrics that are specifically sensitive to wetness (See Below). The propensity for a site's wetness gradient to be correlated with its GIS-disturbance gradient was tested using a Spearman's Rank Correlation. In addition, metrics that were significant for the disturbance gradient (Table 4) were tested with sites ordered according to the wetness gradient to determine if a given metric was more or less significant when viewed from a wetness perspective rather than a disturbance perspective.

1. Methods for deriving wetness gradient

We established a suite of metrics (Table 7) to reflect a wetness gradient using species' associated wetland indicator status (USFWS 1997, USDA 2004). Species with an indicator status of facultative wet or wetter were considered wetland species in this exercise.

Metric ID	Name
1W	Wetland Herb Cover
1X	Ratio of Wetland Herb Cover to Total Herb Cover
3D	Cover of Wetland Species (herb and woody)
3F	Ratio of Wetland to Upland Cover
4J	Wetland Herb Richness
4K	Wetland Tree Richness
4L	Wetland Shrub Richness

Table 7. Metrics used in deriving wetness gradient.
All measures were from the intensive plots if herbaceous and the transects if woody. In this instance, 'wetland' refers to the analysis that included only those species that have a wetland indicator status of facultative wet or obligate.

For each of these metrics, site values were calculated. All ten sites were then ranked from 1 to 10 based on their relative ranking for a particular metric. Higher values were given to the wet end of the gradient such that wetter sites had higher scores. A sites' final position along the wetness gradient was determined by summing the ranks across all seven metrics.

2. Comparison of wetness and disturbance

As in the disturbance gradient, High Bridge and Phillipsburg were also drier than the rest of the sites (Table 8). However, the remaining sites did not resemble the order in the disturbance gradient. Clinton, a less disturbed site, was relatively dry and Wawayanda, also a less disturbed site, was intermediate in wetness. Spearman rank correlations between site scores for the two gradients indicated the lack of a relationship ($r = 0.23$, $p = 0.51$) suggesting that a site's disturbance was not related to it's wetness score.

Wetness Gradient	Values	
High Bridge	1.72	Drier
Phillipsburg	1.86	↓
Clinton	4.0	
Wawayanda	4.86	
Lamington	5.57	
Musconetcong	6.71	
Pohatcong	7.14	
Black River	7.14	
Whippany	8.0	
Berkshire	8.0	Wetter

Table 8. Relative order of sites based on a wetness gradient.

We also performed additional regression analyses based on the site scores for both disturbance and wetness. These analyses included regressing the twenty seven disturbance metrics on site disturbance scores and site wetness scores and again comparing the strengths of the relationships (Table 5A). A similar analysis was done regressing the wetness metrics on site disturbance scores as well as site wetness scores and comparing the strength of the relationships (Table 5B). For the comparison between the two gradients (disturbance and wetness), it was appropriate to rely on regression analyses rather than analysis of variance since there were no a priori classes in the wetness gradient as there were in the GIS-derived disturbance gradient.

In all but one instance, the wetness metrics were highly significant on the wetness gradient and more so than on the disturbance gradient (Table 5B). The exception was wetland herbaceous species richness which was equally important on both gradients. The species richness for wetland trees was the only variable that was not significant for either gradient.

A graphical method to illustrate this comparison between the disturbance gradient and the wetness gradient (using the ratio of wetland herbaceous cover to total herbaceous cover) is presented in Figure 22. When sites were ordered according to the disturbance gradient, Phillipsburg and High Bridge were notably low followed by Wawayanda. The remaining sites were all high and there was no trend along the gradient. Conversely, when sites were ordered along the wetness gradient (Table 8) again Phillipsburg and High Bridge were notably low, but overall there was an increasing trend of a higher ratio of wetland herb species along the gradient.

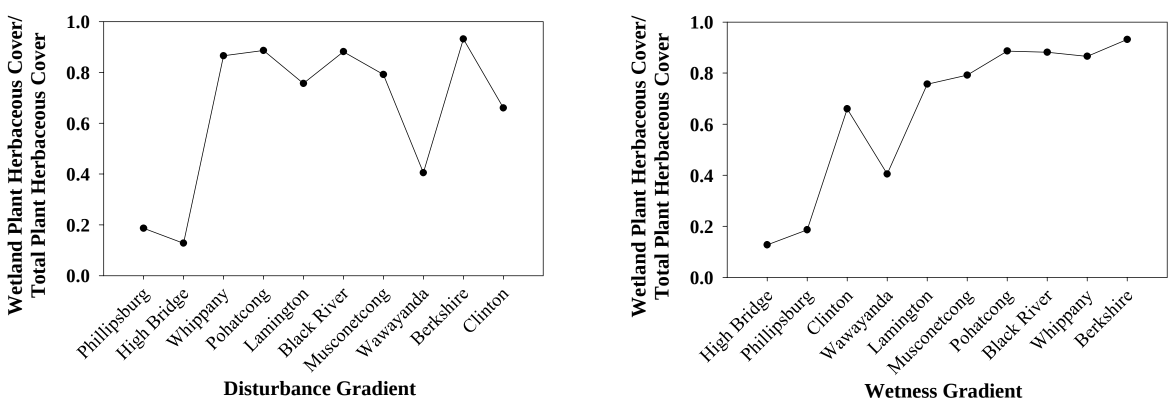


Figure 22. Comparison of sites on the disturbance gradient and the wetness gradient.

In addition to examining sites along the two gradients, the twenty-seven metrics developed to explore sensitivity to the disturbance gradient were reexamined (Table 4) and tested to see if they were significant on the wetness gradient as well as the disturbance gradient (Table 5A). Wetness was confounding disturbance in eight instances out of 22 instances (not counting nonsignificant metrics). These included Non-Native Shrub Area and it's ratio to Total Shrub Area, the Ratio of Non-Native Shrub Stem Density to Total Shrub Stem Density, Total Importance Values for Non-Native and Native Shrubs as well as the ratio, Proportion of Cover in Native Species (Intensive Plots), and Cumulative Non-Native Species Richness (Table 5A). Total Non-Native Shrub Cover had a slightly stronger trend with the wetness gradient than the disturbance gradient (p-value=0.02, r2=0.56 versus p-value=0.02, r^2 = 0.43 respectively). Two additional metrics were significant for the wetness gradient but not the disturbance gradient. These included Total Non-Native Shrub Stem Density and Simpson's Index for Tree Species (Table 5A). Metrics that demonstrate a sensitivity to both gradients should continue to be carefully evaluated to avoid confounding the two gradients. However, for the purposes of this study metrics that did not show strong support for the disturbance gradient as compared to the wetness gradient were dropped from further consideration. We also dropped metrics that did not meet statistical assumptions or were not significant for the disturbance gradient.

<u>Comparison Summary</u>: Metrics that measured Total Tree dbh, Proportion of Trees <0.25m dbh, Total Non-Native Herbaceous Layer Area Cover, Roseaceae Cover in

Intensive Plots, Total Native Genera Richness, Total Native Genera Richness Minus Upland Genera, Simpson's Index for all Herbaceous Layer Species and the Floristic Quality Assessment Index all showed a strong significance along a disturbance gradient without significance on a wetness gradient (Table 5A). Of these, metrics that measured Proportion of Trees <0.25m dbh and Simpson's Index for all Herbaceous Layer Species had low r^2 values and were more unimodal than they were linear, and therefore trends along disturbance could not be inferred. The remaining eight metrics that measured for Total Tree dbh, Total Non-Native Herbaceous Layer Area Cover, Roseaceae Cover in Intensive Plots, Total Importance Values for Native Shrubs, Total Native Genera Richness, Total Native Genera Richness Minus Upland Genera, Cumulative Non-Native Species Richness, and Floristic Quality Assessment Index were significant in showing that the vegetative patterns changed along the proposed disturbance gradient. The Total Native Genera Richness Minus Upland Genera metric was eliminated since it was quite similar to the Total Native Genera Richness metric in measuring genera richness. The remaining seven metrics (Total Tree dbh, Total Non-Native Herbaceous Layer Cover, Roseaceae Cover in Intensive Plots, Total Importance Values for Native Shrubs, Total Native Genera Richness, Cumulative Non-Native Species Richness, and Floristic Quality Assessment Index) were strong candidates in the formulation of the plant IBI.

1. Additional considerations

A number of vegetation metrics were examined but there are a number of other factors that could be influencing wetland condition and are important considerations in the development of IBIs. We examine just a few of the many potential factors here and this list could easily expand as the project develops. For example, we obtained data for of listings of species of special interest for locations in and around the ten sites to assess the critical habitat status for the sites. We compared our species list with the State's list and provided information to the State when we encountered listed species. We also examined the tendency for sites to harbor species that were infrequently encountered in the field. If a particular site had a large number of plant species that were infrequently encountered in the study it could contribute significantly to the regional diversity.

We examined whether a multivariate statistical approach provided additional information to support the metric approach presented above. We also examined whether it might be a more informative approach than the metric approach and include our results here for future reference as the project develops.

Finally, before we took the critical step of selecting metrics for the vegetation IBI, we examined whether our sampling design was adequate to capture trends and patterns in the vegetation community. If the sampling design is critically flawed, then any results or conclusions drawn from further IBI analysis would also be open to question.

Rare Habitat and Species Specific Consideration

Wetlands frequently harbor rare plants and animals. The State of New Jersey has several data sources that were valuable in determining the status of the ten sampled sites with respect to species or habitats of special interest to the State or Federal government. We preliminarily examined the coincidence of listed species and the disturbance gradient.

We consulted with the Office of Natural Lands Management (ONLM)in the Division of Parks and Forestry to obtain rare species information for each of the ten sites (Appendix E). ONLM provided information from the Natural Heritage Database and the Landscape Project mapping (Version 2) for occurrences of rare wildlife or plant species or rare wildlife habitat or natural communities. ONLM also provided information on the Federal and State status for each species as well as their Global and State ranking (Appendix E).

Three sites, Whippany, Pohatcong and Black River, had occurrences of species with Federal status. With the exception of Phillipsburg, all of the sites are habitat for least one rare species at the State level (Table 9, Appendix E). Clinton and Wawayanda had the greatest number of occurrences of rare wildlife species with 19 species with State status while High Bridge and Berkshire had the least with 4 and 5 species respectively. Two sites also have been designated as Natural Heritage Priority Sites. None of the sites had records for occurrences of rare plants. Though there was a trend for more species of interest in less disturbed sites, this result warrants caution as many areas have not been intensively surveyed and a lack of information does not nor should not imply a absence of species of interest.

Site	Federal Listings	State Listings	State Natural Heritage Priority Site
Phillipsburg			
High Bridge		4	
Whippany	1	7	
Pohatcong	1	5	
Lamington		5	
Black River	1	7	*
Mustconetcong		11	
Wawayanda		19	
Berkshire		5	
Clinton		19	*

Table 9. Number of rare species and priority sites within or in close proximity to study sites.
Data sources include the Natural Heritage Data Base and the Landscape Project (Version 2). Data is based on information available as of June 2005 based on approximate site locations. Data provided by the Office of Natural Lands Management, Division of Parks and Forestry. See Appendix E for detailed species listing and Federal and State status.

The Natural Heritage Database includes species information based on many sources including research and observation. However, many areas of the State have not been thoroughly surveyed and so there is the potential for encountering species of interest that are not yet in the database. To augment the Heritage database and to determine if there were species of special interest at any of the sites, we referenced the State's list of plant species of special interest (NJDEP, Special Plants of New Jersey, 2004). Species lists (Appendix C) from the sites were compared with this list to determine if there were plants present that were of special interest. Since some of the plant identifications were not definitive, three categories were created based on the degree of certainty of their identification. Three listed species were definitely encountered including black maple (*Acer nigrum*) at Lamington, foamflower (*Tiarella cordifolia*) at Wawayanda and marsh bedstraw (*Galium palustre*) at three different sites (Table 10a) and information on location of these sightings were submitted to the State. Of the three, only foamflower is considered an endangered plant species. In addition, two more plant species require more detailed identification to verify whether they are also of special interest (Table 10b) and this information was also provided to the State. There were also multiple sub-species that were considered of Federal and State significance but could not be identified to sub-species with certainty (Table 10c). More specific identification may also include some of these species on the list of species of concern.

Species	**Global Rank***	**State Rank***	**Federal Status**	**State Status**	**Sites**
Black Maple *Acer nigrum*	G5	S2			Lamington
Marsh Bedstraw *Galium palustre*	G5	S3			Black River, Wawayanda, Berkshire
Foamflower *Tiarella cordifolia*	G5T5	S1		E	Wawayanda

TABLE 10a. Plants with global and state rankings occurring in study plots. (NJDEP, Special Plants of New Jersey, 2004). *For definitions of rankings, refer to Tables 12d and 12e and Appendix E.

Species	**Global Rank***	**State Rank***	**Federal Status**	**State Status**	**Sites**
Fine-nerve sedge *Carex leptonervia*	G4	S1		E	Lamington, Musconetcong
Orchid species *Platanthera spp.*	??	??			Wawayanda

TABLE 10b. Plants with unconfirmed identifications.
If tentative identifications are correct, could have global and state rankings. These sites will need to be rechecked for these species. (NJDEP, Special Plants of New Jersey, 2004). *For definitions of rankings, refer to Tables 12d and 12e and Appendix E.

Species	Sub species	Global Rank*	State Rank*	Federal Status	State Status	Sites
Northern jack in the pulpit *Arisaema triphyllum*	*stewardsonii*	G5T5	S2			Pohatcong, Lamington, Black River, Musconetcong, Wawayanda, Clinton
Meadow Cuckoo Flower *Cardamine pratensis*	*var. palustirs*	G5T5	S3			Black River, Musconetcong
Hales meadow sedge *Carex granularis*	*var. haleana*	G5T4	S2S3			Phillipsburg
Hairy-stem wild yam *Dioscorea villosa*	*var. hirticaulis*	G4G5T3 Q	S2			High Bridge, Pohatcong, Musconetcong, Wawayanda
Western false lily-of-the-valley *Maianthemum canadense*	*var. interius*	G5T4	S1.1		E	Lamington, Black River, Wawayanda, Clinton
Glandular cinnamon fern *Osmunda cinnamomea*	*var. glandulosa*	G5T?	S2			Pohatcong, Lamington, Black River, Clinton
Opelousas water-pepper *Polygonum hydropiperoides*	*var. opelousanum*	G5T?Q	S2			High bridge, Whippany, Wawayanda
Summer goldenrod *Solidago rugosa*	*ssp. rugosa var. sphagnophila*	G5T?	S3			Lamington, Musconetcong, Wawayanda, Berkshire, Clinton
Narrow-leaf meadow-sweet *Spiraea alba*	*var. alba*	G5T5	S1			Berkshire
Veiny-leaf arrow-wood *Viburnum dentatum*	var. venosum	G5T4T5	S2			Pohatcong, Lamington, Berkshire, Clinton

TABLE 10c. Plants with uncertain identification of sub-species.
Subspecies are listed as having global and state rankings and sites need to be rechecked for these species. (NJDEP, Special Plants of New Jersey, 2004). For definitions of rankings, refer to Tables 12d and e and Appendix E.

G1	Critically Imperiled globally because extreme rarity (5 or few occurrences or very few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extinction.
G2	Imperiled globally because of rarity (6 to 20 occurrences or few remaining individuals or acres) or because of some factor(s) making it very vulnerable to extinction throughout its range.
G3	Either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (e.g., a single western state, a

	physiographic region in the east) or because of other factors making it vulnerable to extinction throughout it's range; with the number of occurrences in the range of 21 to 100.
G4	Apparently secure globally; although it may be quite rare in parts of its range, especially at the periphery.
G5	Demonstrably secure globally; although it may be quite rare in parts of its range, especially at the periphery.
Q	Elements containing "Q" in the global portion of its rank indicates that the taxon is of questionable, or uncertain taxonomical standing, e.g., some authors regard it as a full species, while others treat it at the subspecific level.
T	Element ranks containing "T" indicate that the infraspecific taxon is being ranked differently than the full species.
?	To express uncertainty, the most likely rank is assigned and a question mark added. A range is indicated by the combination of two ranks.

Table 12d. Global element ranks and their definitions.
Source: NJDEP, Special Plants of New Jersey, 2004 and Appendix E (see Appendix for detailed descriptions.

S1	Critically imperiled in New Jersey because extreme rarity (5 or fewer occurrences or very few remaining individuals or acres). Elements so ranked are often restricted to very specialized conditions or habitats and/or restricted to an extremely small geographical area of the state. Also included are elements which were formerly more abundant, but because of habitat destruction or some other critical factor of its biology, they have been demonstrably reduced in abundance. In essence, these are elements for which, even with intensive searching, sizable additional occurrences are unlikely to be discovered.
S2	Imperiled in New Jersey because of rarity (6 to 20 occurrences). Historically many of these elements may have been more frequent but are now known from very few extant occurrences, primarily because of habitat destruction. Diligent searching may yield additional occurrences.
S3	Rare in state with 21 to 100 occurrences (plant species in this category have only 21 to 50). Includes elements which are widely distributed in the state but with small populations/acreage or elements with restricted distribution, but locally abundant. Not yet imperiled in state but may soon be if current trends continue. Searching often yields additional occurrences.
S4	Apparently secure in state, with many occurrences.
S5	Demonstrably secure in state and essentially ineradicable under present conditions.

Table 10e. State element ranks and their definitions
(NJDEP, Special Plants of New Jersey, 2004).

