MONITORING THE ECOLOGICAL INTEGRITY OF PINELANDS WETLANDS

A COMPARISON OF WETLAND LANDSCAPES, HYDROLOGY, AND STREAM COMMUNITIES IN PINELANDS WATERSHEDS DRAINING ACTIVE-CRANBERRY BOGS, ABANDONED-CRANBERRY BOGS, AND FOREST LAND

FINAL REPORT SUBMITTED TO THE
U. S. ENVIRONMENTAL PROTECTION AGENCY

FEBRUARY 2006

Cover image is from a 1995-97 color-infrared aerial photograph (National Aerial Photography Program by Photoscience for the United States Geological Survey) showing active-cranberry bogs in the Hospitality Brook watershed and forest land along the Wading River.

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THE NEW JERSEY PINELANDS COMMISSION

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FEBRUARY 2006

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Executive Summary

Cranberry agriculture, which involves clearing land to construct bogs, damming streams to establish reservoirs, channelizing stream segments, and creating extensive ditch networks, is a major land use in parts of the New Jersey Pinelands. The native cranberry was first cultivated in New Jersey in the mid-19th century. Since that time, the industry has been an important landscape-shaping factor. Harvested cranberry acreage, estimated to be about 3,100 acres in 2002, represents less than one-third of the 11,200 acres that existed at the peak of bog cultivation in 1919. Abandoned-cranberry bogs are now a common feature of the Pinelands landscape.

In 1999, the Pinelands Commission received a Wetlands Development Grant from the United States Environmental Protection Agency (USEPA) to conduct a study of the potential effect of past and present cranberry agriculture on selected landscape features, stream flow, and aquatic communities in the Mullica River and Rancocas Creek basins. The Pinelands Commission and the National Park Service provided additional funding. The results of the study are presented in this report.

Study topics, which are covered in separate sections, include stream drainage patterns and wetland-patch structure, streamflow regimes, diatoms, stream vegetation, macroinvertebrates, and fish. In each section, variations in the landscape, stream, or biological-community characteristic of interest are related to land use in the associated basins. Land uses include forest, active-cranberry bogs (cranberry), and abandoned-cranberry bogs (abandoned bogs). The diatom study also includes developed/agricultural land.

The studies include detailed statistical analyses. Because of sample-size limitations and the many comparisons made in each study, relationships that appear fairly clear may not be statistically significant. Throughout each section, we identify statistically significant results as well as apparent trends that do not meet the strict statistical criteria that were applied.

Part 1 evaluates differences in stream-drainage patterns (drainage density, sinuosity, and ditching), wetland-patch structure (size, shape, and number of wetland patches), and wetland-vegetation cover-type composition between basins draining cranberry bogs, abandoned bogs, and forest. The results of the stream-pattern analysis indicated that the effect of past and present cranberry agriculture on stream-drainage patterns was limited primarily to the occurrence of ditches. The analysis of wetland-patch structure and wetland-vegetation cover-type composition was limited to areas outside cranberry bogs where the native vegetation was removed. There was no significant difference between the three basin types in the relative number, size, shape, and composition of the vegetation-cover types found. Although the differences were not significant, the median and total number of wetland patches and the number of patches for most dominant wetland-cover types were higher in cranberry and abandoned-bog basins compared to forest basins.

Part 2 relates streamflow regimes and stream morphology to land use. Strong relationships exist between some of the flow-regime and channel-morphology metrics. Although no significant difference in these metrics was found between stream types, some general trends suggested that the relationship between channel morphology and flow regime is partly related to land use. In general, cranberry streams had steeper banks, greater bankfull depths, and lower

bankfull width/depth ratios, whereas the gentlest slopes, shallowest channels, and highest width/depth ratios were associated with abandoned-bog streams. Higher bankfull widths and bankfull cross-sectional areas characterized forest streams. Discharge and the frequency of overbank flooding were highest, and spread, which is a measure of streamflow variability, was lowest for cranberry streams compared to the other two stream types.

Part 3 describes the relationship between the composition of diatom assemblages collected from streams draining four different land uses, including forest land, abandoned bogs, cranberry bogs, and developed/upland agriculture. This study focuses on variations in diatom assemblages associated with differences in pH. Neither species richness nor genus richness was significantly different between the four land-use types. A significant difference in species composition existed between the developed/upland agriculture sites and both cranberry and forest sites. Variations in diatom composition were associated with variations in pH and specific conductance. Although species composition varied between forest, abandoned-bog, and cranberry sites, all three stream types were dominated by diatoms associated with pH values below 7, whereas species associated with a pH around 7 dominated the developed/upland agriculture samples.

Part 4 compares channel and bank plant-species composition in forest, cranberry, and abandoned-bog streams. Total channel-vegetation and bank-vegetation cover and channel and bank species richness did not differ significantly between stream types. Species presence-absence data revealed a difference in channel-vegetation and bank-vegetation composition between stream types and these differences appear to be most closely related to the type of canopy cover at a site. Whether canopy type is determined by land use is not known.

Part 5 compares macroinvertebrate assemblages in cranberry, abandoned-bog, and forest streams and evaluates variations in community composition between muck, vegetated-muck, and woody-debris habitats. Both family-level and genus-level macroinvertebrate composition differed significantly between the cranberry streams and the other two stream classes, regardless of habitat type. Overall, the effect of stream type appears to overshadow that of habitat. Many of the taxa encountered are adapted to pond, lake, and slow-moving stream habitats and low-oxygen environments. Although not conclusive, the results suggest that variations in macroinvertebrate composition may be related to a complex environmental gradient involving dissolved oxygen, temperature, specific conductance, stream width, and woody debris.

Part 6 relates differences in fish-assemblage composition, fish abundance, and fish biomass to land use. There was no difference in species richness between forest, abandoned-bog, and cranberry stream types, although variations in species richness were related to several measures of stream size, including basin area, channel width, channel depth, and discharge. An increase in species richness with stream size was primarily due to the addition of new species, rather than species replacement. Cranberry and abandoned-bog streams generally supported greater fish abundance and biomass, which was primarily due to the higher abundance of banded sunfish and eastern mudminnows at streams in these two groups. Greater fish abundance and biomass for cranberry and abandoned-bog streams may be related to the lower pH and dissolved-oxygen levels at these sites, conditions that may favor the banded sunfish and eastern mudminnow.

PART 1. A COMPARISON OF STREAM PATTERNS AND WETLAND LANDSCAPES IN PINELANDS BASINS DRAINING ACTIVE-CRANBERRY BOGS, ABANDONED-CRANBERRY BOGS, AND FOREST LAND

Nicholas A. Procopio and John F. Bunnell

Abstract

Stream and wetland-landscape patterns of watersheds that drain active-cranberry bogs, abandoned-cranberry bogs, and forest land with no history of cranberry agriculture were compared at three different levels of detail. Stream-pattern variables included drainage density, sinuosity, and the number, density, and length of ditches. Landscape-pattern measures included wetland-patch structure (the size, shape, number of wetland patches) and cover-type composition. The results of the stream-pattern analysis indicated that the effect of past and present cranberry agriculture on stream-drainage patterns was limited primarily to the occurrence of ditches. A greater number, density, median length, and total length of ditches were observed in cranberry and abandoned-bog basins compared to forest basins. Drainage density and sinuosity did not differ between basin types. The major Pinelands wetland-vegetation-cover types were represented in most of the 15 study basins. Excluding areas of active-cranberry bogs where the native vegetation was removed, there was no significant difference in the relative number, size, shape, and composition of the remaining vegetation-cover types between the three basin types. The vegetation types removed to establish bogs in the active and abandoned basins are not known. The median and total number of wetland patches and the number of patches for most dominant wetland-cover types were higher in cranberry and abandoned-bog basins compared to forest basins. Although the differences were not significant, these results suggest that past and present cranberry agriculture had some effect on overall wetland-patch structure. For cranberry basins, the greater number and percentage area for open-water and modified-wetland patches was most likely due to the reservoirs and ongoing agricultural activities associated with active cranberry farming.

Introduction

Channelizing and impounding streams can cause substantial changes in the structure and function of aquatic and wetland communities by influencing channel morphology, stream-flow regimes, water-quality characteristics, habitat diversity, food availability, and species composition (Gordon et al. 1992, Allan 1995). Impacts from these activities may extend beyond the modified stream portions and potentially affect the vegetation composition of the wetland landscape (Shankman 1996).

Cranberry agriculture involves the clearing and leveling of land to create bogs. To control the flow of water to and from bogs and to facilitate drainage, diversion canals are created, stream segments may be channelized, and extensive networks of ditches are established (Eck 1990). Dikes are constructed to establish reservoirs, partition bogs, and provide access throughout the farm. These landscape alterations are characteristic of both past and present cranberry agriculture. In New Jersey, cranberry farming is limited to the Pinelands region, where it is concentrated within several stream basins of the Mullica River and Rancocas Creek watersheds. Although cranberry agriculture can represent over one-third of the wetlands of some Pinelands stream basins, the effect of this land use on aquatic and wetland resources has not been investigated in the region.

In this study, we compare stream patterns and wetland landscapes in basins draining active-cranberry bogs, abandoned-cranberry bogs, and forest land with no history of cranberry agriculture. Specifically, we address two questions. First, do stream-drainage patterns, such as drainage density, sinuosity, and ditching, vary among the three basin types? Secondly, are there differences in the wetland-patch structure (i.e., size, shape, and number of wetland patches) and wetland-vegetation cover-type composition between the three basin types?

Methods

Study Basins

We selected 15 study basins in the Mullica River and Rancocas Creek watersheds (Figure 1, Table 1). Using methods described in Zampella et al. (2001, 2003), we delineated basin boundaries and generated land-use profiles for each basin. Land-use data were obtained from the New Jersey Department of Environmental Protection 1995/97 Land Use/Land Cover Update (2001). Land uses were classified using a modified Anderson et al. (1976) system. In this paper, we refer to the Anderson land-use classes of urban land, agriculture, and agricultural wetlands as developed land, upland agriculture, and wetland agriculture, respectively. Although wetland agriculture includes both blueberry and cranberry farming, most of the wetland agriculture in our study basins was related to cranberry.

The 15 study basins were divided equally among active-cranberry bog (cranberry), abandoned-cranberry bog (abandoned bog), and forest basin types. Cranberry basins drained lands with active-cranberry operations. Abandoned-bog basins drained lands with historical cranberry bogs that have succeeded to various wetland-habitat types. Forest basins had no apparent history of cranberry farming. In the cranberry basins, the percentage of basin area classified as wetland agriculture ranged from 5.5% to 27.5% (Table 1). The percentage of altered land (developed land and upland agriculture) was below ten percent in all study basins. The 15 study basins represented first through fourth order (Strahler 1957) streams and a range of basin sizes. There was no significant difference in basin area between the three basin types (ANOVA, $F_{2,12} = 0.059$, $p = 0.943$).

Stream-pattern and Wetland-landscape Data

Stream-pattern data. We used digital hydrography data (NJDEP 1996) for the stream-drainage pattern analysis. Using ArcInfo 8.2 software (Environmental Systems Research Institute, ESRI Inc, Redlands, CA. 1999-2002), digital United States Geologic Survey 7.5 minute topographic quadrangles, and 1995 aerial photographs (NAPP by Photoscience, Inc. for USGS), we visually identified ditches from the hydrogaphy data. In this paper, we refer to each straight-line ditch segment identified from the hydrography data as an individual ditch. We included ditches associated with active or abandoned cranberry agriculture and the remaining streams from the study basins in our analysis.

Wetland-landscape data. Freshwater-wetland data were obtained from the New Jersey Department of Environmental Protection 1995/97 Land Use/Land Cover Update (2001). The New Jersey Department of Environmental Protection classifies wetlands using the Cowardin et al. (1979) system. The Cowardin et al. (1979) classification is hierarchical. Systems, which represent the highest level in the hierarchy, include marine, estuarine, riverine, lacustrine, and palustrine wetlands complexes. Most freshwater wetlands in New Jersey are classified as palustrine. Palustrine wetlands include marshes, swamps, bogs, fens, and ponds. Class represents the next level in the palustrine hierarchy. Palustrine classes include aquatic beds, emergent wetlands, scrub-shrub wetlands, and forest wetlands. Wetlands are further classified according to subclasses, which are based on the predominant life form. Forest wetland and scrub-shrub subclasses included broad-leaved deciduous, needle-leaved deciduous, broad-leaved evergreen, needle-leaved evergreen, and dead. For example, pitch pine lowlands are classified as palustrine forest needle-leaved evergreen wetlands (PFO4). New Jersey freshwater wetlands maps also include Atlantic white cedar as a special subclass (PFO8). The dominant and subordinate subclasses are described when wetland patches are composed of more than one subclass. Lacustrine, riverine, and palustrine open-water wetlands were included under an open-water (OW) cover-type class (Table 4). Throughout this paper, the term wetlands includes water.