Species Occurrence Frequency:

Sites that harbor a number of species that occur in just a few spots are potentially important in contributing to the regional biodiversity. Therefore, we also tallied the number of species at a site that were observed infrequently across all of the sites to see if there was a relationship between uncommon species and the disturbance gradient. For this study, infrequently occurring species were considered those that were recorded in two or less of the ten sites (Figure 23). High Bridge had the highest occurrence of infrequently encountered species at 22 species followed by Berkshire and Phillipsburg. Pohatcong, a mid disturbance site, had a total of eight species that occurred infrequently.

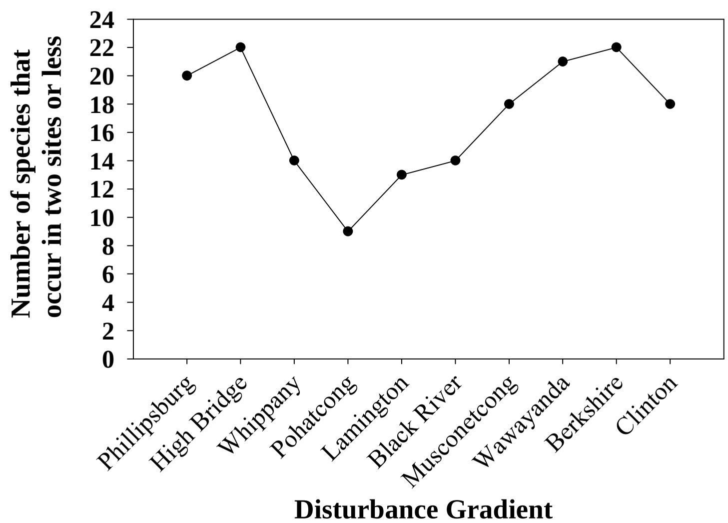


Figure 23. The number of plants that occurred in two sites or less at each site. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

Multivariate Evaluation

Multivariate statistics are frequently used in community ecology to elucidate patterns in community composition and contrast those patterns across different sites. Multivariate analyses such as ordinations and cluster analysis are appropriate for projects such as this where the hypothesis is that plant community composition changes predictably along a disturbance gradient. If the hypothesis is true, then sites that are similar in vegetation should also be located in the same region of the disturbance gradient as well as in ordination space. A particular strength of multivariate analyses that is not possible with univariate statistical approaches is that species composition and as well as various aspects such as abundances or percent cover are evaluated. In univariate approaches, the plant community must necessarily be reduced to summary metrics such as number of species or total tree abundance. In addition, if environmental data are available, they can be used to constrain the ordination via multiple regression to help explain what aspects of the environment may be contributing to the patterns observed in the community data.

While multivariate approaches are often used in the development of IBIs, the one constraint in using this approach in the pilot project is the limited number of sites. Ten sites are likely not sufficient to detect reliable trends in plant community responses to the disturbance gradient. However, it is provided here as a exploration approach that could be developed further as more sites are added.

A number of community measures were evaluated using non-metric multidimensional scaling (NMS) in PC-Ord (McCune and Medford, 1999). Of the various metrics amenable to ordination including density, cover and importance value measures for the different elements of the community, only shrub importance values, total species richness, and herb species cover yielded significant NMS results. In all three cases, only species that occurred at more than 20% of the sites were included, and significance values for two-dimensional solutions, as compared to Monte Carlo tests of randomized data, were all equal to or less than 0.0476. Other pertinent results from the NMS runs are summarized in Table 11. We also regressed a number of environmental variables on the ordination axes to examine what physical patterns might be accounting for the patterns observed in the data.

	Final Stress	Final Instability	Total % Variance Explained
Shrub Importance Values	6.07	.00444	90.4
Total Species Richness	10.48	.00215	84.0
Herb Species Cover	7.18	.00228	68.5

Table 11. Model adequacy of NMS ordinations on several community metrics.

Plant communities are expected to respond to multiple environmental factors and the disturbance gradient is but one factor that represents a set of complex environmental conditions. We also used the multivariate approach to evaluate whether different environmental variables measured in the field correlated with how the sites were positioned in ordination space. Strong correlations are an indication that the vegetation community is responding to particular environmental variables that may or may not co-vary with the disturbance gradient.

Two of the three metrics separated sites relatively well along the *a priori* disturbance gradient. For shrub importance values, Phillipsburg, High Bridge, and Whippany (high disturbance) grouped at one end of the ordination with relatively lower axis 1 and axis 2 scores while Wawayanda, Clinton, and Berkshire Valley (low disturbance) clustering near the opposite end of ordination space with higher scores on both axes (Figure 24). The four intermediate disturbance sites were between the other groups with intermediate scores on the two axes. Both axes were important in separating the sites. The high disturbance sites tended to have higher clay content in the soils and the water table was deeper while the less disturbed sites had longer riparian width and length, higher organic content in the soil, banks tended to be more vegetated and the water table was generally higher. The ability to relate environmental factors to the vegetation patterns is a particular strength of ordinations that is not possible with the metric analyses presented above.

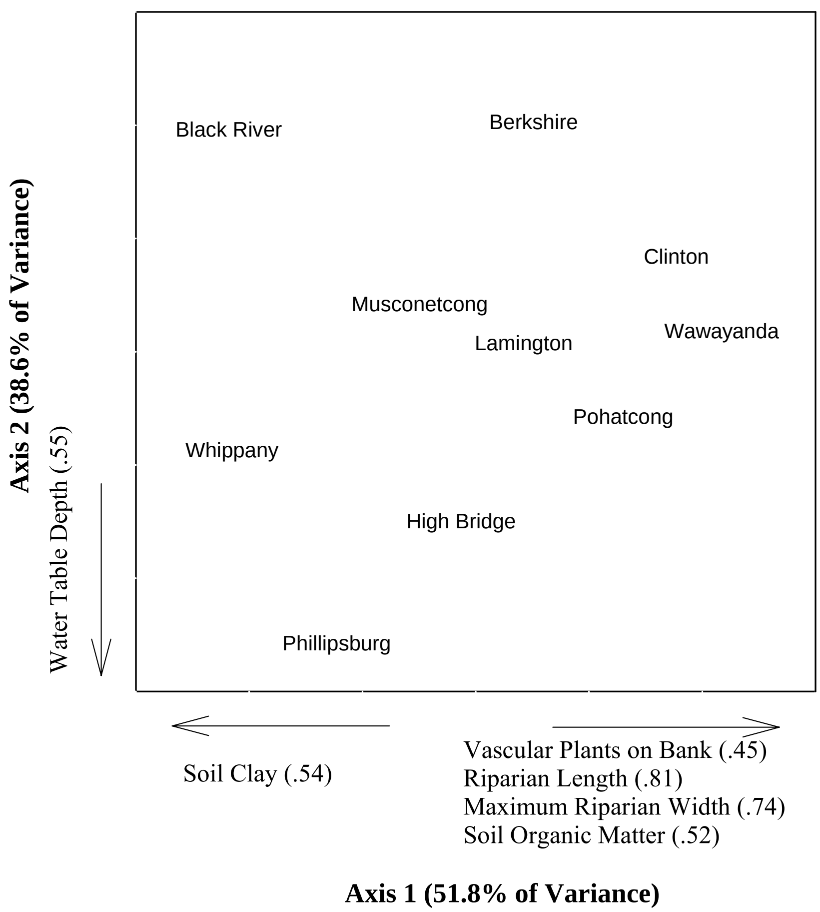


Figure 24. NMS ordination of all ten sites based on shrub species importance values. (Includes all shrubs occurring in more than two of the ten sites; n = 17). Significant environmental variables (with r-values) indicate the direction of increasing variation.

Herb species cover also tended to support the original disturbance gradient (Figure 25). Again, Phillipsburg and High Bridge paired very closely, and Whippany was also in the same end of ordination space. Musconetcong, Lamington, and Pohatcong (three of the moderately disturbed sites), composed another unique cluster, while the fourth, Black River, grouped closely with the three low disturbance sites. However, the major separation of sites was on the x-axis where almost 46 percent of the variation was accounted for on this axis. The herb cover was most distinct for Whippany compared to three of the intermediate disturbance sites, Lamington, Pohatcong and Musconetcong. Environmental variables that also varied along this axis included stream banks that were lower and bank slope was more shallow at Whippany compared to the mentioned intermediate disturbance sites. Intact riparian vegetation was longer at Whippany compared to these sites and the bank was more vegetated. It was the second ordination axis that tended to separate sites along the disturbance gradient but less of the variation between sites was accounted for on this axis (<25 percent). Similar to the shrub importance values, sites on this axis separated by greater depth for more disturbed sites, higher clay content and steep riparian slope parallel to the stream for the more disturbed sites and greater organic soil content for the less disturbed sites.

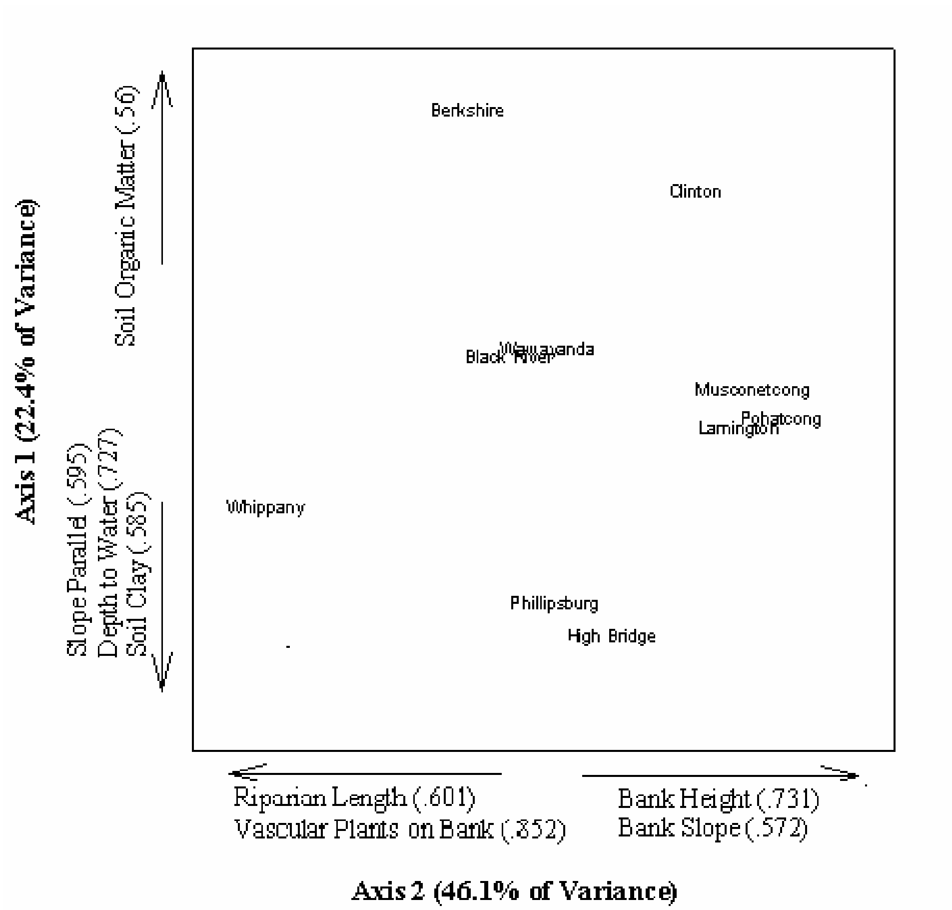


Figure 25. NMS ordination of all ten sites on the basis of their herb communities. (Includes all herbs occurring in more than two of the ten sites; n = 67). Significant environmental variables (with r-values) indicate the direction of increasing variation.

Patterns in the ordination of total species richness are somewhat more difficult to decipher. Two groups of sites clearly sorted at opposite ends of the spectrum: Phillipsburg and High Bridge with high x-axis and low y-axis scores and Black River, Berkshire and Clinton with low x-axis and high y-axis scores (Figure 26). The x-axis explained the majority of the variation (61 percent) between sites and separating Phillipsburg and High Bridge from Black River and Berkshire. Five of the sites tended not to differ on the x-axis. Soil and stream characteristics were important in accounting for this difference. The y-axis, which explained almost 23 percent of the variation more closely aligned sites along the disturbance gradient, suggesting that this gradient was of secondary importance in distinguishing differences in species richness. A vegetation structure measure, canopy cover was important in separating the sites on this particular axis.

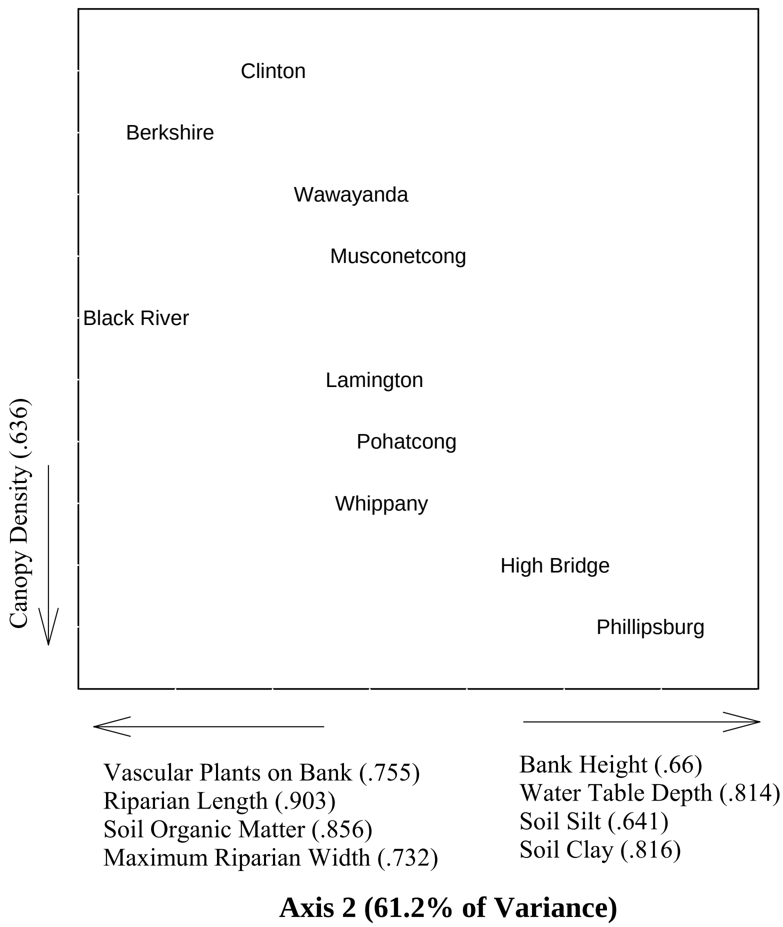


Figure 26. NMS ordination of all ten sites on the basis of their total species richness. Includes all species occurring in more than two of the ten sites; n = 74). Significant environmental variables (with r-values) indicate the direction of increasing variation.

In all three ordinations (Figures 24-26), some aspect of the riparian corridor size correlated strongly with one of the ordination axes. In particular, the length of intact riparian vegetation (see Methods section for how this variable was measured) often paralleled the ordination groupings, yielding r^2 values of 0.81, 0.60, and 0.90 respectively, with the ordinations discussed above. Maximum width of the riparian corridor also correlated with the results for two of the ordinations, with an r^2 value of 0.74 for shrub importance values, and 0.73 for total species richness.

Soil properties were also frequently correlated. Depth to the water table had r^2 values of 0.55, 0.73, and 0.81 for the ordinations. Measurements of percent soil organic matter (r^2 values = 0.52, 0.56, 0.86), percent clay (r^2 values = 0.54, 0.59, 0.81) reflected moderately strong correlations. Each of these soil properties have a bearing on the water retention potential of soils so soil moisture may also be important.

Finally, the relative intensity of hydrologic movements on the sites, particularly overbank flow, was measured in part by an estimation of vascular plant cover on the stream bank next to the transects. Frequent overbank events can remove vegetation (herbaceous and woody) and can prevent establishment and persistence of vegetation. This variable showed correlations with r^2 values of 0.45, 0.85, and 0.75, respectively, for the three relevant ordinations (Figures 24-26).

Evaluation of sampling design

Rarefaction: One of the crucial questions for any ecological sampling is to determine how much area should be surveyed in order to accurately portray the species diversity of a given site. By determining the area to sample after which sampling larger areas does not add new species, it is possible to maximize both sampling thoroughness and efficiency. One way to depict this graphically is with a species-area, or rarefaction, curve. The method of plot sampling used, with quadrats of 0.1, 1.0, 10.0 and 100.0 m^2, lends itself well to a semi-logarithmic version of these curves. Ideally the curve would reach a true asymptote, but in practice, and especially in narrow wetland corridors, a noticeable point of inflection is the most useful feature on such a curve. We examined the rarefaction curves for sites broken into the three disturbance categories.

High Disturbance: The three sites from the high disturbance end of the spectrum show the clearest rarefaction curves (Figure 27). Especially for Phillipsburg and Whippany, few new species are found in plots after moving from the 10 m^2 to the 100 m^2 scale. Thus, sampling at 10 m^2 appears to capture the majority of floral richness at those sites. The curve for High Bridge has not reached the same plateau, and thus 100 m^2 sampling may be most efficient there.

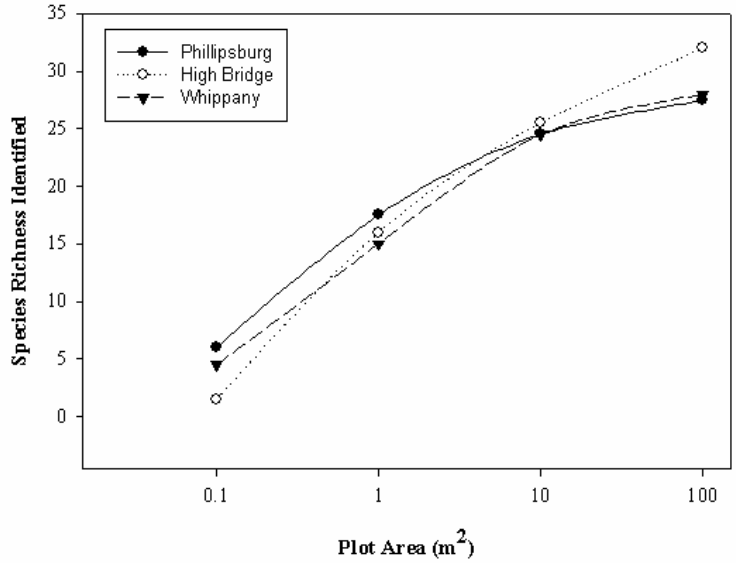


Figure 27. Plant species rarefaction curves for the highly disturbed sites. Data from the intensive plots.

Intermediate Disturbance: The patterns of rarefaction in the four moderate disturbance sites are somewhat less uniform (Figure 28). Only one site, Musconetcong, appears to be leveling off, with little gain in richness after 10 m^2 sampling. Pohatcong and Black River, in contrast, have nearly linear curves, indicating that maximum richness has not been reached, even at the 100 m^2 quadrat size. The curve for Lamington is a bit unusual, with the lag at the smallest plot sizes probably due to the relative paucity of vegetation at the site. Still, it appears that areas of at least 100 m^2 are needed to adequately assess diversity there.

Low Disturbance: With the low disturbance sites, only one, Berkshire, appears to be reaching an asymptote (Figure 29). Both Clinton and Wawayanda have not begun to level off at the 100 m^2 quadrat size. Wawayanda was consistently higher in all measures of richness and Clinton was one of the consistently higher sites.

Summary Comparison: In short, at many sites 10 m^2 quadrats appeared to capture the majority of species diversity (Figure 30) but new information is also gained at the 100 m^2 level, especially with the less disturbed sites. Therefore, 10x10 intensive plots should still be evaluated and the same level of sampling used in this pilot study is recommended for continuing work in this region. (The vegetation sampling protocol also has the advantage of helping to calibrate observers' estimations of plant percent cover, since at each plot, cover is scaled slowly up from the 0.1 m^2 level to the 100 m^2 level.)

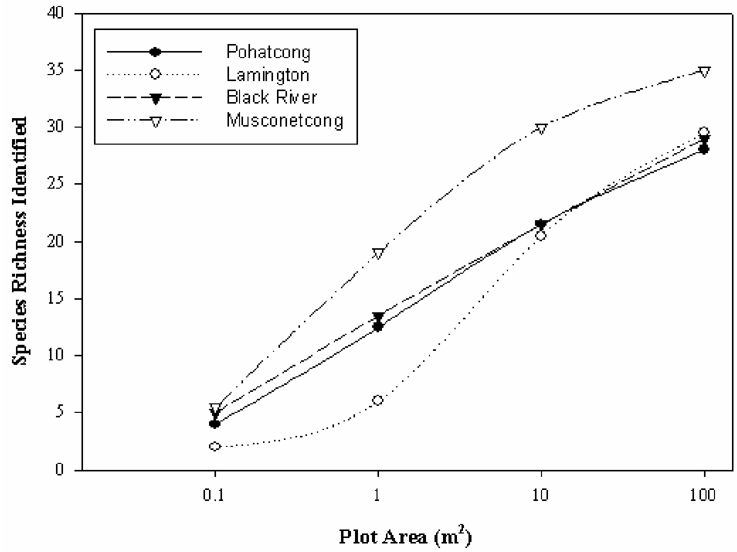


Figure28. Plant species rarefaction curves for moderately disturbed riparian wetland sites.

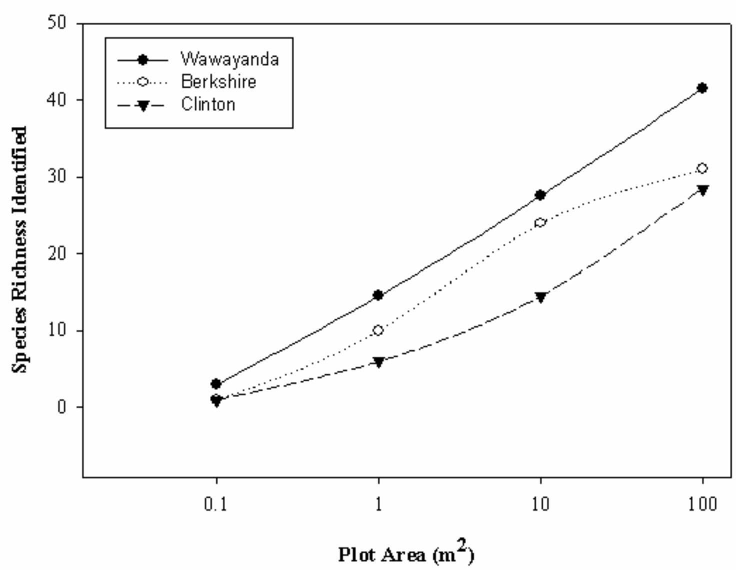


Figure 29. Species rarefaction curves for lower disturbance sites.

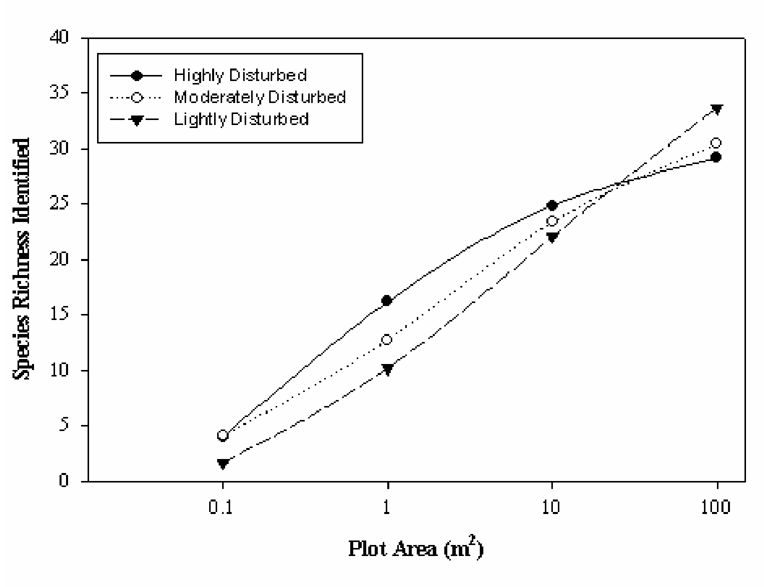


Figure 30. Average species rarefaction curves for wetlands of three disturbance categories.

2. IBI Development

After the additional evaluation of the disturbance gradient, examination of the potential for interactions between the disturbance gradient and a wetness gradient and other considerations including ordinations and factors that contribute to a site's uniqueness (Heritage data and contributions to regional diversity), it was possible to identify potential candidates for inclusion in the plant IBI. Typically seven to eight metrics are used in combination to form an IBI. Since the metrics were frequently quantitative and were measured in different units it was initially necessary to scale the metrics before they could be combined into a single metric. There are several approaches to scaling the metrics and generally the data distribution provides insight into the most appropriate approach. Approaches that are commonly encountered include visually examining the data and identifying distinct break points in the data distribution. Low scores are assigned a value of 1, mid scores a value of 3 and high scores a value of 5. Alternatively, to prevent outlier data points from having an undue influence on the scoring, some IBIs are developed by taking the 5^{th} and 95^{th} percentiles of the data and dividing that data range into three categories, again assigning each category a number of 1, 3 or 5. Since we had a small sample size in this project we had limited confidence that we had captured the full range of variability inherent in each metric. Therefore, we chose another approach and worked within the data range for each metric. As additional sites are added, it is likely that an alternative approach to scaling the data will be more appropriate. To scale the metrics, for each metric the minimum value was subtracted from the maximum value, irrespective of which sites had each of these values. The difference represented the data range encountered for each metric. This range was divided into three equal groups that represented the three different levels of disturbance

(Table 12). Each of the three categories in a metric were ranked and assigned to Group 1, Group 3 or Group 5. In this study, we determined the data range on the same data format that was used in the statistical analysis, thus the data range for proportional data was determined on the arcsine transformation, on the log transform for metrics that required transformation for parametric statistics and finally on the raw data range where no transformations were required. As noted in the data analysis section, as more sites are added to the project, some transformations may not be necessary and adjustment will be necessary in scaling the metric within the context of the IBI.

Name	**Transformation**	**Data Range**	**Group 1**	**Group 3**	**Group 5**
Total tree dbh	Normal	7.7 to 23.2	7.7 to 12.9	13.0 to 18.1	18.2 to 23.2
Total non-native herbaceous cover*	Log	-0.7 to 4.3	2.7 to 4.3	1.1 to 2.6	-0.7 to 1.0
Roseaceae area cover in intensive plots*	Log	0.4 to 4.4	3.1 to 4.4	1.8 to 3.0	0.4 to 1.7
Total importance values for native shrubs	Arcsin	0.3 to 1.4	0.3 to 0.7	0.7 to 1.0	1.1 to 1.4
Total native genera richness	Log	3.2 to 4.0	3.2 to 3.5	3.6 to 3.7	3.8 to 4.0
Cumulative non-native species richness*	Normal	3 to 15	11 to 15	7 to 11	3 to 7
Floristic Quality Assessment Index	Normal	20.9 to 49.9	20.9 to 30.5	30.6 to 40.2	40.2 to 49.9

*Indicates reverse ordering of data such that higher values reflect higher disturbance based on hypothesized trends in how the metric should respond to disturbance.

Table 12. Range Classes for the IBI Metrics with un-scaled data.
Type of transformation is indicated. The data range for each of the three groups is indicated.

For each of the metrics, the sites were assigned 1, 3 or 5 depending on the group they fell within (Table 13). The IBI score was determined by summing across the seven different metrics. Trends in the final IBI score are graphically illustrated in Figure 31a and the average score by category is depicted in Figure 31b.

Site Name	Total Tree dbh	Total Non-Native Herbaceous Cover	Roseaceae Cover	Total Native Shrubs IV	Native Genera Richness	Non-Native SR	FQAI	IBI Score	Disturbance Rank
Phillipsburg	1	1	1	1	1	1	1	**7**	High
High Bridge	1	1	1	1	5	1	1	**11**	High
Whippany	1	1	1	3	1	3	3	**13**	High
Pohatcong	3	3	3	3	3	3	3	**21**	Mid
Lamington	1	1	3	1	3	3	3	**15**	Mid
Black River	3	3	5	5	3	3	3	**25**	Mid
Musconetcong	3	3	3	1	5	3	3	**21**	Mid
Wawayanda	3	3	5	5	5	5	5	**31**	Low
Berkshire	5	5	5	5	5	5	3	**33**	Low
Clinton	5	5	5	3	5	5	5	**33**	Low

Table 13. Ranking and scoring of the seven metrics to form the final IBI score.
The IBI Score represents the sum of all of the metrics class groupings. The disturbance class for each of the sites is indicated. (IV= Importance Value, SR = Species Richness, FQAI = Floristic Quality Assessment Index).

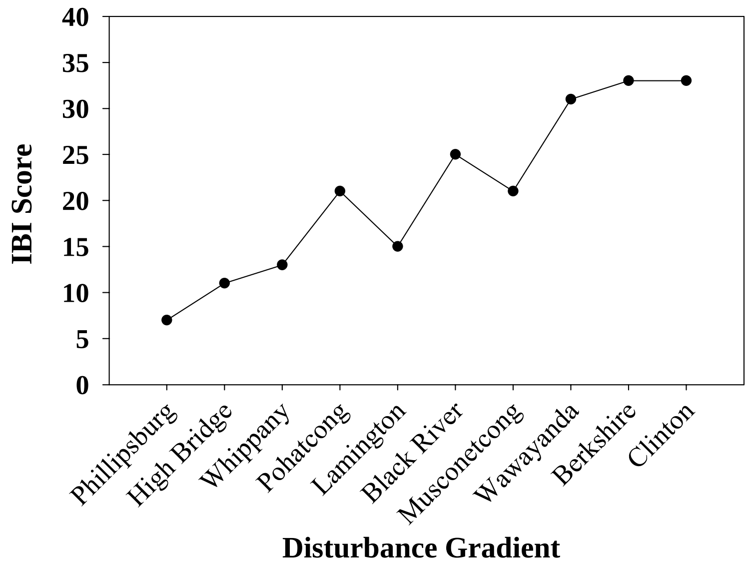


Figure 31a. Final plant IBI score for the ten sites.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

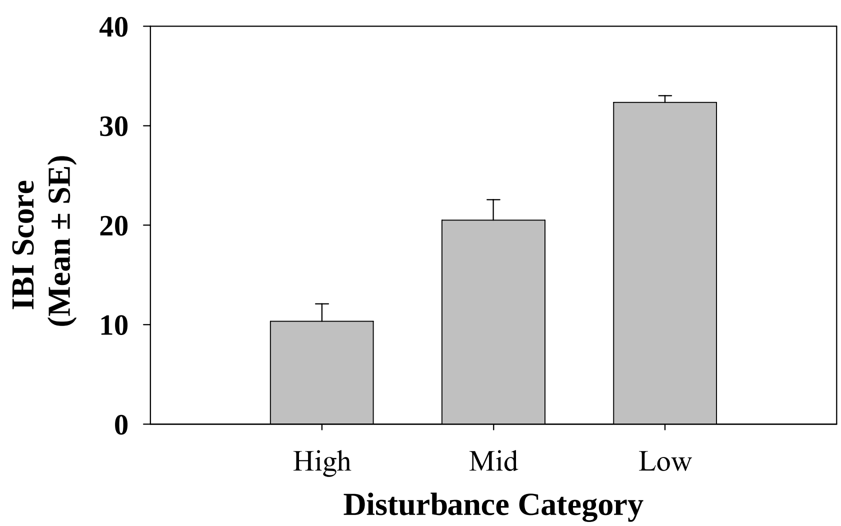


Figure 31b. Mean IBI score by disturbance category.
Sites are grouped into three disturbance categories: high, moderate, and low disturbance.

VII. MACROINVERTEBRATE IBI DEVELOPMENT

Macroinvertebrate IBIs have been developed for different types of wetlands (Table 1). Building on this experience and available information, we initially chose this taxonomic group with hopes that it would more closely align with the State's AMNET program. During the first year however, it became obvious that the wetland macroinvertebrate IBIs developed previously were not appropriate for floodplain wetlands. Specifically many of these IBIs were developed based on standing water, either permanent or seasonal. The hydrology is such in the Highland's floodplain forests that standing water is seasonally and annually quite variable. A different approach was required that would allow characterization of the macroinvertebrate community in such a way that it would reflect the quality of the non-inundated wetlands. After considerable consultation with area experts and the advisory groups, the leaf-litter macroinvertebrate community was chosen to be the focus for the macroinvertebrate IBI. This is the first time to our knowledge that this particular component of the wetland community has been examined in the context of developing an IBI. Therefore, we recognized that it was going to require considerable upfront development in order to determine the feasibility of this approach. Very little is known about leaf-litter macroinvertebrate communities in general and there are no known studies that have addressed this aspect for floodplain forests.

It was anticipated that the leaf-litter macroinvertebrate community would be quite diverse since one would expect representative taxa from the adjacent upland, the adjacent aquatic habitat as well as the local heterogeneous habitat to be present. Riparian systems such as the ones included in this study are documented to support some of the highest biodiversity of terrestrial systems and one could anticipate similar trends in the macroinvertebrate community. Recognizing the potential importance of the information that the macroinvertebrate community might add to understanding wetland communities in the State, Kathy Walz of the State Heritage Program chose to further extend the alignment of her project to identify significant wetland communities in the State and contributed significant resources to advance this aspect of the project. As previously mentioned in the methods, initial site selection was coordinated with Ms Walz's wetland community project and several of the sites coincide between this project and her project.

For the reasons mentioned above, the development of the macroinvertebrate IBI has not progressed as far as the plant IBI. Sampling and protocol development took considerably more effort and time than initially anticipated since the early expectation was that it could draw on existing wetland macroinvertebrate IBIs. Several steps were implemented along the way to facilitate the processing and analysis of the data in order to get some preliminary determination of the feasibility of the current approach. Initially a total of sixteen samples were taken at each site. Several months into the sorting and identification process it became clear that sufficient head-way was not being made to stay within the project schedule. Therefore, we established a sub-sampling procedure whereby 50% of the remaining samples were processed. Two randomly selected samples from each of the four plots made up the sub-sample for a site. A similar approach was taken for the sites that were already done such that all sites were represented in the analysis by a total of eight randomly selected sample plots. Admittedly, this approach reduces the ability to characterize intra-site variability and focused efforts in the future should address variability in the context of sampling requirements.