Data Analysis

Stream Patterns. To evaluate differences in stream patterns among cranberry, abandoned-bog, and forest basins, we compared five drainage variables between the three basin types. The variables were number of ditches, median ditch length, ditch density, drainage density, and sinuosity. The three ditch-related variables represent slightly different measures of human impact. Ditch density was calculated as the total ditch length/basin area. Drainage density and sinuosity were used to compare the remainder of the stream segments among the three basin types. Ditches were excluded from the calculation of these two variables. Drainage density was calculated as the total stream length/basin area (Gordon et al. 1992). Sinuosity, which indicates the curvature of a stream channel, is the ratio of total stream length to the straight-line length (Epstein 2002, Roper 2002). A sinuosity value of 1.0 represents a straight line and values increase with more stream curvature. We calculated a single sinuosity value for each study basin using ArcView software and the formula:

$$S_B=L_N/\Sigma(L_{S1}+L_{S2}+\ldots L_{Sn})$$

where S_B represents sinuosity for an entire study basin, L_N equals the length of all streams in the basin of interest, and $\Sigma(L_{S1}+L_{S2}+\ldots L_{Sn})$ equals the sum of the straight-line distance of each contributing stream segment in the basin.

Wetland-landscape patterns. In our analyses, we used dominant/subordinate subclass data and data that we aggregated by the dominant-cover type. For the aggregated data, adjacent wetland patches with the same dominant-cover type were combined prior to analysis using ArcView software.

To determine if there were differences in the wetland-patch structure (i.e., size, shape, and number of wetland patches) and wetland cover-type composition between cranberry, abandoned-bog, and forest basins, we compared twelve attributes at coarse, intermediate, and fine scales. Wetland-agriculture patches were excluded from all analyses to evaluate differences in the patch structure and cover-type composition of the remaining wetland landscape.

The coarse-scale variables provided a measure of basic wetland-patch structure, and included the percentage of wetlands in a basin and the number of patches, median patch size, and median patch fractal dimension for all wetland patches in a basin regardless of cover type. A fractal dimension is a measure of patch-shape complexity with values ranging from one (simple shape) to two (complex shape). To determine fractal dimension, we used ArcView software with Patch Analyst 3.1 and the formula for vector data (McGarigal and Marks 1994):

$$2 \ * \ \ln P_i \ / \ \ln A_i$$

where P is the perimeter of a patch and A is the area of a patch.

The intermediate-scale variables were the number of patches, median patch size, and median fractal dimension for the aggregated cover types in a basin. Fine-scale variables provided the most detailed information regarding the patch structure, cover-type distribution, and cover-type composition of the wetland landscapes in the basins. The fine-scale variables were Shannon’s evenness index, cover-type richness, cover-type presence-absence, percentage of the wetland area per cover type, and percentage of the wetland patches per cover type. The fine-scale analysis was performed using the dominant/subordinate subclass data. Shannon’s evenness index (J) indicates how evenly the richness and abundance of cover types are distributed throughout a study basin. Shannon’s J ranges from zero to one, with a score of one indicating an even distribution of all cover types in a basin. Shannon’s J was calculated as:

$$J = -\sum_{i=1}^{S} P_i \ * \ \ln P_i / \ln S$$

where S is the total number of cover types in a study basin (cover-type richness) and P is the proportion of each cover type in a basin (Begon et al. 1996).

Statistical Analysis. We completed separate multivariate analysis of variance (MANOVA) tests to determine if there was an overall difference among the three basin types for the five stream-pattern variables (median ditch length, number of ditches, ditch density, drainage density, and sinuosity), the four coarse-scale wetland variables (percentage of wetlands and the number of patches, median patch size, and median patch fractal dimension for all wetland patches), each of the three intermediate-scale wetland variables (the number of patches, median patch size, and median fractal dimension for the dominant wetland cover types), and two of the fine-scale wetland variables (cover-type richness and Shannon’s J). Except for cover-type richness and Shannon’s J, all MANOVAs were completed using ranked data because requirements of normality and homogeneity of variance could not be met by log transformations (Helsel and Hirsh 1992). Tied values were assigned ranks by giving each value the average of the rank each would have received had there not been a tie (Zar 1984). The analysis of variance (ANOVA) *p* values produced during the MANOVAs were corrected using the sequential Bonferroni significance-level adjustment (Rice 1989, 1990). For significant ANOVA results, the Tukey HSD multiple-comparison test was used to identify differences between basin types. Statistical analyses were completed using Statistica 5.5 (Statsoft Inc., Tulsa, OK. 1995).

We used multi-response permutation procedures (MRPP, McCune and Mefford 1999) to determine if there were differences in three fine-scale wetland variables, including cover-type presence-absence, percentage of wetland area per cover type, and percentage of wetland patches per cover type, between the three basin types. MRPP is a nonparametric procedure used to test for group differences in community data (McCune and Grace 2002). MRPP analyses were based on Euclidean distance and we report the *p* and *A* values for each analysis. The *p* value represents the probability that an observed difference is due to chance. The *A* statistic (chance-corrected within-group agreement statistic) describes homogeneity within the groups (i.e., basin types). $A = 1$ when all attributes (i.e., wetland cover types) within a group (i.e., cranberry, abandoned-bog, and forest) are identical, $A = 0$ when heterogeneity within groups equals that expected by chance, and $A < 0$ when heterogeneity within groups is greater than expected by chance. For significant MRPP results, post-hoc MRPP analyses were completed to identify differences between basin types. Post-hoc *p* values were corrected using the sequential Bonferroni adjustment (Rice 1989, 1990). MRPP analyses were completed using PC-ORD for Windows 4.27 (MjM Software, Gleneden Beach, OR 1999).

Results

Stream Patterns

A total of 1,669 ditch segments were identified in the 15 study basins. About 80% of these ditches were associated with cranberry agriculture. The other 348 ditches were related to other land uses, such as blueberry agriculture.

Results of the MANOVA on the five stream-pattern variables indicated a significant difference between basin types (MANOVA, Wilks' lambda = 0.077, $F_{10,16} = 4.17$, $p = 0.006$). Individual ANOVA results revealed a significant difference between basin types for median ditch length, number of ditches, and ditch density, but not for drainage density and sinuosity (Table 2). For median ditch length, number of ditches, and ditch density, Tukey test results indicated that forest basins were significantly different than cranberry and abandoned-bog basins (Figure 2). All three ditch-related variables were lowest in forest basins. Except for a 40 m ditch composed of two segments that extended from active-cranberry bogs in an adjacent watershed to Papoose Branch, forest basins lacked ditches. Neither of these two ditches was visible on historic (1930) or recent (2002) aerial photographs. Although there were no significant differences in the ditch-related variables between cranberry and abandoned-bog basins, these variables were generally greater in cranberry basins compared to abandoned-bog basins. The total number of ditches and total length of ditches was about three times greater in cranberry basins (991 and 114 km) compared to abandoned-bog basins (328 and 29 km).

Wetland Landscapes

For all 15 study basins, the median percentage basin area classified as wetlands (wetlands and water) outside of the footprint of the active-cranberry bogs was about one-third (Table 1). The overall median percentage of water was 1.2%. For the individual study basins, the percentage of wetlands in a basin ranged from 12.2 % in the North Branch Mount Misery Brook basin to 75.5 % in the Deep Run basin. Although the median percentage of wetlands was generally lowest for forest basins, intermediate for cranberry basins, and highest for abandoned-bog basins, there was no significant difference in the percentage of wetlands between the three basin types (MANOVA, Wilks' lambda = 0.325, $F_{8,18}$ = 1.70, $p = 0.167$).

A total of 4,165 land-use patches were present in the 15 study basins. About 45% of these were wetland patches. Excluding wetland agriculture, the total number of wetland patches for cranberry, abandoned-bog, and forest basins was 883, 589, and 377, respectively. The number of wetland patches ranged from 44 patches in the Buck Run basin to 516 patches in the Pole Bridge basin (Table 3). Although the median and total number of wetland patches was lowest in forest basins compared to cranberry and abandoned-bog basins, we found no significant difference in the number of wetland patches between the three basin types (MANOVA, Wilks' lambda = 0.325, $F_{8,18}$ = 1.70, $p = 0.167$).

Wetland-patch size varied considerably among the 15 study basins, ranging from 0.1 ha to > 250 ha. The median wetland-patch size for all 15 basins was 1.6 ha. For the individual basins, the median wetland-patch size ranged from 0.96 ha in the Middle Branch Mount Misery Brook basin to 2.5 ha in the Batsto River above Route 532 basin (Table 3). The median patch size was lowest in forest basins compared to cranberry and abandoned-bog basins, but we found no significant difference between the three basin types (MANOVA, Wilks' lambda = 0.325, $F_{8,18}$ = 1.70, $p = 0.167$).

Median wetland-patch fractal-dimension values were virtually identical for all 15 basins (Table 3). There was no significant difference in median wetland-patch fractal-dimension values between the three basin types (MANOVA, Wilks' lambda = 0.325, $F_{8,18}$ = 1.70, $p = 0.167$).

A total of 37 different wetland cover types occurred in the 15 study basins (Table 4). Forest patches, dominated by trees, represented over 50% of the wetland patches and total wetland area and scrub-shrub patches almost 30% of the wetland patches and 20% of the wetland area. The dominant wetland-forest cover type was PFO4 (pine lowland: primarily pine lowland and pine-hardwood forest patches), followed by PFO1 (hardwood: primarily hardwood and hardwood-pine forest patches), and PFO8 (cedar: primarily cedar and cedar-hardwood patches). The dominant scrub-shrub cover type was PSS1 (deciduous scrub-shrub).

Excluding wetland agriculture, aggregating the wetland data by the dominant cover type and combining adjacent patches with the same classification resulted in 12 dominant cover types and a total of 1,688 wetland patches (Table 5). Similar to the trend for the total number of wetland patches, the number of patches for most of the dominant cover types was highest for the cranberry basins, intermediate for abandoned-bog basins, and lowest for forest basins. The greatest difference in the number of patches between the three basin types was the higher number of open-water (OW) and modified-wetland (MOD) patches in cranberry basins. For all study basins, the majority of the OW patches were palustrine open-water patches (Table 4). Most of the MOD patches were wetlands in which the vegetation was disturbed. These MOD patches were unrelated to those maintained as rights-of-way by utilities (Table 4). Cranberry basins contained 70% of all open-water patches and almost 80% of all modified wetlands patches in the 15 basins. However, there was no significant difference in the number of patches for any cover type between the three basin types (MANOVA, Wilks' lambda = 0.013, $F_{20,6}$ = 2.33, p = 0.149). We also found no significant difference in median cover-type patch size (MANOVA, Wilks' lambda = 0.033, $F_{20,6}$ = 1.34, p = 0.378) or median cover-type fractal dimension (MANOVA, Wilks' lambda = 0.033, $F_{20,6}$ = 1.33, p = 0.383) between the three basin types. The E2EM and PFO3 cover types were excluded from the MANOVAs because the E2EM cover type was present only in one abandoned-bog basin and the PFO3 cover type was present in only two cranberry basins.

Of the 37 individual wetland-cover types, seven were present in all 15 study basins, including PFO4, PFO4/1, PFO8/1, PFO1, PSS1, PEM1, and PFO8 (Table 6). Combined, these seven cover types represented the majority of the wetland area and wetland patches in each of the 15 basins. In contrast, eight wetland cover types were each present in only one of the three basin types. These eight cover types were PFO8/4, PSS3, MODR, PFO1/3, PSS3/4, E2EM1, R2OW, and PFO3/1. Although several wetland cover types varied in frequency of occurrence and percentage of wetland area between the three basin types, the results of the MRPP analyses indicated that there was no significant difference in either wetland cover-type presence/absence (MRPP, A = 0.021, p = 0.129) or percentage of wetland area per cover type (MRPP, A = 0.012, p = 0.307) among the basin types. There was a significant difference in the percentage of wetland patches per cover type (MRPP, A = 0.065, p = 0.026). The post-hoc comparison indicated that the difference was between cranberry and forest basins, but this difference was not significant after applying the Bonferroni significance-level adjustment (Table 7).