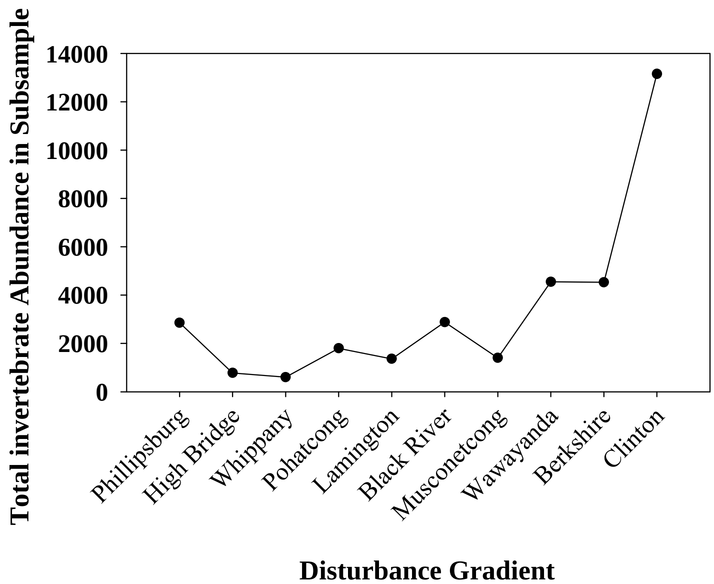
Taxonomic resolution was also addressed as a means to expedite the identification process. With diligence it was possible to get all of the samples sorted and the majority of the Classes identified to Order. Effort was then focused on taking some of the Orders to the Family level. Generally, metrics incorporated into IBIs focus on taxa that are tolerant and intolerant to disturbance. Since little is known about the leaf-litter community in these systems, it is unclear what taxonomic groups or what level of taxonomic resolution is going to be necessary to reflect sensitivity to the disturbance gradient. Many stream IBIs have found that genus level information is sufficient to detect trends but this was determined only after species level data was evaluated (A. Korndorfer, NJDEP Bureau of Freshwater and Biological Monitoring, personal communication). The macroinvertebrate IBIs that have been developed for wetlands have used varying degrees of taxonomic resolution incorporating species, genera, family and order information depending on the metric being analyzed. In short, the results that are presented here are preliminary steps in analyzing the leaf litter macroinvertebrate community and will contribute to an increased understanding of the diversity and importance of floodplain wetland forests as well as the continued development of the macroinvertebrate IBI.

Taxonomy of macroinvertebrates is also quite dynamic. A number of sources were utilized and there was often disagreement within the taxonomic classifications. It is therefore important to document the classification system and resources that were used in this work. Taxonomy for Coleoptera (beetles) adults was derived from An Introduction to the Study of Insects (Borrer, 1989). Taxonomy for Coleoptera larvae was derived using Larvae of Insects, Part II (Peterson, 1951). Taxonomy for the Orders of Diplopoda (millipedes) and Chilopoda (centipedes) were derived using Soil Biology Guide (Dindal, 1990). The taxonomy for the Diptera larvae (flies) was derived using Atlas on the Biology of Soil Arthropods (Eisenbeis, 1987). Collembola Orders (springtails) were keyed using the taxonomic key available on www.collembola.org courtesy of Frans Janssens, Department of Biology, University of Antwerp (RUCA), Antwerp, B-2020, Belgium.

A. Macroinvertebrate Metrics

1. Macroinvertebrate Abundance

Without consideration of taxonomic grouping, there was a tendency for overall macroinvertebrate abundance to increase with decreasing disturbance (Figure 32). Clinton was a marked outlier with over 13,000 individuals in the sorted subsamples. Wawayanda and Berkshire were also higher with over 5,000 individuals. Phillipsburg, a disturbed site, was comparable with Black River whereas High Bridge and Whippany were considerably lower than the other sites. The trends in abundance were significant along the disturbance gradient (regression F=4.58, p=0.06), but this was driven primarily by the very high numbers at Clinton and somewhat higher numbers at the other two relatively undisturbed sites. When analyzed by the disturbance categories, total macroinvertebrate abundance significantly varied between categories with the exception of the moderate and high disturbance categories which were not significantly different.



ANOVA	
P	0.02
F	7.04

Figure 32. Total number of individual invertebrates counted for a site. Counts reflect a subsample (half) of the samples collected at a site. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right. Results of the ANOVA are in the side-table testing for differences between disturbance categories.

2. Class Metrics

Class Richness:

All of the individuals in the subsamples were identified to Class and Class richness and abundances in each class quantified. Differences in taxonomic richness were not notable or significant (F=1.05, p=0.40) at the Class level (Figure 33). Most of the sites had between six and eight Classes with Whippany having the lowest Class richness at six Classes.

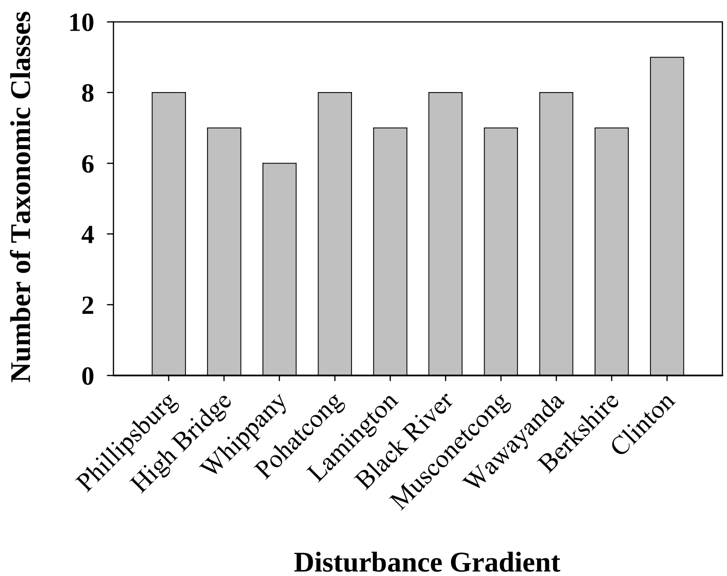


Figure 33. Number of taxonomic classes identified at the different sites. Sites are ordered along a disturbance gradient with decreasing disturbance from left to right.

<u>Abundance within Class:</u>

The Class Arachnida (spiders and mites) was the most dominant Class in terms of number of individuals across all sites (Figure 34). With the exception of Phillipsburg, the number of individuals in this Class increased with decreasing disturbance. The high abundance at Clinton was primarily due to this Class. For Arachnida, all categories were significantly different from each other with the exception of the moderate and high disturbance categories. Hexapoda (insects) and Collembola (springtails) were also represented in most of the sites but there was no clear pattern of increasing or decreasing abundance along the disturbance gradient. Hexapoda did not significantly vary along the disturbance gradient (Table 14) and Collembola did not meet statistical parametric assumptions and thus statistics were not performed.

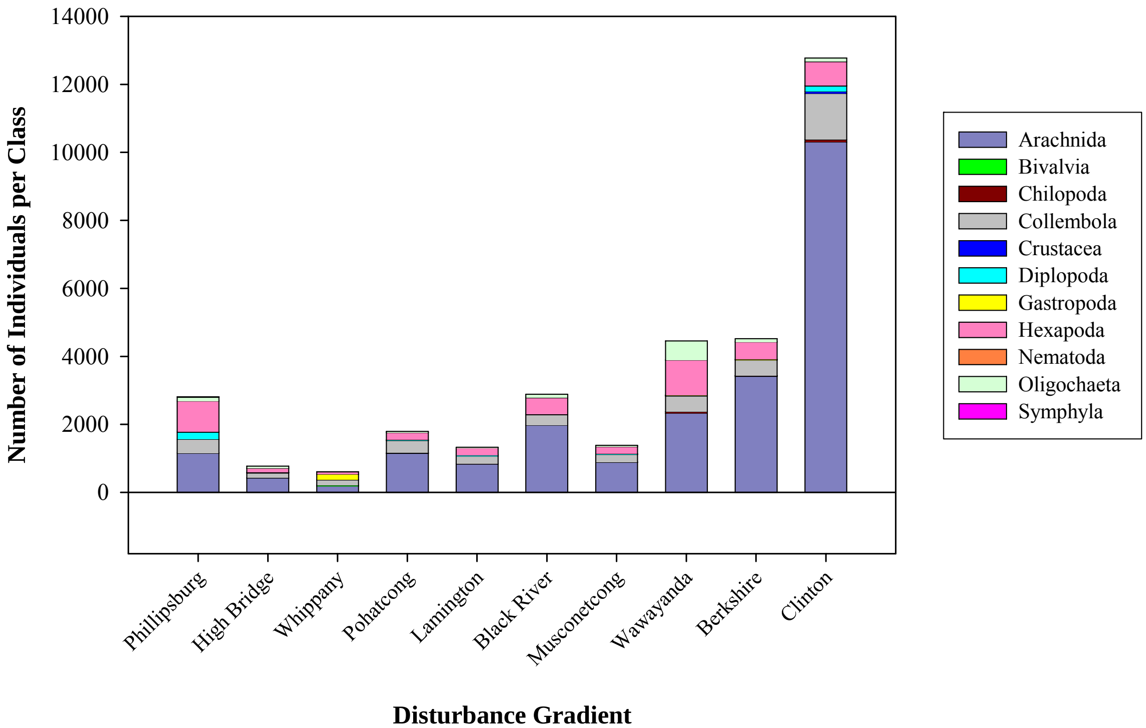


Figure 34. Number of individuals in each Class at the different sites.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

	Disturbance Classes
Arachnida	F=8.24, p=0.01
Hexapoda	F= 2.24, p=0.18
Collembola	Non-normal

Table 14. Differences in abundances the two most commonly occurring taxonomic classes across the three disturbance classes.
A p-value of <0.15 indicated that abundances were significantly different between the classes.

3. Order Level Metrics

<u>Number of Orders per Site:</u>

Order is the next step in taxonomic resolution (Table 15). Individuals in all subsamples were identified to Order and for many Orders this was the finest level of identification there was to work with. Similar to Class, there was little variability with respect to Order richness (Figure 35). As with Class, Whippany had the lowest Order richness with ten and the other two high disturbance sites had fewer Orders than did the intermediate or low disturbance categories.

CLASS	ORDER	FAMILY
Diplopoda	**Chordeumida**	Conotylidae
	Julida	Julidae
	Polydesmida	Paradoxosomatidae
		Polydesmidae
	Spirobolida	Spirobolidae
Chilopoda	Geophilomorpha	
	Lithobiomorpha	Henicopidae
Hexapoda	**Coleoptera adult**	Anthribidae
		Cantharidae
		Carabidae
		Chrysomelidae
		Cincindelidae
		Corylophidae
		Curculionidae
		Halipidae
		Histeridae
		Hydrophilidae
		Leiodidae
		Monommidae
		Nitidulidae
		Phalacridae
		Pselaphidae
		Ptiliidae
		Scarabaeidae
		Scolytidae
		Scydmaenidae
		Staphylinidae
		Tenebrionidae
	Coleoptera larvae	Alleculidae
		Cantharidae
		Carabidae
		Chrysomelidae
		Cicindelidae
		Cucujidae
		Curculionidae
		Elateridae
		Lampyridae
		Monommidae
		Mordellidae
		Nitidulidae
		Platypodidae

		Scolytidae
		Scydmaenidae
		Silphidae
		Staphylinidae
	Diptera larvae	Bibionidae
		Chironomidae
		Muscidae
		Stratiomyidae
		Tipulidae
	Diptera adult	
	Hemiptera adult	Scutelleridae
	Hemiptera instar	
	Odonata larvae	Aeshnidae
	Archaeognatha	
	Blimplike	
	Diplura	
	Hymenoptera	
	Isoptera	
	Lepidoptera larvae	
	Orthoptera	
	Pauropoda	
	Protura	
	Psocoptera	
	Thysanoptera	
	Zygentoma	
Collembola	Entomobryomorpha	
	Neelipleona	
	Poduromorpha	
	Symphypleona	
Arachnida	Acari	
	Araneae	
	Opiliones	
	Pseudoscorpiones	
Bivalvia		
Crustacea	Isopoda	
	Amphipoda	
Gastropoda		
Nematoda		
Oligochaeta		
Symphyla		

Table 15. Classes with known orders and families.
Bold order names indicate all of the orders' members have been identified to the family level.

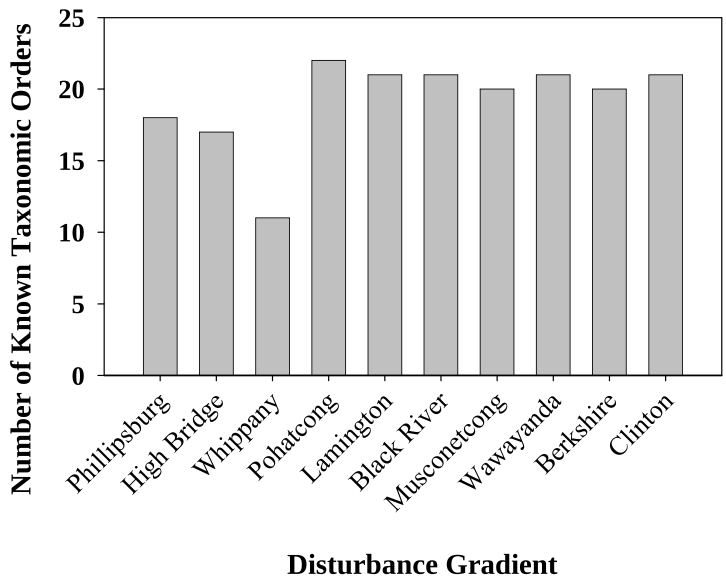


Figure 35. Number of macroinvertebrate orders at each of the sites.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

Number of Individuals per Order:

At the Order level, it is apparent that Acari (mites) of the Class Arachnida was driving the predominance of individuals across the sites (Figure 36). Entomobryomorpha (springtails) was also commonly found in all of the sites but abundances in this Order did not vary with the disturbance gradient. Diptera (flies) was a relatively important member of the invertebrate community in the least disturbed sites as well as in Black River. When the dominating effect of Acari is removed (Figure 37), Poduromorpha (another order of springtails) also tends to occur in higher numbers in the intermediate and least disturbed sites. With Acari removed all three Orders (Entomobryomorpha, Diptera and Poduromorpha) varied significantly by the disturbance gradient (Table 16). For each Order, the least disturbed sites were significantly different from the most disturbed sites.

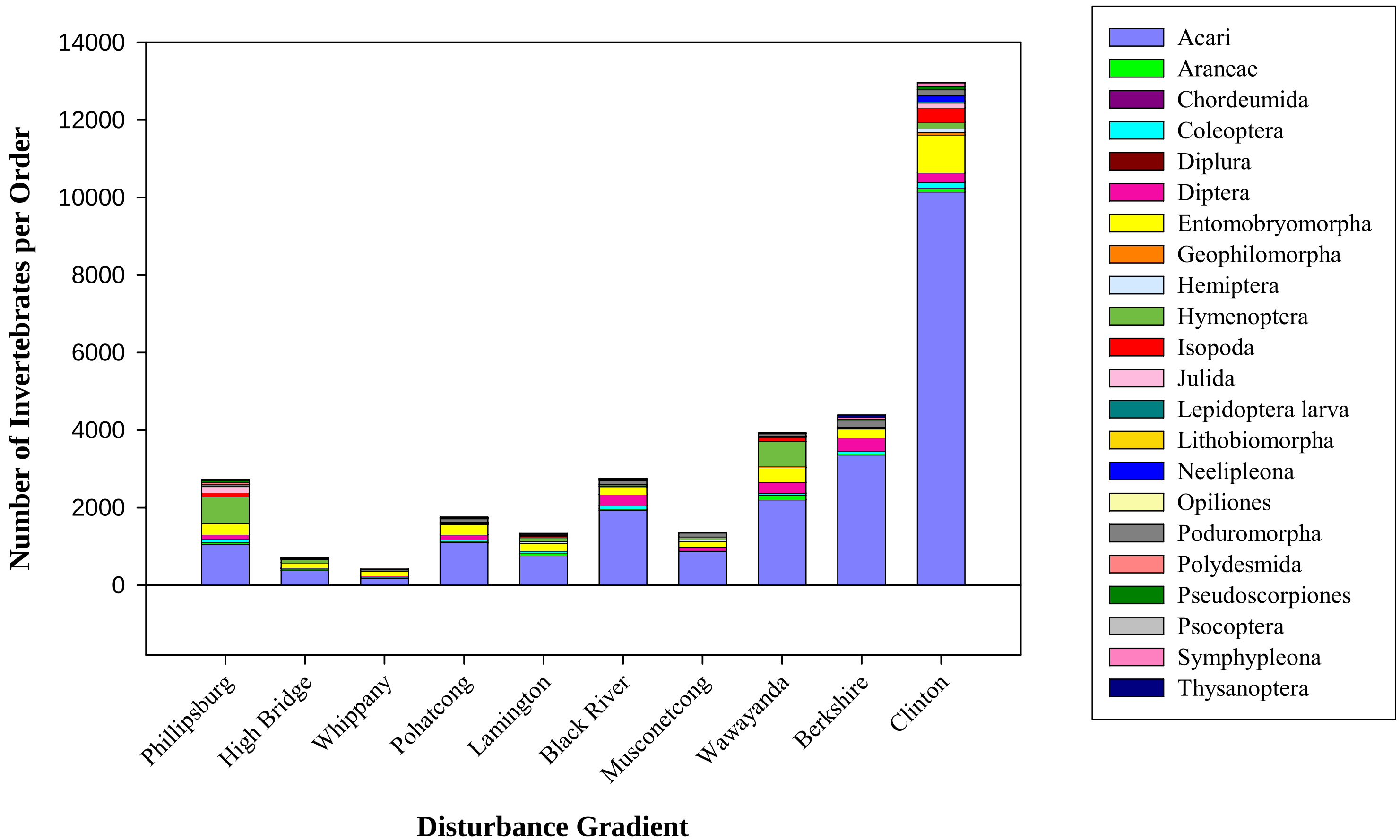


Figure 36. Number of individuals in each macroinvertebrate Order at the different sites. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

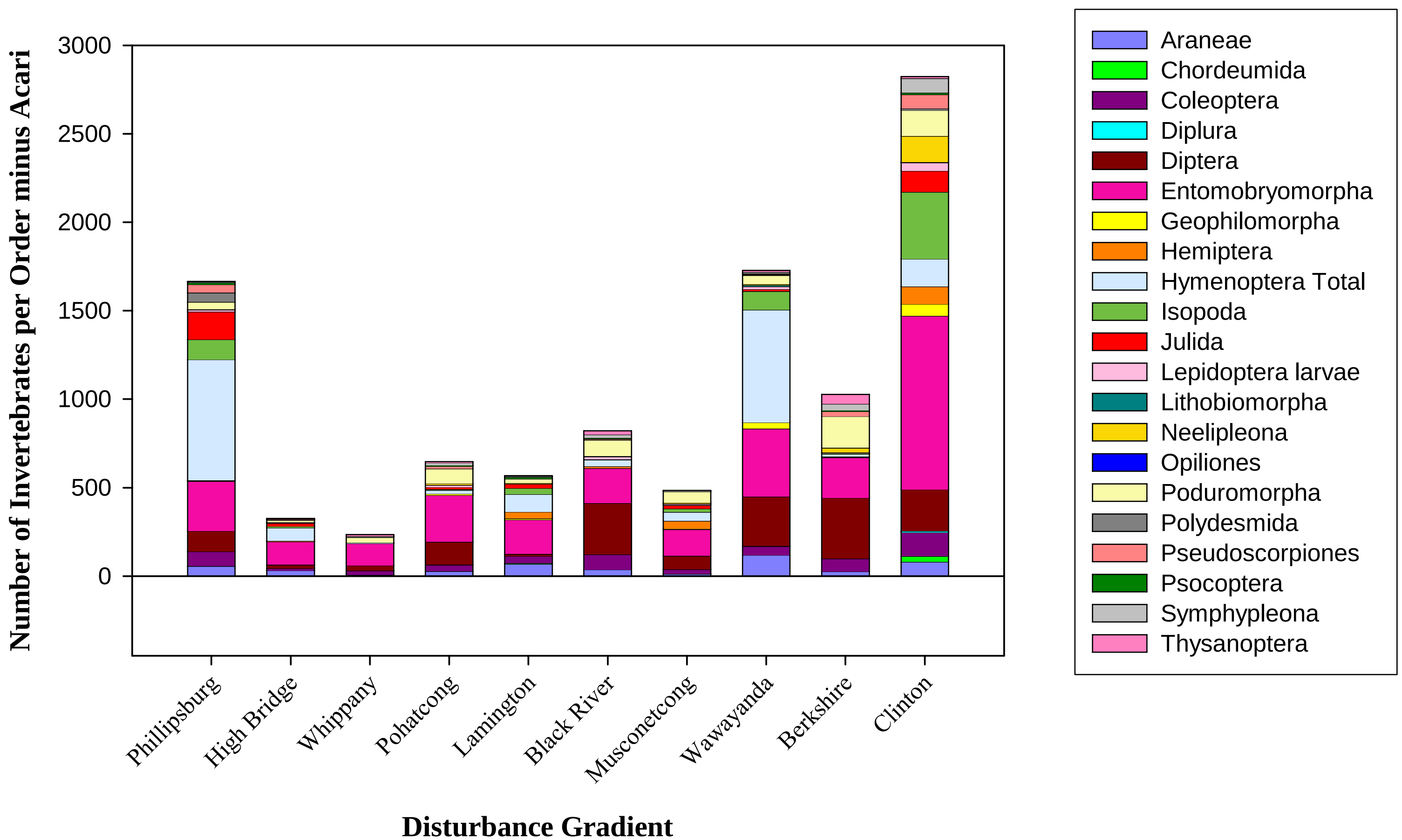


Figure 37. Individuals in each Order at the different sites once Acari has been removed. Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

	Disturbance Classes
Diptera	F=5.46, p=0.04
Poduromorpha	F= 4.18, p=0.06
Entomobryomorpha	F=3.49, p=0.09

Table 16. Test for differences (ANOVA) in abundance in the three most commonly occurring taxonomic Orders across the three disturbance classes once Acari had been removed.

4. Family Level Trends

Breaking the Orders into Families should provide yet finer resolution as to trends and patterns in the macroinvertebrates along the disturbance gradient. There were a number of Families in each order (Table 16) and ideally, efforts should be concentrated on refining the taxonomic resolution toward Families, Genera and Species that are known to reflect a disturbance gradient. With limited resources and schedule, we selected several families that were sedentary and resident for much of the growing season on the premise that these were integrators of site conditions.

The orders that were broken down into families were Coleoptera (beetles) and Diplopoda (millipedes). Coleoptera was selected as it is a very diverse and multifunctional family. Also, many of the species in this group were in intimate contact with the leaf litter (adults and larvae) for much of their lives. It was expected that with finer taxonomic resolution in this group, the probability of finding a sensitivity response to disturbance was higher. Also, the taxonomy of this group is fairly well worked out and keys for identification are available. Beetles have been found to be sensitive to a wetland disturbance gradient in depressional wetlands (Gernes and Helgen 2002) and considerable research has been done on different families and genera within this order both with respect to taxonomy and ecology.

Diplopoda (millipedes) was also selected as it is known to be a forest dwelling group and has shown sensitivity to agriculture. They are also fairly immobile and are likely to reflect local site conditions. Taxonomy is relatively straight forward and the abundances were low enough that if a response to the disturbance gradient was observed, this could prove to be a quite useful group to focus on.

Families in Order Coleoptera (Beetles)

Black River and Phillipsburg had relatively high family richness compared to the other sites with sixteen and twelve families respectively (Figure 38). In general however, the low disturbance sites did not have higher family richness than the other disturbance categories.

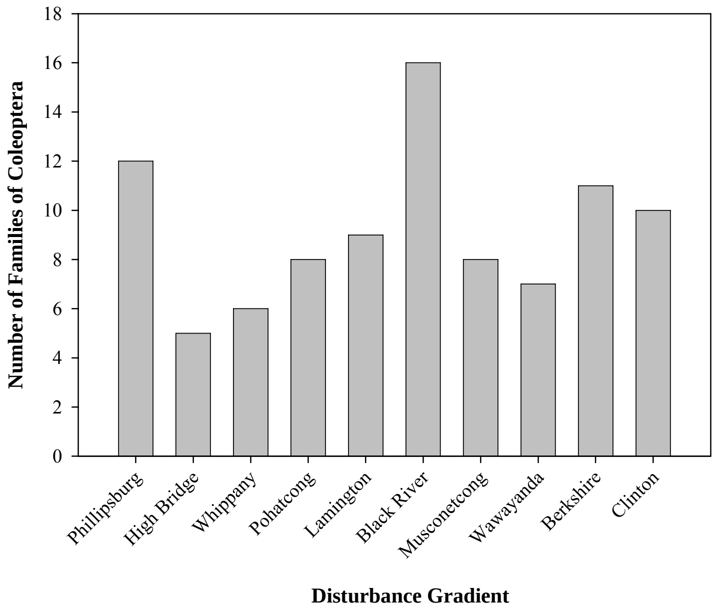


Figure 38. Number of Families in the Order Coleoptera (Beetles).
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

Over 130 individual beetles were encountered in the subsample at Clinton (Figure 39). The next highest sites for beetle abundance were Black River and Phillipsburg with 80 beetles while High Bridge had the lowest count at 12 beetles in the subsample. Staphylinideae (rove beetles) was present at all sites and accounted for over one-third of the number of individuals at Phillipsburg, Black River and Berkshire. This family has a large number of species (over 3000 in the US) many of which are predators. Cantharidae (soldier beetle) was not present in the high disturbance sites and was the most abundant family at Clinton and Lamington and was the second most common at Black River and Wawayanda. While larvae are predaceous, adults are often found on flowers. As it tended to be more abundant in less disturbed sites, this family might be a candidate for taking to the next finer taxonomic level. Nitidulidae (sap beetles) was the most abundant beetle family at Phillipsburg and occurred in two of the disturbed sites and two of the intermediate disturbance sites but not in the low disturbance sites and thus might also warrant refinement in taxonomy.

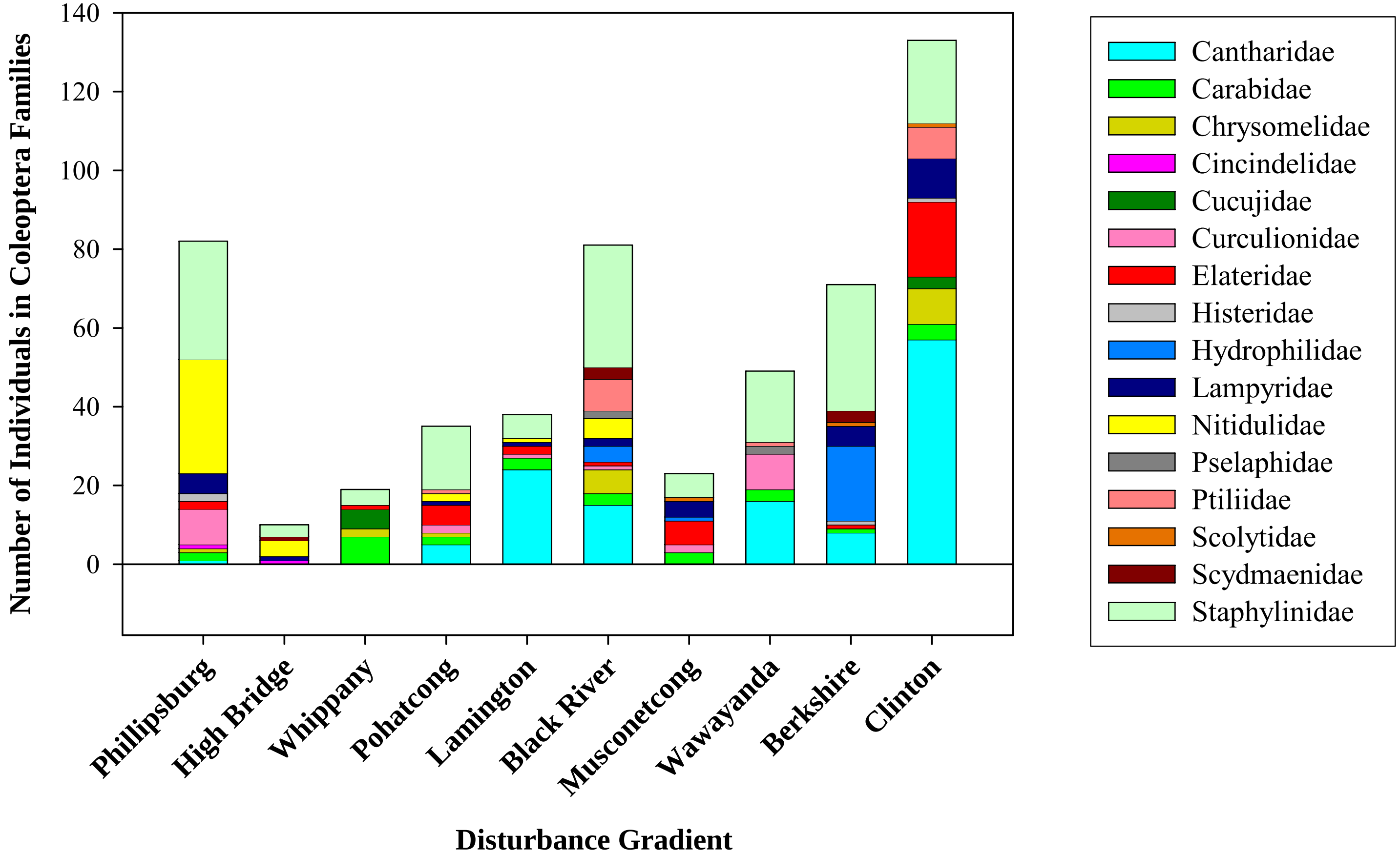


Figure 39. Individuals in each Family of Coleoptera (Beetles) at the different sites.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

Family level information in the Order Diplopoda (Millipedes):

Millipedes as a family are important members of the macroinvertebrate community of forests. Julidae is by far the most common family encountered across the different sites being most abundant at the two ends of the disturbance gradient (Figure 40). It is absent from Whippany and Berkshire and in low numbers at the majority of the sites. More detailed information pertaining to specific genera or species might warrant further taxonomic refinement but the family level does not look to be a sensitivity indicator except for perhaps presence/absence level information.

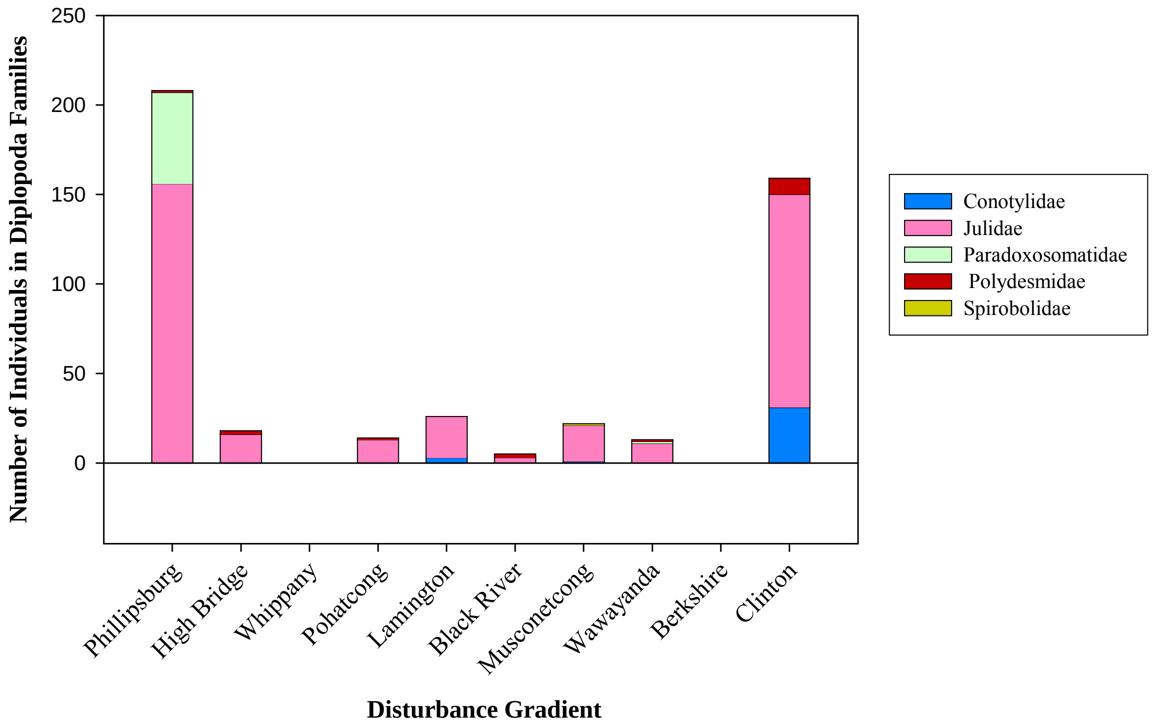


Figure 40. Number of individuals in each Family for the Order Diplopoda (Millipedes) at the different sites.
Sites are arranged on the x-axis according to the land cover disturbance gradient decreasing in disturbance from left to right.

VIII. CONCLUSIONS

Identification of a disturbance gradient is a critical step in the development of IBIs. Our approach of utilizing land cover data at both the watershed and local scale was but one way to identify a disturbance gradient. It was also important to determine if the influence of land cover at the larger watershed scale would be reflected in the wetland plant and macroinvertebrate communities at the scale of the local area sampled. Therefore, calibration and verification of the disturbance gradient is important to determine the validity and continued use of the approach used here. In a preliminary attempt to evaluate the GIS-derived disturbance gradient, we looked at a number of metrics that demonstrated a sensitivity to this gradient and allowed realigned sites based on their metric values rather than the GIS derived disturbance value. Though the sites in the middle part of the metric-derived disturbance gradient shifted positions from the land cover based gradient, the sites at the ends of it stayed in the same relative positions. The one site that changed rank the most, Black River, was somewhat expected as site experience indicated that it probably should have had a higher ranked wetland. Though the wetland buffer for Black River had a high rank, the land cover in the watershed was the primary factor in its intermediate weighting in the land cover based disturbance gradient. As mentioned, this was a preliminary attempt toward evaluating the efficacy of the GIS-derived disturbance gradient and this most certainly needs to be expanded to look at a wider suite of metrics besides those that already exhibited a pattern. See further discussion on the disturbance gradient issue in the Recommendations Section below.

By examining whether wetness was a confounding factor in the disturbance gradient, we were able to identify metrics that were primarily driven by the disturbance gradient. However, the two most disturbed sites, Phillipsburg and High Bridge, were also the driest sites and until additional sites can be added to this work that are more disturbed and also wetter than these two sites we cannot be sure we have identified the lower end of the disturbance gradient.

The combination of the seven metrics in the preliminary plant IBI appeared to distinguish between the disturbance categories. The metrics spanned the range of metrics often seen in wetland IBIs. Four of the seven metrics included some version of non-native species or ruderal species. One metric was a community structure variable (tree dbh) and one was analogous to a diversity measure (native shrub importance values). There was a relatively wide spread in the IBI scores (7-33) and there was a relatively distinct break between the disturbance categories (Table 13).