Shannon's J values were similar and relatively high for all study basins (Table 8). Wetland cover-type richness ranged from 11 in the Batsto River at Route 532 basin to 27 in the Pole Bridge Branch basin (Table 3). There was no significant difference in Shannon's J or cover-type richness between the three basin types (MANOVA, Wilks' lambda = 0.781, $F_{4,22}$ = 0.723, p = 0.585).

A total of 83 wetland-agriculture patches occurred in the 15 study basins (Tables 4 and 5). Seventy-nine of these patches occurred in the five cranberry basins. The other four wetland-agriculture patches were present in abandoned-bog basins (three patches in North Branch Mount Misery Brook and one in West Branch Bass River). These four wetland-agriculture patches were abandoned. In the five cranberry basins, wetland-agriculture patches represented a relatively small percentage (7-10%) of the total number of wetland patches. In contrast, there was a wide range in the percentage of wetland area classified as wetland agriculture in these basins (Batsto River 13%, Pole Bridge Branch 15%, Tom Roberts Branch 16%, Little Hauken Run 36%, and Hospitality Brook 43%).

Discussion

The results of our study indicated that the impact of past and present cranberry agriculture on stream-drainage patterns was limited primarily to the occurrence of ditches. We observed a much greater number, density, median length, and total length of ditches in cranberry and abandoned-bog basins compared to forest basins, but ditches were limited to the portion of the basins in the immediate vicinity of the cranberry operations. Ditches are a prominent feature of any cranberry farm because the ability to control water and drain bogs is crucial (Eck 1990).

In contrast, as indicated by the sinuosity and drainage-density results, we did not find differences among the basin types for the remainder of the stream segments in the basins. The low sinuosity values for all basins (1.08 - 1.27) indicated that the Pinelands stream channels that we studied were sinuous. Although somewhat arbitrary, sinuosity values > 1.0 represent sinuous streams, values > 1.5 meandering streams, and values > 2.1 highly convoluted streams (Gordon et al. 1992, Ward and Trimble 2004).

Although not statistically significant, the generally greater number, density, median length, and total length of ditches in cranberry versus abandoned-bog basins may have been due to differences in the construction of bog complexes over time. Inspection of aerial photographs revealed that most historic cranberry bogs in abandoned basins appeared to be created from wetlands that bordered the stream channels. These bogs tended to reflect natural stream and topographic features. In contrast, bogs in cranberry basins often extended laterally well beyond the riparian corridor and into the surrounding landscape.

Although we don't know what vegetation types were removed to establish bogs in the cranberry and abandoned-bog basins, the results from our wetland-landscape analyses showed that, excluding wetland agriculture, the relative composition of the remaining vegetation cover types was similar among the three basin types. The dominance of forest cover-types in each study basin is consistent with the fact that nearly 70% of the total wetland area in the Pinelands is composed of forest cover types. Although the major Pinelands wetland-vegetation cover types were represented in most of the 15 study basins, the percentage of the total study basin wetland area that was hardwood forest was only 12% compared to the Pinelands-wide percentage of about 30%.

The lack of differences in the size, shape, number, and proportion of wetland patches at any of the three scales revealed that the wetland-patch structure outside the footprint of the cranberry bogs was similar among the basin types. The relatively high and comparable Shannon's J values indicated that, regardless of cover type, the proportion of patches was distributed in a similar manner among the 15 basins. The results of the fractal-dimension analyses showed that basic wetland-patch shape and the patch shape of the dominant cover types did not vary significantly between basin types.

Although not statistically significant, the higher median and total number of wetland patches regardless of cover type and higher number of patches for most dominant cover types for cranberry and abandoned-bog basins compared to forest basins suggested that past and present cranberry agriculture had some effect on overall wetland-patch structure. For cranberry basins, the much greater number and percentage area for open-water and modified-wetland patches indicated that these cover types were more typical of basins with active cranberry agriculture. Reservoirs are typically created to store water for irrigation, harvest flooding, frost protection, and winter flooding (Eck 1990). Since cranberry basins have ongoing agricultural operations that may include activities such as bog construction and vegetation maintenance, it makes sense that these basins also contained more modified-wetland patches.

In conclusion, the impact of past and present cranberry farming on basin-wide stream-drainage patterns and wetland-landscape structure and cover-type composition appeared to be limited primarily to the footprint of the land use. Land was cleared to establish bogs and localized networks of ditches were created for water control. Our study was primarily a landscape assessment of these wetland attributes using aerial photography and GIS data. More detailed, field-based research is needed to determine whether cranberry agriculture has an effect on stream-flow regimes and the structure and function of aquatic communities in the Pinelands.

Acknowledgments

Funding for this study was provided by the U. S. Environmental Protection Agency (State Wetlands Grant Program, Grant No. CD-99298001-1) and the Pinelands Commission.

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Table 1. Land-use profiles for cranberry, abandoned-bog, and forest basins in the Rancocas Creek and Mullica River watersheds. Land-use values are expressed as a percentage of basin area. Land-use data source is New Jersey Department of Environmental Protection 1995/97 Land Use/Land Cover Update (2001). Stream order is based on the Strahler (1957) system.

Basin Type Study Basin	Stream Order	Basin Area (km^2)	Upland Forest	Barren Land	Developed Land	Upland Agriculture	Wetlands (and Water)	Wetland Agriculture
Cranberry Basins								
Batsto River above Route 532	3	5.5	48.0	0.1	1.9	1.9	41.8	6.4
Hospitality Brook	1	6.1	29.5	2.2	1.3	5.4	34.1	27.5
Tom Roberts Branch	3	11.2	55.2	0.2	0.6	1.8	35.5	6.7
Little Hauken Run	1	17.1	36.2	0.3	0.5	1.7	38.4	23.0
Pole Bridge Branch	4	64.0	44.6	0.7	8.6	1.6	38.9	5.5
Median	3	11.2	44.6	0.3	1.3	1.8	38.4	6.7
Abandoned-bog Basins								
Shane Branch	2	6.0	44.7	0.0	0.3	0.5	54.5	0.0
Deep Run	3	6.5	24.4	0.0	0.0	0.1	75.5	0.0
West Branch Bass River	3	17.1	82.7	0.0	0.5	0.2	16.0	0.5
Tulpehocken Creek	3	22.0	56.9	0.0	0.0	0.0	43.1	0.0
North Branch Mount Misery Brook	3	33.6	84.4	0.3	1.6	1.5	12.2	0.1
Median	3	17.1	56.9	0.0	0.3	0.2	43.1	0.0
Forest Basins								
Middle Branch Mount Misery Brook	1	7.5	85.3	0.0	0.0	0.0	14.7	0.0
Buck Run	2	7.8	86.3	0.0	0.0	0.0	13.7	0.0
Skit Branch	3	13.2	80.0	0.0	0.1	0.2	19.7	0.0
Papoose Branch	3	13.4	83.2	0.1	0.0	0.0	16.7	0.0
East Branch Bass River	3	21.4	82.1	0.2	2.0	0.0	15.7	0.0
Median	3	13.3	83.2	0.0	0.0	0.0	15.7	0.0
All Basins Median	3	13.2	56.9	0.1	0.5	0.2	34.1	0.0

Table 2. Results for stream-pattern analysis between cranberry, abandoned-bog, and forest basins. Initial and Bonferroni adjusted *p* values shown for comparison. Bolded results indicate ANOVAs significant after Bonferroni adjustment.

Stream-pattern Attribute	F	Initial *p*	Bonferroni Adjusted *p*
Number of ditches	17.4	0.0003	**0.0125**
Median ditch length	17.4	0.0003	**0.0167**
Ditch density	22.2	0.0001	**0.0100**
Drainage density	0.1	0.9415	0.0500
Sinuosity	0.4	0.7090	0.0250

Table 3. Coarse-scale wetland-patch attributes for cranberry, abandoned-bog, and forest basins in the Rancocas Creek and Mullica River watersheds.

Basin Type Study Basin	Number of Wetland Patches	Median Wetland-patch Size (ha)	Median Wetland-patch Fractal Dimension
Cranberry Basins			
Batsto River above Route 532	67	2.51	1.31
Hospitality Brook	84	0.97	1.32
Tom Roberts Branch	93	1.71	1.32
Little Hauken Run	123	1.74	1.31
Pole Bridge Branch	516	1.67	1.31
Median	93	1.71	1.31
Abandoned-bog Basins			
Shane Branch	86	1.82	1.31
Deep Run	88	1.88	1.33
West Branch Bass River	106	1.19	1.32
North Branch Mount Misery Brook	140	1.29	1.32
Tulpehocken Creek	169	1.90	1.33
Median	106	1.82	1.32
Forest Basins			
Buck Run	44	1.19	1.33
Middle Branch Mount Misery Brook	50	0.96	1.29
Skit Branch	58	2.26	1.33
Papoose Branch	81	1.52	1.33
East Branch Bass River	144	1.17	1.33
Median	58	1.19	1.33

Table 4. Wetland cover-type classes present in 15 Mullica River and Rancocas Creek study basins. Dominant and sub-dominant cover types are separated by a slash. Bolded rows represent the major wetland classes and the sum of the patch values within a particular wetland class. Data are from 1995/1997 NJDEP Land use/Land cover update (2001). Wetlands were classified according to Cowardin et al. (1979).

Wetland Type Code	Wetland Type Description	Number of Wetland Patches	Percentage of Wetland Patches	Percentage of Wetland Area
PFO1	**Hardwood Forest (Palustrine Broad Leaved Deciduous Forest)**	**271**	**14.0**	**12.0**
PFO1	Palustrine Broad Leaved Deciduous Forest	153	7.9	5.9
PFO1/3	Palustrine Broad Leaved Deciduous/Evergreen Forest	4	0.2	0.3
PFO1/4	Palustrine Broad Leaved Deciduous/Needle Leaved Evergreen Forest	74	3.8	4.2
PFO1/8	Palustrine Broad Leaved Deciduous/White Cedar Forest	33	1.7	1.0
PFO1/PSS1	Palustrine Broad Leaved Deciduous/Scrub-Shrub Forest	7	0.4	0.5
PFO3	**Palustrine Broad Leaved Evergreen Forest**	**2**	**0.1**	**0.1**
PFO4	**Pine lowland Forest (Palustrine Needle Leaved Evergreen Forest)**	**554**	**28.6**	**31.2**
PFO4	Palustrine Needle Leaved Evergreen Forest	352	18.2	18.2
PFO4/1	Palustrine Needle Leaved Evergreen/Broad Leaved Deciduous Forest	196	10.1	12.6
PFO4/3	Palustrine Needle Leaved Evergreen/Broad Leaved Evergreen Forest	3	0.2	0.1
PFO4/8	Palustrine Needle Leaved Evergreen/White Cedar Forest	3	0.2	0.2
PFO8	**Cedar Forest (Palustrine White Cedar Forest)**	**194**	**10.0**	**13.8**
PFO8	Palustrine White Cedar Forest	116	6.0	5.3
PFO8/1	Palustrine White Cedar/Broad Leaved Deciduous Forest	76	3.9	8.4
PFO8/4	Palustrine White Cedar/Needle Leaved Evergreen Forest	2	0.1	0.1
PSS1	**Deciduous Scrub-shrub (Palustrine Broad Leaved Deciduous Scrub-shrub)**	**378**	**19.5**	**12.3**
PSS1	Palustrine Broad Leaved Deciduous Scrub-Shrub	276	14.3	7.0
PSS1/3	Palustrine Broad Leaved Deciduous/Broad Leaved Evergreen Scrub-Shrub	8	0.4	0.4
PSS1/4	Palustrine Broad Leaved Deciduous/Needle Leaved Evergreen Scrub-Shrub	54	2.8	2.1
PSS1/8	Palustrine Broad Leaved Deciduous/White Cedar Scrub-Shrub	24	1.2	0.8
PSS1/PFO1	Palustrine Broad Leaved Deciduous Scrub-Shrub/Broad Leaved Deciduous Forest	12	0.6	1.9
PSS1/PEM1	Palustrine Broad Leaved Deciduous Scrub-Shrub/Emergent (Persistent)	4	0.2	0.1
PSS3	**Evergreen Scrub-shrub (Palustrine Broad Leaved Evergreen Scrub-shrub)**	**13**	**0.7**	**0.4**
PSS3	Palustrine Broad Leaved Evergreen Scrub-Shrub	7	0.4	0.2
PSS3/1	Palustrine Broad Leaved Evergreen/Deciduous Scrub-Shrub	5	0.3	0.2
PSS3/4	Palustrine Broad Leaved Evergreen/Needle Leaved Evergreen Scrub-Shrub	1	0.1	0.0
PSS4	**Pine lowland Scrub-shrub (Palustrine Needle Leaved Evergreen Scrub-shrub)**	**98**	**5.1**	**4.2**
PSS4	Palustrine Needle Leaved Evergreen Scrub-Shrub	44	2.3	1.1
PSS4/1	Palustrine Needle Leaved Evergreen/Broad Leaved Deciduous Scrub-Shrub	50	2.6	2.5
PSS4/PFO4	Palustrine Needle Leaved Evergreen Scrub-Shrub/Needle Leaved Evergreen Forest	4	0.2	0.5
PSS8	**Cedar Scrub-shrub (Palustrine White Cedar Scrub-shrub)**	**34**	**1.8**	**1.5**
PSS8	Palustrine White Cedar Scrub-Shrub	9	0.5	0.1
PSS8/1	Palustrine White Cedar/Broad Leaved Deciduous Scrub-Shrub	25	1.3	1.4
PEM1	**Palustrine Emergent (Persistent)**	**159**	**8.2**	**5.9**
PEM1	Palustrine Emergent (Persistent)	130	6.7	3.7
PEM1/PSS1	Palustrine Emergent (Persistent)/Broad Leaved Deciduous Scrub-Shrub	29	1.5	2.2
E2EM	**Estuarine Intertidal Emergent**	**1**	**0.1**	**0.0**
OW	**Open Water**	**121**	**6.3**	**5.8**
L2OW	Lacustrine Littoral Open Water	13	0.7	2.7
POW	Palustrine Open Water	99	5.1	3.0
R2OW	Riverine Lower Perennial Open Water	1	0.1	0.0
R3OW	Riverine Upper Perennial Open Water	8	0.4	0.1
MODAg	**Wetland Agriculture (Modified Agricultural Wetlands)**	**85**	**4.8**	**12.7**
MOD	**Other Modified Wetlands**	**24**	**1.2**	**0.2**
MODD	Disturbed areas (surface/vegetation disturbed)	20	1.0	0.2
MODR	Right-of-ways (areas maintained by utilities)	4	0.2	0.0