The development of a leaf-litter macroinvertebrate IBI lagged considerably behind the plant IBI primarily due to two factors. First and foremost, the resources required to conduct a taxonomic survey of macroinvertebrates was nontrivial. After hundreds of hours of working with the macroinvertebrate taxonomy, the identification still remained at the very coarse resolution of Order with just a few Orders taken to Family. Macroinvertebrate IBIs often utilized multiple resolutions of taxonomy in their metrics and that may ultimately happen with this IBI. However, finer resolution information is necessary to detect the appropriate resolution and a top down approach does not provide that type of information. The second major and nontrivial factor in the slower development of the macroinvertebrate IBI is that we selected to work on the leaf-litter community. The reasons for this choice remain valid as this group has very good potential to reflect current wetland quality as the organisms are short-lived and in intimate contact with the forest floor. However, limited work has been done on leaf-litter communities in general and fewer yet have been done for wetlands. Wetlands are biotically diverse and the leaf litter macroinvertebrates are likely one of the most taxonomically diverse groups within the wetland community. There are a number of sampling protocols for macroinvertebrates that stratifies and subsamples a whole sample (in our case a macroinvertebrate plot) rather than identifying and enumerating the majority of the individuals. Once more is known about the diversity and variability in the leaf-litter community and how it varies within sites (with time of year and along a disturbance gradient), this might prove to be an effective and necessary strategy.

IX. RECOMMENDATIONS

As with all pilot studies, recommendations for the next steps in the project are based on the limited information that has been learned in the current effort. As more sites are added to the study, patterns will be better elucidated and next steps more clearly defined. Therefore, the recommendations herein will change and become obsolete as more is known.

An important and upfront recommendation is that there be continued evaluation of our approach to identify a disturbance gradient. The approach we used is but one of several approaches that could have been used and we selected this method because the availability of information was broad in extent and relatively current. This approach is also often used in a variety of situations to help define a disturbance gradient. However, there is an on-going need to verify our approach with information and data that incorporates local and watershed factors that are not based exclusively on remotely sensed data. Changes in local and regional hydrology, land cover/land use and invasive species distributions are examples of information that could prove useful.

As new information becomes available, either with land cover data or with alternative ways to classify a disturbance gradient, the gradient may have to be adjusted. For example, the advisory committees suggested evaluating the current disturbance ranking criteria with new land cover data when it becomes available. This will be informative since the disturbance gradient used here is based on 1995-1997 land cover and in a State that is rapidly changing, this data likely does not reflect the best available information. However, this information was not available at the time this project was launched and if newer information is used and the current disturbance gradient is modified, the rankings of the sites in this study may need revising.

When the disturbance gradient was derived, the watershed and wetland buffer land cover were weighted equally. Our rationale for equal weighting was the potential for hydrologic alteration as the proportion of altered land cover increased in the watershed. Since the wetlands in this study are closely linked to streams, changes in hydrology could be reflected in the wetland. Similar arguments were posed for the proportion of altered land in the wetland buffer. When Black River shifted notably in the disturbance gradient verification process it suggested that perhaps a weighting might be appropriate to consider. Other scenarios are possible with weighting one factor more than the other or including other factors. Different approaches will likely result in further shifts in the ordering of the sites and at this point with just ten sites we do not have enough information to make informed recommendations. However, continued diligence to the disturbance gradient and particularly how sites shift in the middle of the gradient as more sites are added will help improve on and refine the criteria necessary to adequately define the disturbance gradient.

As additional sites are included in the model development, priority should be directed toward two efforts. First and foremost, sites need to be added that are more disturbed and also wet. Our two most disturbed sites were also the driest and it is not clear which environmental factor accounted for the trends we saw with these sites. With the addition of new disturbed wet sites, attention should be directed toward recalibrating and testing the metrics used in the IBI as well as others that showed trends.

The second effort in identifying and adding new sites is to strive for a more even geographic distribution of disturbance categories throughout the Highlands. Currently there is a strong longitudinal gradient with less disturbed sites in the north and most disturbed sites in the south. This gradient is primarily a reflection of the geology and topography of the Highlands with steeper slopes and more extensive forest cover in the north which has resulted in longitudinal differences in land use practices and land use histories.

New Jersey has experienced a long history of land alteration. As a consequence, pristine wetland conditions are a relative term. Even for the least disturbed sites in this study, there was an obvious human signature. The Clinton site is just below Clinton Reservoir and the stream that flows through the site experiences dramatic fluctuations in discharge based on water management of the reservoir. Berkshire has high species diversity but the tree canopy is dominated by a single even-age stand of *Acer rubrum* suggesting some past event had a strong influence on the current vegetation. Where resources are available, a historic analysis of land cover would facilitate evaluating what is currently seen on the site and interpreting wetland quality.

The FQAI used in this study exhibited one of the strongest patterns of sensitivity to the existing disturbance gradient. The methodology we used was developed and tested in Pennsylvania and entailed considerable fine-tuning and calibration before it was complete. Since the existing Pennsylvania model demonstrated sensitivity in New Jersey further consideration and adjustment of this model will likely be a fruitful endeavor. Once the model has been developed it can be used in a variety of settings beyond the scope of IBIs.

This work is based on one year of field sampling in the growing season. Inter-annual and intra-site variability in the vegetation will be important to consider in the robustness of the plant IBI. Consideration of temporal and spatial variability in the macroinvertebrate community will be critical in the continued development of the leaf-litter community.

As more riverine wetland sites are added and seasonal and interannual variability are evaluated, the vegetation IBI model will become more robust. Functional IBIs typically incorporate between 30-40 reference sites. The ten sites in this study are a start in the process of developing a functional IBI. As new sites are added, they should span a wider range of stream orders still maintaining the geographic and wetland type constraints in this study. One should remain critical as to whether the current disturbance gradient and its methodology adequately reflects what is seen in the data and on the ground. As sites are added, many of the metrics we evaluated need to be revisited and some of the current metrics may be replaced with better and more sensitive metrics.

The macroinvertebrate leaf litter community is resource intensive but has promise for indicator development. Even at coarse taxonomic resolutions, patterns were evident along the disturbance gradient. Continued refinement of the taxonomy will help elucidate trends and identify community and species metrics that are sensitive to the disturbance gradient. Relatively little is known about the wetland leaf litter community and as a consequence this work has the potential to make a significant contribution to our scientific understanding of wetland systems as well as to guide policy and management decisions.

Though progress has been slower than with the vegetation, the rationale for committing resources to the leaf litter macroinvertebrate community still has merit in that these communities are likely to be responsive to wetland condition since they are in such intimate contact with the environment. Their relatively short life cycles and quick response to environmental cues were desirable traits for aquatic IBIs and the same argument holds for wetland leaf litter communities. The results that are presented here are preliminary steps in analyzing the leaf litter macroinvertebrate community and will contribute to an increased understanding of the diversity and importance of floodplain wetland forests as well as the continued development of the macroinvertebrate IBI.

As the project moves forward and additional information is gathered, there is a need for a concerted effort to more directly link wetland indices to water quality indices such as chemistry and biological indicators. This will be a nontrivial task as it will require linking two systems that though spatially adjacent necessarily function at different spatial scales within the landscape. However, it is only through collaboration and coordination of parties involved that a long term goal of this project to better understand wetland condition and its relationship to water quality can be achieved.

Wetland resources span a number of resource, policy and jurisdictional interests and as EPA continues to emphasize the incorporation of wetlands into water quality reporting, there is a ongoing need to emphasize coordination and collaboration within and across programs. As this project develops it will benefit from and contribute to programs currently in place within the Bureau of Freshwater and Biological Monitoring. Collaboration will enhance the ability to identify and develop the linkages between the wetland IBIs and the water quality indicators. The baseline data gathered to develop the IBIs and continued monitoring of these reference wetlands will increase our understanding of temporal trends in wetland response to disturbance.

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APPENDIX A: ADVISORY COMMITTEES

Appendix A: Advisory Committees:

I. DEP Steering Group: Internal Advisory Committee

Rob Piel	NJDEP Land Use Regulation Program
Al Korndoerfer	NJDEP Water Monitoring Management
Dave Fanz	NJDEP Land Use Regulation Program
Debra Hammond	NJDEP Water Criteria and Standards
JoDale Legg	NJDEP Land Use Regulation Program
Marjorie Kaplan	NJDEP Office of Policy, Planning and Science
Ginger Kopkash	NJDEP Land Use Management
Kati Wessling	NJDEP Land Use Management
Kathy Walz	NJDEP Natural Heritage Program

II. NJDEP Wetlands Monitoring External Advisory Group

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Brian Zarate	NJDEP Endangered & Nongame Species Program	Brian.Zarate@dep.state.nj.us

APPENDIX B:
SITE INFORMATION

Phillipsburg Site Description

Study Disturbance Rank: HIGH

Site Location
Phillipsburg is located on township owned land, in Pohatcong Township, Warren County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 40 47.773 °N	75 09 41.272 °W
	Corner of Plot 5	40 40 46.240 °N	75 09 40.537 °W
Upland Transect	Corner of Plot 6	40 40 46.452 °N	75 09 39.703 °W
	Corner of Plot 10	40 40 48.001 °N	75 09 40.411 °W

River Information
The site is located on the Lopatcong Creek, a third order stream at the location of the site. The average width of the river is 8.13m. The bank extends, on average, .627m above the river.

Site Access
Park in the parking lot for the ball field on Hunt Ave at the point where Liberty Blvd makes a "T" with Hunt Ave. Walk along the right side of the ball field for about 50m. You will exit the ball field through a fence gate. Follow along the fence from here, until you reach the river. Make a right at the river and walk about 15m. Plots 5 to 1 go along the river from this point to the right (north).

Surrounding Area
The corner of plot 10 is on the edge of a homeowner's lawn. To the east, the site's forested buffer is 0-30m. There are housing developments directly to the south and west of the site. 140m to the north is agricultural land.

Topography and Species
Phillipsburg is a highly disturbed, very dry, forested and open site. It has some dense shrubby areas, some open waste areas, and is lacking in any hummock or mucky areas. Garbage covers the site in many places. The dominant trees are Acer negundo, Acer platanoides, and Juglans nigra. Rosa multiflora, Lindera benzoin and Cornus racemosa dominate the shrub layer. The common herbaceous species are Microstegium vimineum, a small, unknown matted grass, Impatiens pallida, and Alliaria officinalis.

Lopatcong Creek – Downstream

Wetland View in Riverside Transect

Site Garbage in Upland Transect

High Bridge Site Description

Study Disturbance Rank: HIGH

Site Location
High Bridge is located on private land in High Bridge Borough, Hunterdon County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 39 35.997 °N	74 59 09.430 °W
	Corner of Plot 5	40 39 33.533 °N	74 54 10.169 °W
Upland Transect	Corner of Plot 6	40 39 33.180 °N	74 54 07.948 °W
	Corner of Plot 10	40 39 34 647 °N	74 54 07.202 °W

River Information
The site is located on the Raritan River, a third order stream at the location of the site. The average width of the river is 18.167m. The bank extends, on average, .627m above the river.

Site Access
Park in the driveway of a private home listed on the property access information in the files. Walk to the back of the Walls' yard into the woods. They have a maintained path that leads from the back of the yard to the river. Just before the river, make a left turn off of the path into a wooded area. Plot one begins about 30m along the river from this path. The transects extend East from the river to the area beyond a small stream (where the second transect is located).

Surrounding Area
The site is surrounded by development. A county road with a restaurant and houses sits on the opposite site of the river from where the site is located. Old Jericho Road follows along the south side of the river, and is also lined with houses as well as agricultural land. The buffer to these houses and roads from the river varies from 0m to 50m to 125m. From Plot 6, the lawn of one of these houses is in clear view.

Topography and Species
High Bridge sits in the floodplain of the Raritan River. It is a mostly dry, upland site, with very small river tributaries separating parts of it. The dominant trees are Fraxinus americana, Acer rubrum, and Tilia americana. Rosa multiflora, Rhodotypos scandens, Lindera benzoin and Berberis thunbergii, as well as many tree seedlings, dominate the shrub layer. The common herbaceous species are Alliaria officinalis and Microstegium vimineum.

High Bridge Site Photos

Raritan River – Downstream

Upland Transect View

Riverside Transect View

Whippany Site Description

Study Disturbance Rank: HIGH

Site Location
Whippany is located on land owned by Morris County Parks in Morris Township, Morris County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 48 37.6 °N	74 30 48.3 °W
	Corner of Plot 5	40 48 39.1 °N	74 30 47.1 °W
Upland Transect	Corner of Plot 6	40 48 39.9 °N	74 30 48.9 °W
	Corner of Plot 10	40 48 38.4 °N	74 30 49.9 °W

River Information
The site is located on the Whippany River, a third order stream at the location of the site. The average width of the river is 6.867m. The bank extends, on average, .313m above the river.

Site Access
Park in the pull-off at the bridge on Sussex Ave where the Morris County Parks trail crosses. Follow down the trail to the left (south) for about 175m. Transect 1-5 (Riverside) is on the left (east) side of trail, 35m from the river. Transect 6-10 (Upland) is on the right (west) side of the trail, paralleling a water holding depression.

Surrounding Area
Whippany is immediately surrounded by deciduous and wetland forest. There are houses and developments 175m to the east, 275m to the west, 700m to the north, and 1000m to the south.

Topography and Species
Whippany is currently used as a recreation area. A multi-use trail separates the two transects. The ground is very flat, with a dry, cracked clay soil base, underlain by a fragipan layer. Although being very uniformly flat, several macrotopographic depressions are found throughout the site. 77m from the river, a pool of standing water lined the 6-10 transect. The dominant trees are Fraxinus pennsylvanica and Quercus palustris. Cornus racemosa, Ilex verticillata, and Rosa multiflora dominate the shrub layer. The common herbaceous species are Phalaris arundinaceae, Polygonum hydropiperoides, Leersia oryzoides and Pilea pumila.

Whippany River – Upstream

Floodplain View – Riverside Transect

Recreational Trail dividing Riverside and Upland Transects

Pohatcong Site Description

Study Disturbance Rank: MODERATE

Site Location
Pohatcong is located on county owned land, in Washington Township, Warren County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 44 50.13 °N	75 00 21.32 °W
	Corner of Plot 5	40 44 49.73 °N	75 00 23.35 °W
Upland Transect	Corner of Plot 6	40 44 48.02 °N	75 00 22.80 °W
	Corner of Plot 10	40 44 48.32 °N	75 00 20.72 °W

River Information
The site is located on the Pohatcong Creek, a fourth order stream at the location of the site. The average width of the river is 10.567m. The bank extends, on average, .53m above the river.

Site Access
Turn onto Mill Pond Road from State Highway 57. You will drive over the bridge for Pohatcong Creek and then come to a pull-off on the left at a point where the road makes a 90-degree turn to the right. Park in this gravelly pull-off on the left (.32 miles down Mill Pond Road). After parking, walk back to the bridge. Cross the bridge and make a left into an overgrown area between the bridge and an old brick building. Walk towards the river. Once you reach the river, walk in the river heading downstream (south). You will pass an island where the water channels on both sides of the landmass. After the island, walk about 64m until you reach a shallow sandbar in the river (this may be absent in times of flooding or excess rain). 5m after the sandbar make a left up the bank. There will be a very small channel coming from the forest and entering the river at this point. Follow the channel about 30 meters until you reach an open, wetland area. Plot 1 is located here, 30m from the river.

Surrounding Area
The land immediately surrounding the wetland is mostly covered in overgrown Rosa multiflora. Development and agricultural land surround the site 350m to the east, 550m to the west, and directly north. An active train track encompasses the southern border of the site 225m to the south. After the train track, deciduous forest extends another 225m.

Topography and Species
Pohatcong is a forested wetland amidst much encroachment of more upland exotic species. Its topography varies from moderately wet forest to very mucky, hummock and hollow regions. The dominant trees are Acer rubrum and Fraxinus pennsylvanica. Lindera benzoin, Rosa multiflora and Berberis thunbergii dominate the shrub layer. The common herbaceous species are Symplocarpus foetidus, Osmunda cinnamonea, and Alliaria officinalis.

Pohatcong Creek - Downstream

View from Riverside Transect toward Stream

Wetland View – Upland Transect

Wetland View – Riverside Transect

Lamington Site Description

Study Disturbance Rank: MODERATE

Site Location
Lamington is located on land owned by the Upper Raritan Watershed Association in Tewksbury Township, Hunterdon County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 72 36.50 °N	74 75 37.14 °W
	Corner of Plot 5	40 72 33.14 °N	74 75 35.57 °W
Upland Transect	Corner of Plot 6	40 72 33.02 °N	74 75 32.72 °W
	Corner of Plot 10	40 72 37.41 °N	74 75 34.94 °W

River Information
The site is located on the Lamington River (tributary #4), a third order stream at the location of the site. The average width of the river is 4.04m. The bank extends, on average, .697m above the river.

Site Access
Park in the pull-off at the power line cut off of Fairmont Road (county highway 512). Follow along the road (heading east) for about 50m until you reach two wide paths leading into the woods on the right. Take the less worn, descending path on the left. After about 175m, you will meet up with the river and cross a very old, grass covered stone bridge. After crossing the bridge, make a right off of the path and follow along the river from here about 64m. The corner of plot 1 is near the base of a large tree, 10m from the river that can be recognized by its appearance immediately after you cross a small stream that flows into the river.

Surrounding Area
A county road crosses the river 112m to the North of the site. Beyond this, there is contiguous forest to the north for about 300m and south for about 700m, following the river corridor. 250m to the east and west of the site are agricultural land. The site is an old industrial facility and a known contaminated site according to NJDEP.