Table 5. Intermediate-scale patch attributes for the dominant wetland-cover types in cranberry, abandoned-bog, and forest basins in the Rancocas Creek and Mullica River watersheds. The E2EM, PFO3, and MODAg (wetland agriculture) cover types were not included in the analysis. Refer to Table 4 for explanation of wetland-cover types.

Wetland-cover Type	Frequency of Occurrence (%)			Total Number of Patches			Median Cover-type Patch Size (ha)			Median Cover-type Fractal Dimension		
	Cranberry	Abandoned	Forest	Cranberry	Abandoned	Forest	Cranberry	Abandoned	Forest	Cranberry	Abandoned	Forest
PFO4	100	100	100	252	141	101	1.9	2.2	1.4	1.33	1.31	1.34
PSS1	100	100	100	146	103	92	1.7	1.1	1.0	1.31	1.32	1.33
PFO1	100	100	100	108	80	38	2.6	1.7	1.5	1.33	1.33	1.32
OW	100	100	60	83	31	5	1.9	2.6	0.7	1.30	1.30	1.29
PFO8	100	100	100	81	63	43	1.7	1.6	2.5	1.30	1.33	1.33
PEM1	100	100	100	58	65	33	1.2	1.3	0.9	1.31	1.32	1.34
PSS4	80	100	100	42	33	20	1.3	3.1	1.5	1.32	1.30	1.30
MOD	60	40	20	19	2	3	0.3	0.3	0.2	1.32	1.36	1.37
PSS8	60	80	60	16	11	5	1.5	3.4	2.7	1.32	1.33	1.30
PSS3	20	20	40	1	2	8	0.5	1.2	1.8	1.31	1.33	1.32
E2EM	-	20	-	-	1	-	-	0.2	-	-	1.35	-
PFO3	20	-	-	2	-	-	4.0	-	-	1.33	-	-
MODAg	100	40	-	79	4	-	3.0	5.0	-	1.28	1.27	-

Table 6. Fine-scale patch attributes for wetland-cover types in cranberry, abandoned-bog, and forest basins in the Rancocas Creek and Mullica River watersheds. Refer to Table 4 for explanation of wetland-cover types. MODAg was not included in the analyses.

Wetland-cover	Frequency of Occurrence (%)			Median Percentage of Wetland Area			Median Percentage of Wetland Patches		
Type	Cranberry	Abandoned	Forest	Cranberry	Abandoned	Forest	Cranberry	Abandoned	Forest
PFO4	100	100	100	25.7	19.3	29.0	19.0	20.1	20.8
PFO4/1	100	100	100	13.8	19.9	9.0	12.9	8.6	5.2
PFO8/1	100	100	100	7.7	4.2	8.8	7.1	2.3	4.0
PFO1	100	100	100	7.6	4.9	3.7	8.9	7.1	4.9
PSS1	100	100	100	7.2	7.5	8.6	10.8	12.5	21.5
PEM1	100	100	100	5.3	7.8	3.5	7.1	8.9	6.2
PFO8	100	100	100	1.6	6.9	5.7	3.6	7.0	7.4
POW	100	100	40	7.7	2.5	0.8	8.6	4.3	0.0
PSS1/8	100	60	20	1.5	2.0	0.4	1.9	0.6	0.0
PSS1/4	80	100	100	1.2	2.7	4.7	1.5	3.8	2.0
PFO1/4	80	100	80	1.3	6.6	2.9	2.4	4.7	3.4
PEM1/PSS1	80	80	60	0.6	4.7	2.4	1.6	1.2	1.4
PSS4	60	80	100	0.6	1.8	2.0	1.2	1.8	3.4
PSS4/1	60	80	80	1.9	2.7	3.4	1.6	3.4	2.5
PFO1/8	60	80	60	0.8	1.1	1.5	1.1	2.3	2.0
MODD	60	20	-	0.1	0.0	-	1.2	0.0	0.0
L2OW	60	20	20	4.7	7.0	6.4	1.0	0.0	0.0
PSS8/1	40	80	60	1.2	2.5	1.2	0.0	1.2	0.7
PSS1/PFO1	40	60	20	4.2	1.4	2.1	0.0	0.6	0.0
PSS8	40	40	20	0.3	0.6	0.2	0.0	0.0	0.0
R3OW	40	40	20	0.6	0.2	0.3	0.0	0.0	0.0
PSS1/3	20	40	40	0.2	0.1	4.5	0.0	0.0	0.0
PSS4/PFO4	-	80	-	-	2.5	-	-	0.7	-
PFO1/PSS1	20	40	20	1.1	0.4	1.7	0.0	0.0	0.0
PSS1/PEM1	-	60	-	-	0.7	-	-	0.9	-
PSS3/1	20	-	40	0.0	-	3.0	0.0	-	0.0
PFO4/3	-	-	40	-	-	4.3	-	-	0.0
PFO4/8	40	-	-	2.9	-	-	0.0	-	-
PFO8/4	-	20	20	-	0.4	2.8	-	0.0	0.0
PSS3	-	20	20	-	0.3	5.4	-	0.0	0.0
MODR	-	20	20	-	0.2	0.2	-	0.0	0.0
PFO1/3	20	-	20	0.8	-	2.7	0.0	-	0.0
PSS3/4	-	-	20	-	-	1.2	-	-	0.0
E2EM1	-	20	-	-	0.1	-	-	0.0	-
R2OW	-	20	-	-	0.1	-	-	0.0	-
PFO3/1	20	-	-	0.3	-	-	0.0	-	-
MODAg	100	40	-	15.8	0.0	-	8.7	0.0	-

Table 7. MRPP results for percentage of wetland patches per cover type for cranberry, abandoned-bog, and forest basins. Bolded results were significant before Bonferroni significance-level adjustment.

Comparisons			A	Initial *p* value	Bonferroni *p* value
All basin types			0.065	**0.026**	-
Cranberry	vs	Forest	0.081	**0.027**	0.017
Cranberry	vs	Abandoned-bog	0.041	0.093	0.025
Abandoned-bog	vs	Forest	0.027	0.171	0.050

Table 8. Fine-scale wetland-patch attributes for cranberry, abandoned-bog, and forest basins in the Rancocas Creek and Mullica River watersheds.

Basin Type Study Basin	Wetland Cover-type Richness	Shannon's Evenness (J)
Cranberry Basins		
Batsto River above Route 532	11	0.84
Hospitality Brook	16	0.86
Tom Roberts Branch	16	0.84
Little Hauken Run	17	0.87
Pole Bridge Branch	27	0.83
Median	16	0.84
Abandoned-bog Basins		
Shane Branch	20	0.89
Deep Run	16	0.85
West Branch Bass River	20	0.86
North Branch Mount Misery Brook	18	0.83
Tulpehocken Creek	24	0.85
Median	20	0.85
Forest Basins		
Buck Run	14	0.87
Middle Branch Mount Misery Brook	12	0.83
Skit Branch	13	0.79
Papoose Branch	22	0.87
East Branch Bass River	20	0.81
Median	14	0.83

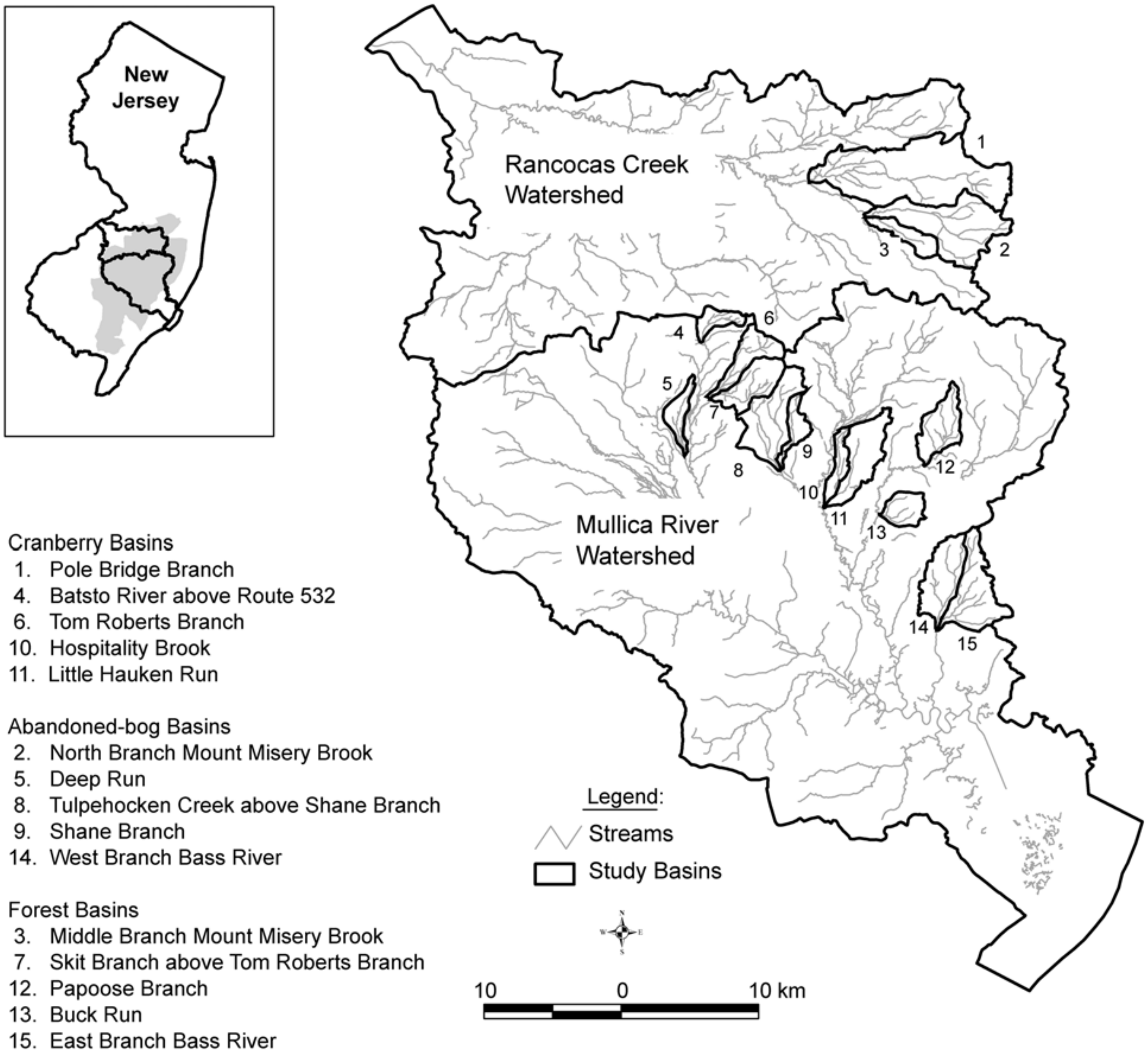

Figure 1. Location of 15 study basins in the Rancocas Creek and Mullica River watersheds in the New Jersey Pinelands (shaded region of inset).