Topography and Species
Lamington sits in the open floodplain forest of the Lamington River. It is a mostly dry, upland site, with many very small streams flowing through it to the river. It is a very rocky, glaciated landscape, lacking in hummocks. The upland transition is sudden and steep. The dominant trees are Fraxinus nigra, Acer nigrum, and Betula allegheniensis. Rosa multiflora, Lindera benzoin and Berberis thunbergii, dominate the shrub layer. The common herbaceous species are Symplocarpus foetidus, Impatiens capensis, and Microstegium vimineum.

Lamington River – Upstream

Wetland Transect View

Upland Transition and Transect View

Black River Site Description

Study Disturbance Rank: MODERATE

Site Location
Black River is located on state owned land in the Black River Wildlife Management Area in Chester Township, Morris County, NJ.

GPS Coordinates

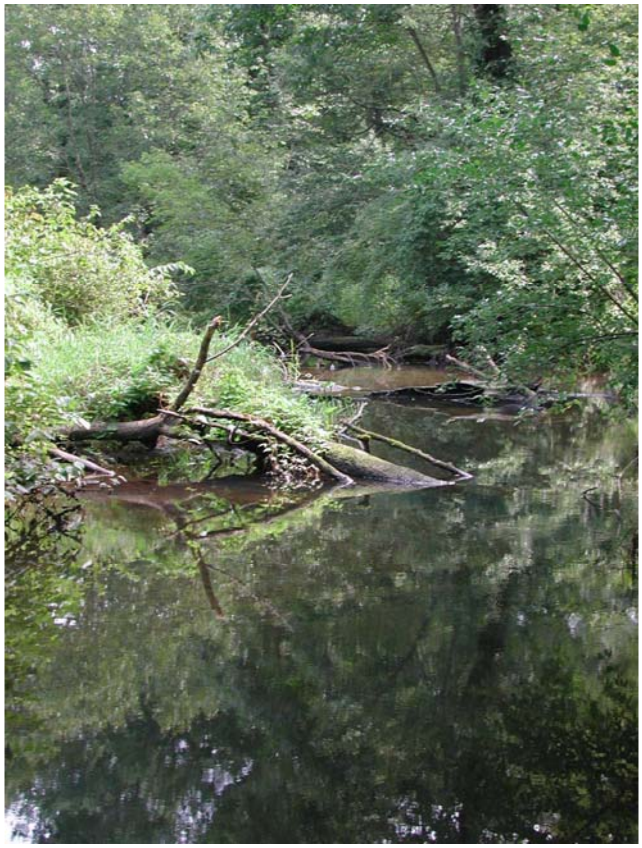
Riverside Transect	Corner of Plot 1	40 49 27.38 °N	74 39 04.85 °W
	Corner of Plot 5	40 49 27.73 °N	74 39 06.94 °W
Upland Transect	Corner of Plot 6	40 49 25.79 °N	74 39 07.76 °W
	Corner of Plot 10	40 49 25.46 °N	74 39 06.20 °W

River Information
The site is located on the Lamington River, a third order stream at the location of the site. The average width of the river is 5.5m. The bank extends, on average, .392m above the river.

Site Access
Parking at the site is at the cul-de-sac at the end of Horton Drive. Walk straight into the wooded area from the cul-de-sac. Walking downhill, you will go through a wooded area, then through a grassy power line cut, followed by pinewoods. Upon exiting the pinewoods there is a grassy lot once again. Walk straight still, but to the right side of the grassy lot. This will lead you to a path that opens onto a dirt track. Follow the dirt track to the right for about 400m. On this walk you will pass two power line towers on your right. Shortly after passing the second power line tower, pink flagging will be tied to a tree on the left side of the dirt track.   At the pink flagging, a flagged trail will lead you NE another 400m to the plot 10 corner flag.

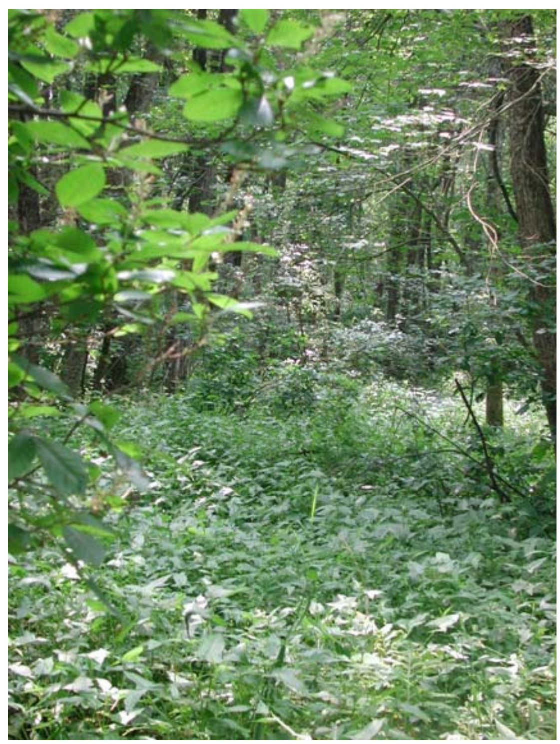
Surrounding Area
Several housing developments are located 800m to the south of the site. Old-field agricultural land is located 300m due north of the site. The site, to the east and west, is extensively buffered with forest and forested wetland, following the Lamington River corridor.

Topography and Vegetation
Black River is a very moist site, comprising of many sedge hummocks and mucky vegetation-covered areas. Its extreme wetness is due to the fragipan layer in the soil, producing a perched water table. The dominant and only trees are Acer rubrum and Fraxinus nigra. Ilex verticillata, Clethra alnifolia and Lindera benzoin dominate the shrub layer. The common herbaceous species are Phalaris arundinaceae, Carex bromoides, Carex stricta, Osmunda sensibilis, and Impatiens capensis.



Lamington River – Upstream

Black River Wetland View



Black River Wetland View

Black River Site Photos

Musconetcong Site Description

Study Disturbance Rank: MODERATE

Site Location
Musconetcong is located on state owned land in Allamuchy State Park, in Mount Olive Township, Morris County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 55 11.06 °N	74 43 51.97 °W
	Corner of Plot 5	40 55 11.24 °N	74 43 54.03 °W
Upland Transect	Corner of Plot 6	40 55 10.77 °N	74 43 53.97 °W
	Corner of Plot 10	40 55 10.47 °N	74 43 51.90 °W

River Information
The site is located on the Musconetcong River, a first order stream at the location of the site. The average width of the river is 9.03m. The bank extends, on average, .472m above the river.

Site Access
Park in the parking lot for Allamuchy State Park at the point where Continental Drive makes a "T" with Waterloo Road. Walk straight back down Continental Drive from the parking lot for about 270m until you arrive at the location where the Musconetcong River crosses Continental Drive. Walk about 80m beyond the bridge until you arrive at a path leading off to the left. Follow this path until it makes a "T" with another path. Make a left onto the new path. Just before reaching the river, another smaller path will lead to the right. Follow this path to the right as it follows along the river, away from the river through the tall herbs, and on the banks of the river for about 110m. Shortly before the river bends to the right, the path turns right and then fades out. Keep walking in the same general direction through the grassy herbaceous area until you are in the woods. Turn left about 30m into the woods. This will take you to the river. The riverside transect starts here. A landmark for the corner of Plot 1 is the location where the roots of a medium sized Hornbeam (Carpinus caroliniana) create an interlocking ledge on the bank of the river. The tree leans slightly over the river.

Surrounding Area
Directly to the east of the river is a playground and housing development. The edge of the park extends to the banks of the river. At the location of the site, there is a small island that separates the rivers most distal banks. Therefore, this park cannot be seen from the site. There is a small buffer between the houses and the river of about 10m. 700m to the south there is commercial land and an interstate highway. To the north and west there is an extensive deciduous forest buffer included in Allamuchy State Park.

Topography and Species
Musconetcong sits in the forested wetland floodplain of the Musconetcong River. It is a moderately wet forest, lacking in hummocks and mucky areas, but having some open, moist, grassy regions. The dominant trees are Acer rubrum, Ulmus americana and Fraxinus nigra. Ilex verticillata, Rosa multiflora, Lindera benzoin and Berberis thunbergii, dominate the

shrub layer. The common herbaceous species are Symplocarpus foetidus, Carex leptalea, and Cardamine pratensis.

Musconetcong River – Downstream

Upland Transect View

Riverside Transect View

Wawayanda Site Description

Study Disturbance Rank: LESS DISTURBED

Site Location
Wawayanda is located on state owned land in Wawayanda State Park in Vernon Township, Sussex County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	41 11 52.02 °N	74 25 36.71 °W
	Corner of Plot 5	41 11.56.90 °N	74 25 34.63 °W
Upland Transect	Corner of Plot 6	41 11 57.97 °N	74 25 34.26 °W
	Corner of Plot 10	41 11 58.10 °N	74 25 36.73 °W

River Information
The site is located on the Wawayanda Creek, a third order stream at the location of the site. The average width of the river is 4.077m. The bank extends, on average, .245m above the river.

Site Access
Park on the left side of Rustic Road, between Jordan Drive and Curving Hill Drive, in the small, gravelly pull-off just after a small creek crossing. Follow the small creek down until you reach the larger, Wawayanda Creek. Follow Wawayanda Creek to the left (east) for about 100m. Plot 1 is in this wet, shrubby area.

Surrounding Area
There is a housing development 80m north of the site and about 500m to the west of it. Otherwise, the site is extensively buffered by deciduous and some coniferous forest.

Topography and Species
Wawayanda sits in a lowland swath between a stream channel and an upland that rises at a slope of approximately 30-degrees. It is a heavily glaciated forested floodplain wetland, consisting of many scattered rocks and boulders. Its topography ranges from fairly flooded areas of dense shrubs and vegetation, to mucky wetlands with hummocks. Towards the upland transition, drier areas are found intertwined with more rocky, water retaining regions. The dominant trees are Acer saccharum and Carpinus caroliniana. Lindera benzoin, Rosa multiflora and Vaccinium corymbosum dominate the shrub layer. The common herbaceous species are Onoclea sensibilis, an unknown Carex sp., Impatiens capensis, and Polystichum acrostichoides.

Wawayanda Creek – Upstream

Riverside Transect View

Upland Transect View

Berkshire Valley Site Description

Study Disturbance Rank: LESS DISTURBED

Site Location
Berkshire Valley is located on state owned land in the Berkshire Valley Wildlife Management Area in Jefferson Township, Morris County, NJ.

GPS Coordinates

Riverside Transect	Corner of Plot 1	40 91 93.97 °N	74 60 37.60 °W
	Corner of Plot 5	40 91 90.35 °N	74 60 37.72 °W
Upland Transect	Corner of Plot 6	40 91 90.30 °N	74 60 40.83 °W
	Corner of Plot 10	40 91 93.92 °N	74 60 41.07 °W

River Information
The site is located on the Rockaway River, a fourth order stream at the location of the site. The average width of the river is 9m. The bank extends, on average, .317m above the river.

Site Access
Park at the cul-de-sac at the end of Mettle Lane. Walk about 10m to the left of the end of the cul-de-sac where a small dirt track leads into the woods. Follow this dirt track until it soon dissipates in the woods. Ascend up the small hill ahead of you, veering slightly left as you ascend. As you descend down the other side of the hill, follow down the hill towards the left. You will be looking out at the narrow wetland to your right. Soon you will descend into the open wetland. There are 29m in between this marked upland boundary and the shrubby, open region, near the river. To avoid this shrubby open area, the transects are located in this 29m region, 36m from the river.

Surrounding Area
A housing development is located 300m to the west of the site. This development is separated from the site by a sandy, loamy hill. All other development is fairly distant: state highways 1400m to the east and south, and Berkshire Valley Road due north 1000m.

Topography and Vegetation
The site is very moist and comprised of many small sedge hummocks. The dominant and only overstory tree, Acer rubrum, covers the site in uniform fashion. These trees all appear to be the same age, and fairly young (average DBH .104m). Ilex laevigata and Lindera benzoin dominate the shrub layer. Some common herbaceous species are Carex stricta, Impatiens capensis, and Polygonum arifolium.

Rockaway River – Downstream

Upland Transition Zone

View from Upland towards River

Clinton Brook Site Description

Study Disturbance Rank: LESS DISTURBED

Site Location
Clinton Brook is located on private land in West Milford Township, Passaic County, NJ.

GPS Coordinates could not be taken at this site

General Location*	41 06 57.2 °N	74 44 65.6 °W

*General Coordinates were acquired using Microsoft Terraserver (www.terraserver.com) on 5/02/05. Coordinates were provided by the U.S. Geological Survey from the 3/11/1991 Digital Ortho-Quadrangles (digitized and othro-rectified aerial photographs), North American Datum 1983 / UTM Zone 18N.

River Information
The site is located on the Clinton Brook, a third order stream at the location of the site. The average width of the river is 12.167m. The bank extends, on average, .34m above the river.

Site Access
Park in the private driveway after obtaining permission. Follow a maintained path that leads from the driveway, into the forest. About 100m down the path you will cross a stream and then the path will turn to the right. At this point, turn left into the forest and walk perpendicular to the path until you reach the river. After reaching the river, walk to the left, upstream, for about 25m until you reach the plot 10 flag 2m from the river.

Surrounding Area
The site, due north, is extensively buffered by coniferous and deciduous forest owned by the Newark Watershed Association. There is housing and agricultural land 125-250m to the northeast and east, 350m to the west and 200m to the south.

Topography and Species
Clinton Brook sits near the base of the ridge that forms the border of the Watchung Valley. It is a coniferous, heavily glaciated forest, consisting of many large scattered rocks and boulders. Except for a small region on the northern upland side, the forest is a dry, upland one, with few herbaceous species. The riverside transect retains very little water due to its rocky topography. Except for where tree roots have formed stable ground, there are not many locations for vegetation to grow. The wetland region on the northern upland side holds water in a small pool and creates the only area where true wetland vegetation can grow. The dominant trees are Tsuga canadensis, Betula allegheniensis, and Acer rubrum. Lindera benzoin and Berberis thunbergii, as well as many tree seedlings, dominate the shrub layer. The common herbaceous species are Symplocarpus foetidus, Impatiens capensis, and Osmunda cinnamonea.

Clinton Brook –Upstream

View of Hemlocks in Riverside Transect

Wetland View

APPENDIX C:
VEGETATION SPECIES LIST

Appendix C: Species List

Nomenclature derived from Gleason and Cronquist, 1991, except for Eurybia divaricata, Symphyotrichum lateriflorum, and Symphyotrichum novi-belgii which were derived from USDA, 2004.

Genus	Species	Common Name
Acer	negundo	Box Elder Maple
Acer	nigrum	Black Maple
Acer	platanoides	Norway maple
Acer	rubrum	red maple
Acer	saccharum	sugar maple
Alisma	subcordatum	small water palntain
Alliaria	officinalis	garlic mustard
Alnus	incana	speckled alder
Amelanchier	canadensis	serviceberry
Amphicarpa	bracteata	hog peanut
Aralia	nudicaulis	Wild Sarsaparilla
Arisaema	atrorubens	jack-in-the-pulpit
Arisaema	triphyllum	small jack-in-the-pulpit
Asclepias	incarnata	swamp milkweed
Aster	sp1	Pohatcong Unknown Aster
Aster	sp2	Wawayanda Unknown Aster
Athyrium	filix-femina	lady fern
Barbarea	vulgaris	common wintercress
Berberis	thunbergii	Japanese barberry
Betula	allegheniensis	yellow birch
Betula	lenta	black birch
Betula	populifolia	gray birch
Bidens	cernua	Nodding Beggartick
Bidens	vulgata	Big Devils Begggartick
Boehmeria	cylindrica	false nettle
Brachyeletrum	erectum	bearded shorthusk
Cardamine	impatiens	Narrow Leaf Bitter Cress
Cardamine	pratensis	Cuckoo-Flower
Carex	bromoides	Brome-like Sedge
Carex	crinita	Fringed Sedge
Carex	debilis	White-edged Sedge
Carex	echinata	Star Sedge
Carex	gracillima	Graceful Sedge
Carex	granularis	Limestone meadow sedge
Carex	laevivaginata	smooth sheath sedge
Carex	leptonervia	nerveless woodland sedge
Carex	leptalea	Bristle-stalked sedge
Carex	lupulina	hop sedge

Carex	lurida	shallow sedge
Carex	Sp1	Highbridge Unknown Sedge
Carex	Sp2	Clinton Unknown Sedge
Carex	Sp3	Clinton Unknown Sedge
Carex	Sp4	Clinton Unknown Sedge
Carex	Sp5	Wawayanda Unknown Sedge
Carex	Sp6	Wawayanda Unknown Sedge
Carex	Sp7	Wawayanda Unknown Sedge
Carex	Sp8	Wawayanda Unknown Sedge
Carex	Sp9	Wawayanda Unknown Sedge
Carex	stricta	tussock sedge
Carex	swanii	swans sedge
Carex	tribuloides	blunt broom sedge
Carex	venusta	Dark Green Sedge
Carex	virescens	Ribbed Sedge
Carex	vulpinoidea	Fox Sedge
Carex	radiata	Eastern Star Sedge
Carex	squarrosa	Squarose Sedge
Carpinus	caroliniana	hornbeam
Carya	ovata	shagbark hickory
Celastrus	orbiculatus	Asiatic bittersweet
Celtis	occidentalis	Hackberry
Chelone	glabra	aster-like w/wt vein down leaf
Chimaphila	maculata	spotted wintergreen
Cicuta	bulbifera	bulb-bearing water hemlock
Cicuta	maculata	water hemlock or spotted cowbane
Cinna	arundinacea	Sweet Woodreed
Circaea	quadrisulcata	enchanter's nightshade
Clethra	alnifolia	sweet pepperbush
Cornus	racemosa	gray dogwood or panicled
Corylus	americana	Hazlenut/Filbert
Dactylis	glomerata	Orchard Grass
Dioscorea	villosa	wild yamroot
Dryopteris	cristata	crested wood fern
Elaeagnus	umbellata	autumn-olive
Elymus	virginicus	Virginia Wild-Rye
Equisetum	arvense	field horsetail
Euonymus	alata	Burning Bush
Eupatorium	dubium	eastern Joe-Pye weed
Eupatorium	rugosum	white snake root
Eurybia	divaricata	white wood aster
Fagus	grandifolia	American beech
Fragaria	vesca	wood strawberry
Fraxinus	americana	white ash
Fraxinus	nigra	black ash