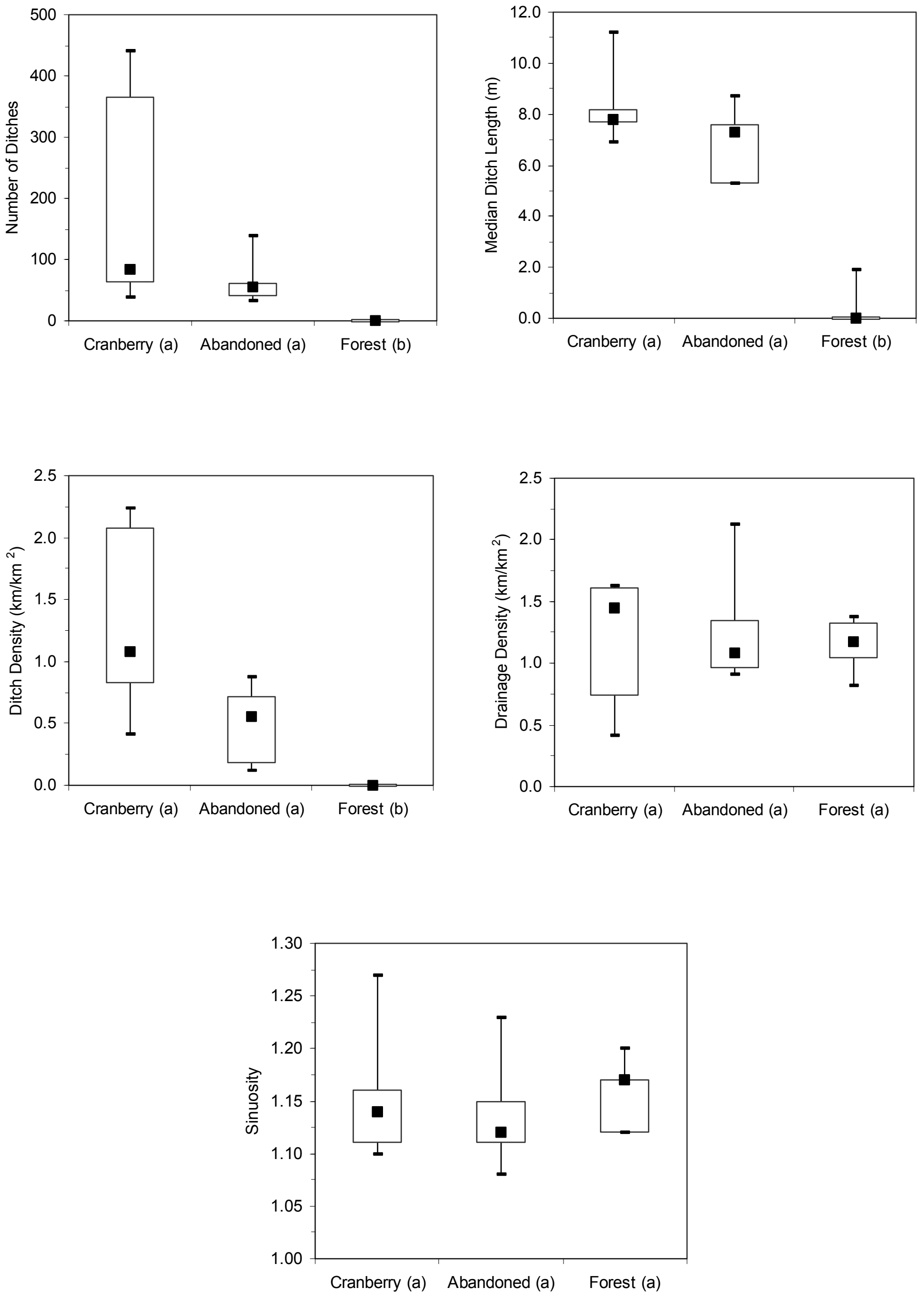

Figure 2. Box plots showing the 10th, 25th, 50th (median), 75th and 90th percentiles for five stream-pattern variables in cranberry, abandoned-bog, and forest basins. Basin types with the same letters were not significantly different based on Tukey HSD.

PART 2. HYDROLOGIC AND MORPHOLOGIC VARIABILITY OF STREAMS DRAINING ACTIVE-CRANBERRY BOGS, ABANDONED-CRANBERRY BOGS, AND FOREST LAND

Nicholas A. Procopio

Abstract

In the New Jersey Pinelands, the creation of reservoirs and modification of stream channels are common practices used to facilitate the efficient production of cranberries. The potential impacts to hydrologic and geomorphic aspects of streamflow and channel structure have not been adequately addressed. In this study, the streamflow regimes of twelve sites and the stream-channel morphologies of eleven sites were compared for basins with upstream active-cranberry agriculture, upstream abandoned-cranberry bogs, and basins with no apparent history of agriculture. Measures of flow regime included median basin-area normalized discharge values, three measures of streamflow variability (interquartile range, spread, and a modified Richards-Baker Flashiness Index), and the frequency of overbank flooding. Measures of stream-channel morphology included bank slope, bankfull width, bankfull depth, bankfull width/depth ratio, and bankfull area. Strong relationships existed between some of the flow-regime and channel-morphology metrics. Although no significant difference in these metrics was found between stream types, some general trends suggested that the relationship between channel morphology and flow regime might be partly related to land use. In general, cranberry streams had steeper banks, greater bankfull depths, and lower bankfull width/depth ratios, whereas the gentlest slopes, shallowest channels, and highest width/depth ratios were associated with abandoned-bog streams. Higher values of bankfull-width and bankfull cross-sectional area characterized forest streams. Discharge and the frequency of overbank flooding were highest and spread was lowest for cranberry streams compared to the other two stream types.

Introduction

The cranberry is a major agricultural resource in the New Jersey Pinelands. To facilitate the cultivation and harvest of cranberries, large reservoirs are often created upstream of the bogs by damming stream segments (Eck 1990). The reservoirs accommodate the large amount of water needed for seasonal harvests, either in late summer or autumn, for winter and spring flooding to prevent against frost, and for irrigation and pest control. More commonly, spray irrigation technology is utilized for irrigation during the growing season and to prevent against frost damage. Ditching and channelizing stream channels is another common practice in modern and historic cranberry cultivation (Eck 1990, Procopio and Bunnell 2006). Ditches accommodate the need to move water from bog to bog during harvests or flooding events. Channelization allows for a quick and efficient way to draw water for irrigating, harvesting, or flooding and to rapidly remove water off bogs after flooding events (Eck 1990).

Upstream reservoirs and stream channelization may affect the natural flow dynamics of streams. Reservoirs can decrease peak flows and reduce variability in unaltered stream reaches (Gordon et al. 1992, Allan 1995, Whiting 2002). Diversions of stream flow, if large enough, can alter morphologic characteristics of the stream channel by decreasing stream width and depth (Brinson et al. 1981, Whiting 2002). Channelization can lead to reduction of water, sediments and nutrients to the flood plain as well as increase channel width, channel depth, and gradient while removing any natural meander pattern in the channelized section and increase peak flows downstream (Brinson et al. 1981, Gordon et al. 1992). These alterations, along with riparian vegetation removal associated with channelization, have the potential to impact aquatic communities (Keller 1978, Vannote et al. 1980, Poff and Ward 1989, Gordon et al. 1992, Poff and Allan 1995, Richter et al. 1996, Poff et al. 1997, Bunn and Arthington 2002, Olden and Poff 2003).

The hydrologic and geomorphic variability imposed by stream-channel alterations and water manipulation in drainages containing large areas of cranberry bogs, either active or abandoned, have not been adequately addressed in the Pinelands. I studied streams that drain three land uses, including those that drain active-cranberry agriculture, abandoned-cranberry agriculture, and forest basins with no apparent history of agriculture. I addressed two major questions. First, is stream discharge and discharge variability related to past or present land uses? Secondly, are there differences in stream morphology between land uses?

Methods

This study was limited to twelve acid-water streams in the Mullica River and Rancocas Creek basins in the outer-coastal plain province of southern New Jersey (Figure 1). The twelve study basins were located in the Wading River, Oswego River, Bass River, and Batsto River systems in the Mullica River Basin and Greenwood Branch in the Rancocas Creek basin. The study sites were located in basins with upstream active-cranberry agriculture (cranberry sites), upstream abandoned-cranberry agriculture (abandoned-bog sites), and forested basins with no apparent history of cranberry agriculture (forest sites). Drainage basin areas range from 4.6 to 56.7 square kilometers. The selected study basins contain minimal altered land (developed land and upland agriculture) (Figure 1, Table 1). The data set used to create the land-use profiles uses a modified Anderson et al. (1976) system. In this paper, I refer to the Anderson-type land-use classes of urban land, agriculture, and agricultural wetlands as developed land, upland agriculture, and wetland agriculture, respectively. Collectively, developed land and upland agriculture are referred to as altered land. Wetland agriculture includes cranberry bogs and blueberry fields. Most wetland agriculture in the study basins is cranberry agriculture.

A network of partial-record stream-discharge stations, consisting of staff gages and high-flow crest gages, was established to gather discharge data at eleven of the twelve monitoring sites. High-flow crest gages were used to determine the maximum staff reading between site visits and the number of overbank flooding events. Average-daily discharge data for an additional site (McDonalds Branch) were obtained from the United States Geological Survey (USGS). All staff gages and high-flow crest gages were measured weekly to monthly on the same day between October 2000 and September 2003. Based on USGS convention, I refer to the three separate October to September monitoring periods as individual water years. Thirty-four readings were made in the first water year (October 2000 - September 2001), nineteen readings were made in the second water year (2001 – 2002), and thirteen readings were made in the third water year (2002 – 2003). Dates when a stream was dry were recorded as having zero flow. Bankfull discharge values were used for dates when overbank flooding occurred. After removing dates when a stream was frozen, the period of record included a total of 63 to 66 staff gage and high-flow crest gage measurements for each of the twelve study sites.

Instantaneous discharge measurements were made under a variety of flow conditions for the eleven partial-record stream-discharge stations during the study period. Instantaneous discharge measurements were made using a Pygmy meter, a Price AA meter, or a portable Parshall flume depending on in-stream flow conditions (Carter and Davidian 1968, Rantz 1982).

Measured discharge values and staff-gage readings were used to create rating curves for each study site. Rating curves were developed using log transformed staff-gage and stream-discharge measurements and least square regression. The rating curves were used to estimate stream discharge for each staff-gage measurement and high-flow crest-gage measurement that did not exceed bankfull stage. This partial-record dataset was used to calculate median, 25th and 75th percentiles, and three discharge-variability metrics, including interquartile range, spread, and a modified Richards-Baker Flashiness Index (modified R-B Index, Baker et al. 2004).

The 25th and 75th percentiles were used to characterize low and high flows, respectively. The frequency of overbank flooding was calculated as the percentage of occurrences when the high-flow crest gage reading exceeded the bankfull stage between observation dates. Spread (interquartile range divided by the median) is a nonparametric analog to the coefficient of variation and is independent of basin size (Richards 1989, Doupe and Pettit 2002). The Richards-Baker Flashiness Index measures the absolute change in daily discharge values relative to the total discharge using the following equation (Baker et al. 2004):

$$\text{Richards-Baker Flashiness Index} = \sum_{i=1}^{n} \left| q_i - q_{i-1} \right| / \sum_{i=1}^{n} q_i$$

where q_i is the daily discharge value. The index is typically calculated per annum and then averaged to provide an average annual flashiness value. A larger value indicates a more variable flow regime. For this study, the index was modified to accommodate the partial-record data set. Rather than summing the difference of day-to-day fluctuations in streamflow, the differences between sample-to-sample streamflows were summed. Additionally, the index was computed over the entire study period, rather than per year, since the number and frequency of measurements varied from year to year.

Except for McDonalds Branch, the morphology of stream channels associated with each discharge-monitoring site was measured. Procedures followed recommendations by Gordon et al. (1992), Wharton (1995), and Davis et al. (2001). Cross-sectional transects were established twenty-five meters apart and varied in number from three to twenty-three transects per site. Bankfull-depth measurements were made at 10-centimeter intervals across each transect. Bank slope was determined from each detailed cross-sectional profile and bankfull area was calculated by summing the area (width x depth) of each 10-centimeter section. Average bank slope, average bankfull depth, bankfull width, width/depth ratio, and bankfull area were each averaged for all transects at a site.

Data Analysis

Ten variables, including median discharge, the frequency of overbank flooding, three discharge-variability measures (interquartile range, spread, and modified R-B index), and five stream morphology measures (bank slope, bankfull width, bankfull depth, bankfull area, and width/depth ratio), were compared between the three stream types. Median discharge and frequency of overbank flooding were each analyzed using Analysis of Variance (ANOVA) on ranked data. The three discharge-variability measures and the five stream morphology measures were analyzed using multivariate analysis of variance (MANOVA) on ranked data. Discharge measurements were normalized by drainage basin area to allow for comparison between sites. Spearman rank correlation was used to test the intercorrelation of each of the ten variables and study-basin characteristics, including basin area, stream order, percentage wetland agriculture, and percentage altered land. All MANOVAs and ANOVAs were completed using ranked data because requirements of normality and homogeneity of variance could not be met by log transformations (Helsel and Hirsch 1992).

Results and Discussion

Stream Discharge

Streamflow varied greatly among the 12 monitoring sites. Over the three-year study period, the median basin-area normalized flow for the 12 sites ranged from 0.001 cubic meters per second/square kilometer (cms/km^2) at North Branch Mount Misery Brook to 0.047 cms/km^2 at Hospitality Brook (Table 2). Based on precipitation data from a nearby location (Office of the State Climatologist of New Jersey 2006), the October 2001 to September 2002 water year was the driest of the three periods and the October 2002 to September 2003 water year was the wettest (Table 3). Median annual discharge was lowest at all twelve sites during the second water year. Except for two monitoring sites, median annual discharge was greatest during the third water year. The two exceptions were Tom Roberts Branch, a cranberry stream, and Papoose Branch, a forest stream.

Overall, median discharge was greatest in cranberry streams and lowest in abandoned-bog streams (Figure 2, Table 2), but the difference between stream types was not significant (ANOVA, $F_{2,9} = 0.930$, $p = 0.429$). The two sites with the highest median discharge were Hospitality Brook and Little Hauken Run. Both are first order cranberry streams.

Streamflow Variability

The interquartile range of all the monitoring sites ranged from 0.001 cms/km^2 at Pole Bridge Branch to a maximum of 0.033 cms/km^2 at Hospitality Brook. The median value for all twelve monitoring sites was 0.010 cms/km^2. Median interquartile range was greatest in cranberry streams and lowest in forest streams, but the difference between them was minimal (Table 2).

Spread, which is a measure of streamflow variability, was greatest during the first year for a majority of the study sites. The two sites with the highest spread values, North Branch Mount Misery Brook, an abandoned-bog site, and Middle Branch Mount Misery Brook, a forest site, are neighboring streams in the eastern portion of the Rancocas Creek Basin (Figure 1). Middle Branch Mount Misery Brook was intermittent, a feature that can produce high spread values. Cranberry sites displayed the lowest spread values, indicating the least variable stream-flow conditions over the study period (Figure 3, Table 2). This may be due to the presence of upstream reservoirs, which can reduce streamflow variability downstream (Gordon et al 1992, Allan 1995, Whiting 2002).

The modified Richards-Baker index ranged from 0.18 at Papoose Branch, a forest site, to a maximum of 0.59 at Tulpehocken Creek, a basin with extensive abandoned-bog complexes. The median R-B index value of all twelve sites was 0.38. Median R-B index values were highest for abandoned-bog sites, intermediate for cranberry sites, and lowest for forest sites (Figure 4, Table 2). This indicates that streamflow between observation dates was least variable for forest sites. Although some general differences in streamflow variability were observed, the results of the MANOVA indicated no significant overall difference in interquartile range, spread, or the modified R-B index between stream types (MANOVA, Wilks' lambda = 0.408, $F_{6,14} = 1.32$, $p = 0.312$).

There were strong correlations among several of the variables (Tables 4, 5). All three variability metrics (interquartile range, spread, and modified R-B index) were correlated to median streamflow. The interquartile range was positively correlated with median discharge, showing that, as median discharge at a site increased, so did the relative range of low and high flows. The spread and modified R-B index were both negatively correlated with the median discharge indicating that streams with higher median flows are less variable. Both spread and the modified R-B index showed a negative correlation with bankfull depth and bankfull area. Additionally, spread was negatively correlated with the bank slope and positively correlated with width to depth ratio. Study streams with deeper channels, a larger cross-sectional area, and steeper banks tend to be less variable. The interquartile range was not correlated with any of the stream morphology measures. Due to the large number of comparisons, conclusions regarding the statistical significance of these associations cannot be made.

Flooding Frequency

Flooding occurred within each stream type (Figure 5). Although no significant difference in flooding frequency was found between stream types (ANOVA, $F_{2,8} = 1.568$, $p = 0.266$), over the entire study period, flooding occurred most frequently at cranberry sites and least frequently at forest sites (Figure 5). For each water year, average flooding frequency was greatest in cranberry sites and lowest in forest sites. The highest overall frequency of overbank flooding occurred at two cranberry sites, Hospitality Brook (34% of observation dates) and Little Hauken Run (62% of observation dates). The higher rates of flooding at the cranberry sites are most likely due to the need to drain water off the bogs rapidly and periodic water releases related to harvesting, frost protection and pest control (Eck 1990).

As mentioned previously, precipitation was highest in the third water year and lowest in the second water year (Table 3). The highest average flooding frequencies for all three basin types occurred during the third water year, coinciding with the greatest annual precipitation. During the drier second water year, flooding occurred during nine of the twelve months at the cranberry sites, whereas flooding occurred only in June at the abandoned-bog and forest sites. June coincided with the highest monthly precipitation for that water year.

Papoose Branch experienced a higher percentage of overbank flooding (26% of observation dates) compared to the other forest sites. Because forested basins in the Pinelands are predominately groundwater fed, the higher frequency of flooding at Papoose Branch was unexpected (Rhodehamel 1979, Poff and Ward 1989). Two sites, Middle Branch Mount Misery Brook, a forest site, and West Branch Bass River, an abandoned-bog site, did not experience overbank flooding during the study period. An impoundment upstream from the West Branch Bass River site may have reduced the potential for overbank flooding.

Stream Morphology

Results of the MANOVA did not indicate any significant overall difference in bank slope, bankfull width, bankfull depth, bankfull area, or width/depth ratio between stream types (MANOVA, Wilks' lambda = 0.057, $F_{10,8} = 2.553$, $p = 0.099$). However, several general differences between stream types were apparent (Table 6). Based on median values, cranberry streams had steeper banks, greater bankfull depths, and lower bankfull width/depth ratios, whereas the gentlest slopes, shallowest channels, and highest width/depth ratios were associated with abandoned-bog streams. Higher bankfull widths and bankfull cross-sectional areas characterized forest streams.

Many of the stream morphology metrics were intercorrelated (Table 5). Bankfull depth and width to depth ratios were negatively correlated. Bankfull depth was also strongly correlated with bankfull area. Additionally, bankfull area was negatively correlated with width to depth ratios. Bank slope was positively correlated with bankfull depth and bankfull area. These relationships indicate that larger and deeper streams have steeper banks. The negative association between bank slope and width to depth ratios lends support to the previous statement and suggests that bank slope tends to be greater in cranberry streams with deeper and narrower channels. Bankfull width was not correlated with any of the morphologic variables but it was the only variable associated with basin area. Although there were no statistical differences between groups, the width to depth ratio was negatively correlated with the percentage wetland-agriculture in a basin. This suggests that wetland agriculture (cranberry) is associated with relatively narrow and deep channels. Due to the large number of comparisons, conclusions regarding the statistical significance of these associations cannot be made.

Acknowledgements

I thank Robert Zampella, John Bunnell, Kim Laidig, Jennifer Ciraolo, Christina Burns, and Jason Shvanda for assisting with various aspects of this study. The New Jersey Division of Parks and Forestry authorized the state-lands research permits. Funding for this study was provided by the U. S. Environmental Protection Agency (State Wetlands Grant Program, Grant No. CD-99298001-1), the Pinelands Commission, and the National Park Service.

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Table 1. Stream discharge and channel morphology study sites in the Mullica River and Rancocas Creek basins. Wetland agriculture and altered land (developed and upland agriculture) are expressed as a percentage of basin area.

Site Type and Stream Name	Basin area (km^2)	Stream order	Wetland agriculture	Altered land
Cranberry Streams				
Hospitality Brook	4.9	1	34.25	8.38
Little Hauken Run	15.6	1	25.12	2.32
Pole Bridge Branch	34.8	3	3.85	8.41
Tom Roberts Branch	11.1	3	6.74	2.43
Abandoned-bogs Streams				
North Branch Mount Misery Brook	29.4	3	0.08	3.29
Shane Branch	4.6	2	0.00	0.21
Tulpehocken Creek	56.6	4	0.07	0.20
West Branch Bass River	16.8	3	0.56	0.58
Forest Streams				
East Branch Bass River	21.1	3	0.00	2.03
McDonalds Branch	6.1	1	0.00	0.00
Middle Branch Mount Misery Brook	7.3	1	0.00	0.00
Papoose Branch	11.4	3	0.00	0.00

Table 2. Stream-discharge summary statistics for the twelve monitoring sites in the Mullica River and Rancocas Creek basins. Units are cubic meters per second per km^2 (cms/km^2) for the median and interquartile range.

Site Type and Stream Name	Median	Interquartile range	Spread	Modified R-B index
Cranberry Streams				
Hospitality Brook	0.0466	0.0330	0.71	0.24
Little Hauken Run	0.0301	0.0178	0.59	0.24
Pole Bridge Branch	0.0034	0.0013	0.39	0.42
Tom Roberts Branch	0.0102	0.0101	0.99	0.38
Median	**0.0202**	**0.0140**	**0.65**	**0.31**
Abandoned-bog Streams				
North Branch Mount Misery Brook	0.0011	0.0071	6.36	0.42
Shane Branch	0.0080	0.0239	2.99	0.56
Tulpehocken Creek	0.0053	0.0099	1.86	0.59
West Branch Bass River	0.0120	0.0104	0.86	0.37
Median	**0.0067**	**0.0101**	**2.42**	**0.49**
Forest Streams				
East Branch Bass River	0.0194	0.0114	0.59	0.21
McDonalds Branch	0.0060	0.0047	0.78	0.19
Middle Branch Mount Misery Brook	0.0023	0.0108	4.71	0.47
Papoose Branch	0.0128	0.0090	0.70	0.18
Median	**0.0094**	**0.0099**	**0.74**	**0.20**
All Streams				
Median	**0.0091**	**0.0103**	**0.82**	**0.38**

Table 3. Monthly precipitation data for each water year (WY) and average monthly precipitation data (cm) for the entire study period from Indian Mills, New Jersey. The long-term average (1931-2004) is 116.7 cm (Office of the State Climatologist of New Jersey 2006).

Month	WY01 (2000-2001)	WY02 (2001-2002)	WY03 (2002-2003)	Study period average
October	5.1	3.9	18.3	9.1
November	8.0	2.5	13.4	8.0
December	9.0	6.6	12.1	9.2
January	7.6	4.6	5.8	6.0
February	5.9	1.7	15.4	7.7
March	18.2	11.4	8.5	12.7
April	4.6	8.2	7.9	6.9
May	8.0	10.7	10.6	9.7
June	10.1	13.1	19.4	14.2
July	4.6	4.1	8.7	5.8
August	13.3	11.5	11.4	12.1
September	5.6	7.3	24.7	12.5
Annual total	100.0	85.5	156.2	113.9

Table 4. Spearman rank order correlations coefficients (Spearman rho) between the 25th, 50th, and 75th percentiles. All correlations are significant ($\alpha = 0.05$) after Bonferonni correction.

	25th Percentile	50th Percentile	75th Percentile
25th Percentile	1.00		
50th Percentile	0.91	1.00	
75th Percentile	0.72	0.90	1.00

Table 5. Spearman rank correlation matrix for study basin, stream discharge, and channel morphology variables. Bolded Spearman rho coefficients are significant ($p < 0.05$).