Fraxinus	pensylvanica	green ash
Galium	asprellum	rough bedstraw
Galium	palustre	marsh bedstraw
Geranium	maculatum	wild geranium
Geum	canadensis	white avens
Geum	laciniatum	rough avens
Geum	sp1	Berkshire Unknown Avens
Glyceria	melicaria	melic mannagrass
Glyceria	striata	fowl mannagrass
Hackelia	virginiana	Virginia Stickseed
Hamamelis	virginiana	witch hazel
Hesperis	matronalis	Dame's rocket
Humulus	lupulus	common hop
Ilex	laevigata	Smooth Winterberry
Ilex	opaca	American Holly
Ilex	verticillata	common winterberry
Impatiens	capensis	jewelweed
Impatiens	pallida	Pale Jewelweed
Iris	Sp1	Berkshire Unknown Iris
Iris	Sp2	Phillipsburg Unknown Iris
Iris	versicolor	larger blue flag
Juglans	nigra	black walnut
Juncus	effusus	soft rush
Juncus	tenuis	path rush
Krigia	biflora	two-flower dandelion
Leersia	oryziodes	Rice Cutgrass
Ligustrum	vulgare	common privet
Lindera	benzoin	spice bush
Liriodendron	tulipifera	tulip poplar
Lonicera	japonica	Japanese honeysuckle
Lonicera	morrowi	morrow's honeysuckle
Ludwigia	palustris	water-purslane
Lycopus	uniflorus	Northern Bugleweed
Lycopus	virginicus	Virginia Water Horehound
Lysimachia	ciliata	fringed loosestrife
Lysimachia	nummularia	moneywort
Maianthemum	canadense	Canada mayflower
Microstegium	vimineum	Japanese winegrass
Mikania	scandens	climbing hempweed
Mitchella	repens	partridgeberry
Monotropa	uniflora	Indian pipe
Morus	alba	White Mulberry
Myosotis	laxa	Smaller Forget-me-not
Nyssa	sylvatica	black gum
Onoclea	sensibilis	sensitive fern

Osmorhiza	claytonii	clayton's sweetroot
Osmunda	cinnamomea	cinnamon fern
Osmunda	claytoniana	Interrupted Fern
Osmunda	regalis	flowering or royal fern
Ostrya	virginiana	hophornbeam
Oxalis	europaea	yellow wood sorrel or sour grass
Panax	trifolius	Dwarf Ginseng
Parthenocissus	quinquefolia	Virginia creeper
Peltandra	virginica	arrow arum
Phalaris	arundinacea	reed canary grass
Physocarpus	opulifolius	Ninebark
Pilea	pumila	clearweed
Platanthera	sp.	Wawayanda Unknown Orchid
Poa	palustris	fowl meadow grass
Podophyllum	peltatum	Mayapple
Polygonatum	pubescens	hairy soloman's seal
Polygonum	arifolium	halberd-leaved tearthumb
Polygonum	hydropiperoides	mild water pepper
Polygonum	hydropiper	water pepper
Polygonum	persicaria	lady's thumb
Polygonum	sagittatum	arrow-leaved tearthumb
Polygonum	sp1	Musconetcong Unknown Smartweed
Polystichum	acrostichoides	christmas fern
Potentilla	simplex	common cinquefoil
Prenanthes	Sp	white lettuce
Prunella	vulgaris	selfheal or heal-all
Prunus	serotina	black cherry
Quercus	alba	white oak
Quercus	bicolor	swamp white oak
Quercus	palustris	pin oak
Quercus	rubra	red oak
Ranunculus	hispidus	hispid buttercup
Ranunculus	sp1	Black River Unknown Buttercup
Rhodotypos	scandens	jetbea
Ribes	americanum	American Black Currant
Rorippa	sylvestris	creeping yellow cress
Rosa	multiflora	multiflora rose
Rosa	palustris	swamp rose
Rubus	occidentalis	black rasberry or thimbleberry
Rubus	phoenicolasius	Wineberry
Rumex	obtusifolius	Bitter Dock
Sanguisorba	canadensis	Canadian Burnet
Sassafrass	albidum	sassafrass
Saururus	cernuus	lizard's tail
Scutellaria	lateriflora	mad-dog skullcap

Sedum	telephium	witch's moneybags
Senecio	aureus	golden ragwort or squaw-weed
Sium	suave	water parsnip
Smilax	rotundifolia	greenbrier
Solidago	flexicaulis	nettle-like no stingers
Solidago	patula	rough-leaved goldenrod
Solidago	rugosa	toothed hairy alt lf/angled stem
Solidago	Sp1	Berkshire Unknown Goldenrod
Solidago	Sp2	Musconetcong Unknown Goldenrod
Solidago	canadensis	Canada goldenrod
Spiraea	alba	meadowsweet
Symphyotrichum	lateriflorum	Calico aster
Symphyotrichum	novi-belgii	New York Aster
Symplocarpus	foetidus	skunk cabbage
Thalictrum	polygamum	tall meadow rue
Thelypteris	novaboracensis	NY Fern
Thelypteris	palustris	marsh fern
Tiarella	cordifolia	heartleaf foamflower
Tilia	americana	american basswood
Tovara	virginiana	jumpseed or virginia knotweed
Toxicodendron	radicans	poison ivy
Tsuga	canadensis	hemlock
Ulmus	americana	American elm
UNKNOWN	7c	Clinton Unknown
UNKNOWN	10br	Black River Unknown
UNKNOWN	2br	Black River Unknown
UNKNOWN	2p	Pohatcong Unknown
UNKNOWN	2w	Whippany Unknown
UNKNOWN	3p	Pohatcong Unknown
UNKNOWN	4ph	Phillipsburg Unknown
UNKNOWN	6ph	Phillipsburg Unknown
Urtica	dioica	stinging nettle
Uvularia	sessilifolia	sessile-leaved bellwort
Vaccinium	corymbosum	highbush blueberry
Veratrum	viride	False Hellebore
Viburnum	acerifollium	maple-leaf viburnum
Viburnum	dentatum	arrowwood viburnum
Viburnum	lentago	nannyberry
Viburnum	prunifolium	blackhaw viburnum
Viola	conspersa	american dog violet
Viola	Sp1	Berkshire Unknown Violet
Viola	Sp2	Wawayanda Unknown Violet
Viola	Sp3	Musconetcong Unknown Violet
Viola	Sp4	Pohatcong Unknown Violet
Viola	Sp5	Whippany Unknown Violet

Viola	Sp6	High Bridge Unknown Violet
Viola	Sp7	Phillipsburg Unknown Violet
Viola	Sp8	Lamington Unknown Violet
Vitis	Sp1	High Bridge Unknown Grape
Vitis	Sp2	Phillipsburg Unknown Grape

APPENDIX D: LIST OF VEGETATION METRICS EXAMINED DURING DEVELOPMENT OF IBI

Appendix B: List of metrics examined during development of IBI

Metric List

Dominance
1A Prop. Total Herbaceous Cover in Top 3 Taxa
1B Prop. Intensive Canopy in Top 2 Tree Taxa
1C Prop. of Transect-wide Tree DBH in Top 2 Taxa

Herbaceous
1R Total Herbaceous coverage area
1U Total non-native herbaceous cover
1V Proportion of non-native herb cover to total
1W Total wetland herbaceous cover
1X Proportion of wetland herb cover to total

Shrub
1D Total Shrub Coverage Area (Entire Transect)
1E Total Non-Native Shrub Area (Transect)
1F Ratio of Non-Native:Total Shrub Area

1G Total Transect Shrub Stem Density (per 1000 m^2)
1H Total Non-Native Shrub Stem Density
1I Ratio of Non-Native:Total Shrub Stem Density

Tree
1J Total Tree DBH (per 1000 m^2)
1K Number of Trees < .2m DBH
1L Number of Trees < .25m DBH
1M Proportion of Trees < .2m DBH
1N Proportion of Trees < .25m DBH
1O Number of Trees >.25m DBH
1P Proportion of Trees >.25m DBH
1Q Average Tree DBH per site

Combinations
1S Shrub Area per Canopy Cover
1T Herbaceous Area per Canopy Cover

Taxa Specific
1Y Roseaceae Area Cover (Intensive Plot)

Importance Value
2A Total Importance Value for Non-Native Shrubs
2B Total Importance Value for Native Shrub Sp.

2C Ratio of Non-Native:Native Shrub Importance Values
2D Maximum importance values at each site

Cover
3A Proportion of Cover in Native Species (Intensive)
3B Proportion of Cover in Non-Native Species
3C Ratio of Non-Native:Native Intensive Plot Cover

3D Proportion of Cover in Wetland Species (Intensive)
3E Proportion of Cover in Upland Species
3F Ratio of Wetland:Upland Intensive Plot Cover

Richness
4A Asteraceae Sp. Richness in Intensive Plots
4B Roseaceae Sp. Richness in Intensive Plots
4JJ Graminoid Sp. Richness in Intensive Plots
4KK Graminoid Sp. Richness proportion in Intensive Plots

4C Total Genera Richness
4D Total Genera Richness Minus Non-Native Genera
4E Total Genera Minus Non-Native and Upland Genera
4F Ratio of "Extracted (4E)" Genera to Total Genera

4G Total Shrub Sp. Richness
4H Non-Native Shrub Sp. Richness
4I Ratio of Non-Native Shrub Sp. Richness to Total Shrub Sp. Richness

4J Wetland (O, FW, FW+) Herb Richness in Intensive Plots
4K Wetland Tree Richness in Intensive Plots
4L Wetland Shrub Richness in Intensive Plots

4M Richness of Woody Sp. in Intensive Plots
4N Richness of Perennial Sp. in Intensive Plots
4O Ratio of Woody Sp. Richness to Perennial Sp. Richness
4NN Ratio of Annual Species Richness to Total Species Richness in Intensive Plots

Location Specific
4P Herbaceous Richness (riverside plot only)
4Q Wetland Herb Richness (riverside)
4R Ratio of Wetland:Total Herbs (riverside)
4S Non-Native Herb Richness (riverside)
4T Ratio of Non-Native:Total Herbs (riverside)

4U Native Herb Richness (riverside)
4V Ratio of Native:Total Herbs (riverside)

4W Herbaceous Richness (upland plot only)
4X Wetland Herb Richness (upland)
4Y Ratio of Wetland:Total Herbs (upland)
4Z Non-Native Herb Richness (upland)
4AA Ratio of Non-Native:Total Herbs (upland)
4BB Native Herb Richness (upland)
4CC Ratio of Native:Total Herbs (upland)

Cumulative
4DD Cumulative Sp. Richness
4EE Cumulative Non-Native Richness
4FF Cumulative Native Richness
4GG Cumulative Herbaceous Richness
4HH Cumulative Shrub Richness
4II Cumulative Tree Richness
4LL Ratio of Cumulative Shrub Richness to Total Richness
4MM Ratio of Cumulative Tree Richness to Total Richness

Location
5A Ratio of Riverside to Upland Herbs
5B Ratio of Riverside to Upland Wetland Herbs
5C Ratio of Riverside to Upland Wetland Herb Proportion
5D Ratio of Riverside to Upland Non-Native Herbs
5E Ratio of Riverside to Upland Non-Native Herb Proportions
5F Ratio of Riverside to Upland Native Herbs

Similarity Indices
6A Simpson's Index of the Ratio of Riverside to Upland Species

6B Simpson's Index for Riverside Plots Only

6C Simpson's for all Herbaceous Sp.
6D Simpson's for all Tree Sp.
6E Simpson's for all Shrub Sp. (based on stems)
6F Simpson's for all Shrub Sp. (based on area)
6G Simpson's for Each Strata (based on Sp.)
6H Simpson's for All Strata in Plots (exc. canopy)

6I Simpson's Index for Upland Plots Only

6J Shannon-Weiner Diversity for Total Species
6K Shannon-Weiner Diversity for Shrub Area
6L Shannon-Weiner Diversity for Shrub Density
6M Shannon-Weiner Diversity for Herbaceous Area
6N Shannon-Weiner Diversity for Tree Basal Area
6O Shannon-Weiner Diversity for Tree Density

Conservation Coefficient

7A C/C, Floristic Diversity Index across sites

APPENDIX E:
NATURAL HERITAGE AND LANDSCAPE PROJECT MAPPING SPECIES DATA FOR THE TEN SITES

Appendix F: Natural Heritage Database of rare species and natural communities listed by site.

Site	Species	Federal Status	State Status*	Grank *	Srank*
Philipsburg	None				
High Bridge	Eastern box turtle		Special Concern	G5	S5B
	Northern spring salamander		Special Concern	G5T5	S3
	Jefferson salamander		Special Concern	G4	S3
	Wood turtle		T	G4	S3
Whippany	Red shouldered hawk		E/T	G5	S1B, S2N
	Wood turtle		T	G4	S3
	Bog turtle	LT	E	G3	S2
	Barred owl		T/T	G5	S3B
	Bobcat		E	G5	S3
	Eastern box turtle		Special Concern	G5	S5B
	Veery		Special Concern	G5	S3B
Pohatcong	Bog turtle	LT	E	G3	S2
	Eastern box turtle		Special Concern	G5	S5B
	Great blue heron		S/S	G5	S2B,S4N
	Northern spring salamander		Special Concern	G5T5	S3
	Wood turtle		T	G4	S3
Lamington	Barred owl		T/T	G5	S3B
	Cooper's hawk		T/T	G5	S3B, S4N
	Eastern box turtle		Special Concern	G5	S5B
	Northern spring salamander		Special Concern	G5T5	S3
	Red shouldered hawk		E/T	G5	S1B, S2N
Black River	Arogos skipper		E	G3G4T1T2	S1
	Barred owl		T/T	G5	S3B
	Eastern box turtle		Special Concern	G5	S5B
	Bog turtle	LT	E	G3	S2
	Great blue heron		S/S	G5	S2B, S4N
	Red shouldered hawk		E/T	G5	S1B, S2N
	Veery		Special Concern	G5	S3B
	Wood turtle		T	G4	S3
	Natural Heritage Priority Site				
Musconetcong	wood turtle				
	bird species of special concern				

	barred owl				
	wood turtle				
	cooper's hawk				
	Bobcat				
Wawayanda	Barred owl		T/T	G5	S3B
	Black-throated warbler		Special Concern	G5	S3B
	Canada warbler		Special Concern	G5	S3B
	Cerulean warbler		Special Concern	G4	S3B
	Golden-winged warbler		Special Concern	G4	S3B
	Cooper's hawk		T/T	G5	S3B, S4N
	Broad-winged hawk		Special Concern	G5	S3B
	Northern goshawk		E/E	G5	S1B, S4N
	Red-shouldered hawk		E/T	G5	S1B, S2N
	Least flycatcher		Special Concern	G5	S3B
	Veery		Special Concern	G5	S3B
	Winter wren		Special Concern	G5	S3B, S4N
	Solitary vireo		Special Concern	G5	S3B
	Great blue heron		S/S	G5	S2B, S4N
	Wood turtle		T	G4	S3
	Eastern box turtle		Special Concern	G4	S5B
	Marbled salamander		D	G5	S3
	Bobcat		E	G5	S3
	Timber rattlesnake		E	G4T4	S2
	Natural Heritage Priority Site				
Berkshire	Barred owl		T/T	G5	S3B
	Jefferson salamander		Special Concern	G4	S3
	Marbled salamander		D	G5	S3
	Red-shouldered hawk		E/T	G5	S1B, S3N
	Veery		Special Concern	G5	S3B
Clinton	Barred owl		T/T	G5	S3B
	Black-throated warbler		Special Concern	G5	S3B
	Canada warbler		Special Concern	G5	S3B
	Cerulean warbler		Special Concern	G4	S3B
	Golden-winged warbler		Special Concern	G4	S3B
	Cooper's hawk		T/T	G5	S3B, S4N
	Broad-winged hawk		Special Concern	G5	S3B
	Northern goshawk		E/E	G5	S1B, S4N
	Red-shouldered hawk		E/T	G5	S1B, S2N
	Least flycatcher		Special Concern	G5	S3B
	Veery		Special Concern	G5	S3B
	Winter wren		Special Concern	G5	S3B, S4N
	Solitary vireo		Special Concern	G5	S3B
	Great blue heron		S/S	G5	S2B, S4N
	Wood turtle		T	G4	S3

	Eastern box turtle		Special Concern	G4	S5B
	Marbled salamander		D	G5	S3
	Bobcat		E	G5	S3
	Timber rattlesnake		E	G4T4	S2
	Natural Heritage Priority Site				

* See attached for code definitions