	Basin area (km^2)	Stream order	Wetland agriculture	Altered land	Flooding frequency	Median	Interquartile range	Spread	Modified R-B index	Bank slope	Bankfull width	Bankfull depth	Bankfull area	Width/depth ratio
Basin area (km^2)	1.000													
Stream order	**0.750**	1.000												
Wetland agriculture (%)	0.153	0.002	1.000											
Altered land (%)	0.268	0.111	**0.738**	1.000										
Flooding frequency	-0.200	-0.2.99	0.483	0.409	1.000									
Median	-0.301	-0.236	0.374	0.127	0.232	1.000								
Interquartile range	-0.503	-0.434	0.128	0.063	0.205	**0.622**	1.000							
Spread	-0.189	0.019	-0.274	-0.282	0.100	**-0.580**	0.042	1.000						
Modified R-B index	0.224	0.255	-0.050	0.099	-0.118	**-0.622**	0.028	0.566	1.000					
Bank slope	0.355	-0.130	0.385	0.588	-0.050	0.355	-0.055	**-0.764**	-0.545	1.000				
Bankfull width	**0.645**	0.581	-0.037	0.210	-0.041	0.027	-0.500	-0.273	-0.455	0.464	1.000			
Bankfull depth	0.255	-0.025	0.560	0.310	-0.059	**0.700**	0.164	**-0.709**	**-0.618**	**0.718**	0.355	1.000		
Bankfull area	0.191	-0.025	0.468	0.296	-0.036	**0.736**	0.209	**-0.645**	**-0.718**	**0.700**	0.482	**0.936**	1.000	
Width/depth ratio	-0.136	0.170	**-0.688**	-0.410	0.014	**-0.682**	-0.200	**0.736**	0.555	**-0.718**	-0.118	**-0.945**	**-0.818**	1.000

Table 6. Stream-channel morphology summary statistics for the eleven monitoring sites in the Mullica River and Rancocas Creek basins.

Site Type and Stream Name	Number of transects	Bank slope (degrees)	Bankfull width (m)	Bankfull depth (m)	Width/depth ratio	Bankfull area (m^2)
Cranberry Streams						
Hospitality Brook	10	55.96	4.52	0.62	8.66	3.39
Little Hauken Run	23	56.67	4.43	0.63	7.45	2.73
Pole Bridge Branch	3	63.66	4.87	0.58	9.00	2.54
Tom Roberts Branch	3	34.78	3.93	0.39	9.96	1.51
Median	**7**	**56.32**	**4.48**	**0.60**	**8.83**	**2.64**
Abandoned-bogs Streams						
North Branch Mount Misery Brook	5	46.91	5.56	0.37	17.24	1.93
Shane Branch	10	30.76	3.23	0.20	17.53	0.64
Tulpehocken Creek	10	33.73	4.72	0.47	11.06	2.14
West Branch Bass River	3	50.37	4.91	0.65	7.55	3.05
Median	**8**	**40.32**	**4.82**	**0.42**	**14.15**	**2.03**
Forest Streams						
East Branch Bass River	6	62.57	5.25	0.61	9.37	2.97
Middle Branch Mount Misery Brook	3	42.35	2.63	0.27	11.81	0.70
Papoose Branch	9	43.62	5.17	0.52	10.98	2.67
Median	**6**	**43.62**	**5.17**	**0.52**	**10.98**	**2.67**
All Streams						
Median	**6**	**46.91**	**4.72**	**0.52**	**9.96**	**2.54**

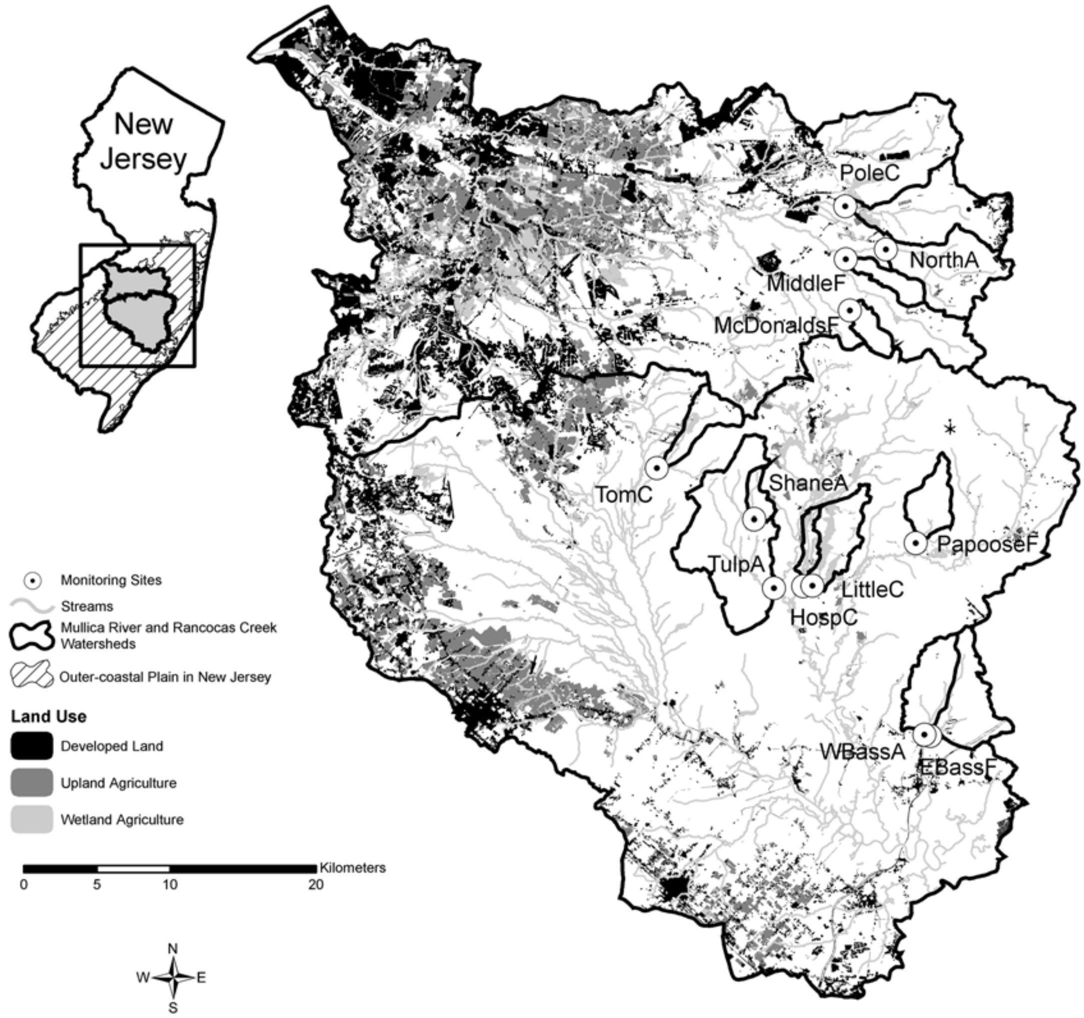

Figure 1. Location of 12 hydrologic monitoring sites in the Mullica River and Rancocas Creek Basins. Site types include forest (F), abandoned-bog (A), and cranberry (C). The last capital letter in each site name refers to the stream type. Refer to Table 1 for complete site names.

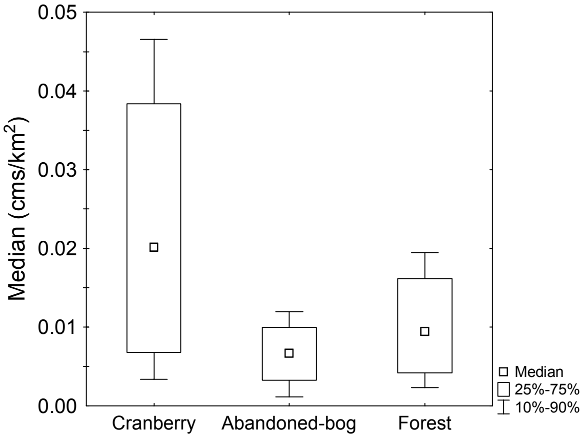

Figure 2. Box-plot of median basin-area normalized discharge for cranberry sites, abandoned-bog sites, and forest sites.

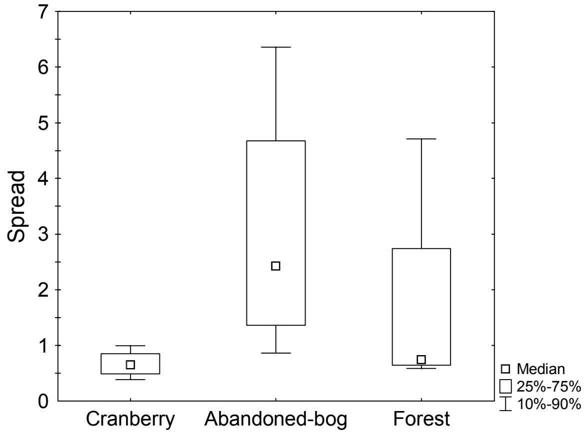

Figure 3. Box-plot of spread for cranberry sites, abandoned-bog sites, and forest sites.

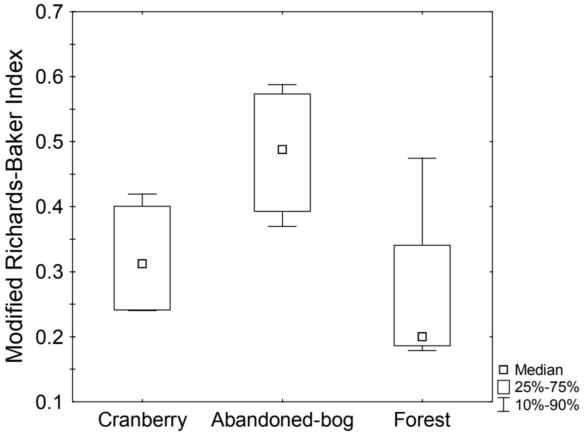

Figure 4. Box-plot of the modified Richard-Baker index of flashiness for cranberry sites, abandoned-bog sites, and forest sites.

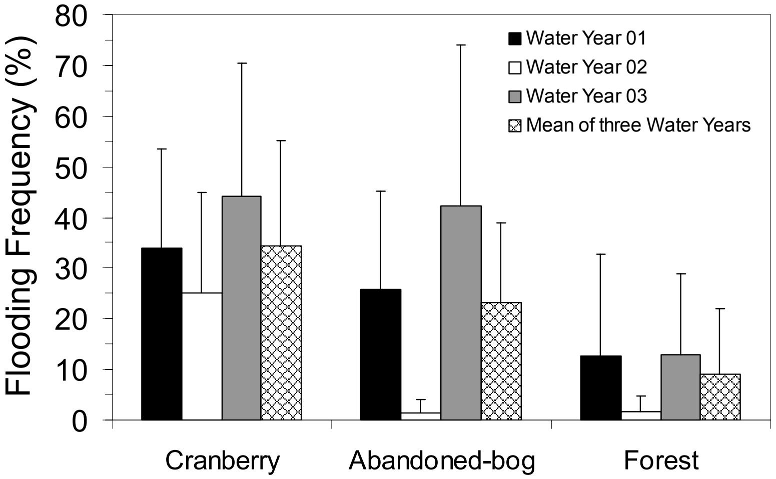

Figure 5. Average flooding frequency (%) for each water year and the entire three-year study period for cranberry, abandoned-bog and forest sites.

PART 3. DISTRIBUTION OF DIATOMS IN RELATION TO LAND USE AND pH IN BLACKWATER COASTAL PLAIN STREAMS

Robert A. Zampella, Kim J. Laidig, and Rex L. Lowe

Abstract

We compared the composition of diatom assemblages collected from New Jersey Pinelands blackwater streams draining four different land uses, including forest land, abandoned-cranberry bogs, active-cranberry bogs, and developed and upland-agricultural land. We addressed two questions. First, do diatom assemblages vary among land-use types? Secondly, are variations in diatom assemblages associated with differences in pH? Over a two-year period, we collected 132 diatom taxa at fourteen stream sites. Between-year variability in the composition of stream samples was high. Most diatom species were rarely encountered and were found in low abundance. Specific conductance and pH were higher at developed/agricultural sites compared with all other site types. Neither species richness nor genus richness was significantly different between stream types. However, clear community patterns were evident and a significant difference in species composition existed between the developed/agricultural sites and both cranberry and forest sites. The primary community gradient, represented by the first axis of a DCA ordination, was associated with variations in pH and specific conductance. Acidobiontic and acidophilous diatoms characterized the dominant species at forest, abandoned-bog, and cranberry sites, whereas indifferent (circumneutral) species dominated the developed/agricultural samples. Although our study demonstrated a relationship between the composition of diatom assemblages and watershed conditions, several factors, including taxonomic problems, the large number of diatom species, incomplete pH classifications, and year-to-year variability may limit the utility of diatoms species as indicators of watershed conditions in the New Jersey Pinelands.

Introduction

Diatoms can be valuable indicators of water-quality characteristics (Lowe 1974, Pan et al. 1996, Stevenson and Pan 1999, Barbour et al. 1999), especially pH (Meriläinen 1967, Lowe 1974, Charles 1985, van Dam et al. 1994, Battarbee et al. 1999). The close relationship between the composition of modern diatom assemblages and pH has allowed the development and application of paleolimnological methods to reconstruct the pH history of lakes and infer the possible effect of increasing acidity due to acid precipitation (Arzet et al. 1986a, 1986b, Dixit 1986, Ford 1986, Battarbee and Charles 1986, Winkler 1988, Charles and Smol 1988, Dixit et al. 1988, 1992, Holmes et al. 1989). Fewer studies have addressed the effect of an increase in pH on the composition of diatom assemblages (Simola 1986, Ohl et al. 1990, Chessman et al. 1999).

New Jersey Pinelands (Pine Barrens) streams are representative of blackwater coastal plain streams found along the east coast and Gulf Coast of the United States (Patrick 1996). Pinelands streams draining forested watersheds are characterized by highly acidic and nutrient-poor water, whereas streams draining developed lands and upland agriculture display elevated pH and dissolved-solid concentrations (Morgan and Good 1988, Zampella 1994). The median pH of streams that are minimally disturbed by development and upland agriculture and those draining altered watersheds ranges from 4.2 - 4.4 and 6.2 - 6.4, respectively (Zampella 1994).

The acid-water diatom flora that characterizes the region reflects the low pH of Pinelands streams (Patrick et al. 1979, Moul and Buell 1979, Morgan 1987, Patrick 1996). Characteristic genera include *Actinella*, *Eunotia, Frustulia*, *Fragilaria*, and *Pinnularia*. Moul and Buell (1979) suggested that a change in pH to neutral or alkaline conditions caused by pollution might eliminate most of the existing acid-water algal flora.

In this study, we compare the composition of diatom assemblages collected from streams draining four different land uses, including forest land, abandoned-cranberry bogs, active-cranberry bogs, and developed and upland-agricultural land. Although all four types represent acid-water streams, the streams draining areas with a higher percentage of developed and upland-agricultural lands are characterized by higher pH values. We address two major questions. First, do diatom assemblages vary among land-use types? Secondly, are variations in diatom assemblages associated with differences in pH?

Methods

Study-site Selection

We selected four streams representing each of three land-use types, including forest, active-cranberry bogs (cranberry), and developed and upland-agricultural lands (developed/agricultural land), and two streams representing the abandoned-cranberry bog (abandoned bog) land-use type (Figure 1, Table 1). Twelve streams are tributaries of the Mullica River and two are tributaries of the Rancocas Creek. All streams are associated with the Kirkwood-Cohansey aquifer system (Rhodehamel 1979a, 1979b). The fourteen streams were included in earlier water-quality, stream-vegetation, fish or anuran studies, and land-use profiles (Table 1) were completed as part of those studies (Zampella et al. 2001, 2003). The data set used to create the land-use profiles is based on a modified Anderson et al. (1976) system. In this paper, we refer to the Anderson-type land-use classes of urban land, agriculture, and agricultural wetlands as developed land, upland agriculture, and wetland agriculture, respectively. Collectively, we refer to developed land and upland agriculture as altered land. Wetland agriculture includes cranberry bogs and blueberry fields. Most wetland agriculture in the study basins is cranberry agriculture. Cranberry cultivation is a major land use in parts of the Pinelands. Harvested cranberry acreage, estimated to be about 3,100 acres in 2002 (U. S. Department of Agriculture 2003), represents less than one-third of the 11,200 acres that existed at the peak of bog cultivation in 1919 (Eck 1990). The abandoned-cranberry bogs are now a common feature of the landscape.

Our four forest sites were located in undeveloped watersheds with no apparent agricultural history (Figure 1, Table 1). The two abandoned-bog sites were located in streams draining abandoned-cranberry bogs and forest with no active-cranberry bogs. The four active-bog sites were located immediately downstream from active-cranberry farms in watersheds dominated by forest. Abandoned bogs bordered three of the active-bog sites. One developed/agricultural stream site was located in an abandoned bog and another was located downstream from a tributary with abandoned bogs. All abandoned bogs have succeeded to emergent, shrub, or forested wetland types. Altered land in the developed/agricultural basins ranged from 29% to 62%.

Stream Habitats

In 1999, we completed field measurements of pH and specific conductance at the twelve Mullica River basin sites (Zampella et al. 2001). We collected monthly samples during baseflow conditions in June, July, August, and October 1999. Specific conductance was measured with an Orion model 122-meter and pH was measured with an Orion model-250A meter. From May through November 2001 and April through November 2002, we used the same methods to collect monthly pH and specific conductance samples at all cranberry, abandoned-bog, and forest sites. The developed/agricultural sites were not sampled during this period.

With the exception of one site, where median specific conductance differed by 16.4 μS cm^{-1}, specific conductance and pH values for the eight sites sampled in both periods were similar. The median absolute difference in pH and specific conductance between the 1999 and 2001-2002 periods for the eight sites was 0.2 units and 3.1 μS cm^{-1}, respectively. Based on these results, we used the 1999 data for the developed/agricultural sites and the more recent 2001-2002 data for the other sites to calculate median values and compare water quality (Table 1).

We monitored stream discharge at the forest, abandoned-bog, and cranberry sites between October 2000 and October 2003. Discharge was not measured at one site (Buck Run). The U. S. Geological Survey measured discharge less frequently at or near three of the four altered sites as part of a separate study (Zampella et al. 2001). The exception was Great Swamp Branch. In our analysis, we limited the cranberry, abandoned-bog, and forest site discharge measurements to those that most closely matched the U. S. Geological Survey sampling dates. Because data are not available for all sites on all dates, we ranked discharge values for each date and used these ranks to calculate a median discharge rank for each site (Table 1).

We used a spherical densiometer to measure canopy cover directly above the points where diatoms were sampled. Mean canopy cover for each site was based on four spherical densiometer readings.

Diatom Sampling

We used periphyton samplers that held 16 glass microscope slides to collect diatom samples. The samplers were placed at each stream site for about two weeks on four separate occasions. The sampling dates were: July 15 - 31, 2002, September 13 - 30, 2002, July 6 - 17, 2003, and September 12 - 29, 2003. The use of artificial substrate is effective in streams with highly variable habitat conditions or natural substrate that is not suitable for sampling (Stevenson and Pan 1999). Our study streams are characterized by muck or sand sediment and the presence of hard substrate, represented by woody debris, is highly variable.

Each year, we pooled slides collected in July and September as a single sample. The slides were soaked in 30% hydrogen peroxide for 24 hours and scraped into a beaker. The remaining organic matter was oxidized using potassium dichromate. Following repeated episodes of distilled water addition, diatom settling, and decantation of dichromate from the samples, the diatoms were mounted in Naphrax. Diatoms were identified to species and enumerated using a light microscope. For each sample, up to 600 and 500 diatoms were counted in 2002 and 2003, respectively. Taxonomic references used included Camburn and Charles (2000), Hustedt (1930), Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b), and Patrick and Reimer (1966, 1975).

We determined the relative abundance of each species in each year and calculated a mean relative abundance for the two-year period. Species richness and relative abundance was based on all taxa collected during the two years, including those taxa identified only to genus.

pH Categories

We assigned taxa to pH categories using Meriläinen (1967), Lowe (1974), van Dam et al. (1994), and Charles (1985). With the exception of van Dam (1994), who distinguishes between indifferent (no apparent optimum or insensitive to pH) and circumneutral (mainly occurring at pH about 7) categories, all categorize diatoms as either acidobiontic, acidophilic, indifferent (circumneutral), alkaliphilic, or alkalibiontic as defined by Hustedt (Hustedt 1938-1939 in Meriläinen 1967):

1) acidobiontic - occurring at pH values below 7, optimum distribution at pH 5.5 or less;
2) acidophilous - occurring at about pH 7 and with widest distribution at pH values below 7;
3) indifferent - occurrence around pH of 7;
4) alkaliphilous - occurring at pH values about 7 and with widest distribution at pH values above 7; and
5) alkalibiontic - occurring at pH values above 7.

Categorizations vary somewhat among the four sources, but the differences are generally limited to classifying a taxon either as acidobiontic or acidophilous or alkalibiontic or alkaliphilous. To resolve these differences, we condensed the classification to three categories. Acidobiontic, acidophilous, and acidophilous-indifferent taxa were classified as acidobiontic-acidophilous. Alkalibiontic, alkaliphilous, and indifferent-alkaliphilous taxa were classified as alkalibiontic-alkaliphilous. Indifferent or circumneutral species were classified as indifferent.

Data analysis

We used detrended correspondence analysis (DCA, Hill 1979a, Hill and Gauch 1980) and TWINSPAN (Hill 1979b) to ordinate and classify diatom species and the fourteen stream sites using mean relative-abundance data for the two-year period. Log-transformed relative-abundance data were used in the DCA analysis. In the DCA diagrams, the scores were rescaled and shown as proportionate to the longest axis (% of Max).

The same data and nonparametric multi-response permutation procedures (MRPP, McCune and Mefford 1999) were used to determine if differences in diatom composition existed among the four stream classes and between individual classes. The MRPP analyses were based on Euclidean distance. Significance levels of the multiple tests were adjusted using the sequential Bonferroni method (Rice 1989, 1990). We report the p and A values for each analysis. The p value describes the likelihood that an observed difference is due to chance. The A statistic (chance-corrected within-group agreement) describes agreement within groups (i.e., stream type). $A = 1$ when all attributes within a group are identical, $A = 0$ when within group heterogeneity equals that expected by chance, and $A < 0$ when within-group heterogeneity is greater than expected by chance.

We also used MRPP to determine if differences in the relative abundance of dominant taxa included in each of the pH categories (acidobiontic-acidophilous, indifferent, and alkalibiontic-alkaliphilous) existed among the four stream types. Dominant-diatom taxa are those comprising more than 75% of a sample.

We used analysis of variance to assess differences in taxonomic richness among stream types. Species-level and genus-level richness data for the two-year period were log transformed for the ANOVAs.

Using Spearman rank correlation, we related the first and second DCA axes derived from ordination of the mean relative-abundance data to pH, specific conductance, percent-canopy cover, discharge ranks, basin area, and the percentage of altered land (developed land and agriculture), wetland agriculture, and combined wetlands and water cover in associated drainage basins. Significance levels for Spearman rank correlations and ANOVAs were adjusted using the sequential Bonferroni method (Rice 1989, 1990).

We used an alpha level of 0.05 to assess significance for all tests. Ordinations, TWINSPAN classifications, and MRPP analyses were performed using PC-ORD for Windows 4.27 (MjM Software, Gleneden Beach, OR 1999). ANOVAs and correlation analyses were performed using Statistica 5.5 (Statsoft Inc., Tulsa, OK, 1995).

Results

Stream Habitats

Median pH and specific conductance at the developed/agriculture sites ranged from 6.3 to 6.8 and 63 μS cm^{-1} to 118 μS cm^{-1}, respectively (Table 1). Median pH at all other sites ranged from 4.2 to 5.1. Median specific conductance was less than 50 μS cm^{-1} at these sites. Mean (± 1 SD) canopy cover at the diatom-sampling points ranged from 6.5 ± 9.2% for abandoned bogs to 28.5 ± 27.6% for active-cranberry bogs. Discharge was generally lower in the abandoned-bog streams.

Species Inventory

The samples included three problematic taxa, *Eunotia exigua*, *E. tenella* and *E. paludosa*. Because these three species overlap morphologically at the ends of their size ranges, they look very similar at the light microscopy level. To address the potential taxonomic uncertainty, we completed our analyses using a composite species comprised of the three *Eunotia* species**.**

Forty-three genera, comprising 132 taxa (134 taxa with *Eunotia exigua*, *E. tenella* and *E. paludosa* as separate species), including 105 species, 7 varieties, and 20 taxa identified only to genus, were collected over the two-year period at the fourteen sites (Table 2). Between-year variability in the composition of stream samples was high. Only 51 taxa were collected in both years. Thirty-eight taxa were collected only in 2002 and 43 taxa were collected only in 2003. All 132 taxa were treated as species in the analyses.

The genus *Eunotia* was found at all sites. Other widely distributed genera, in order of decreasing frequency of occurrence at fourteen sites, were *Frustulia* (93%), *Tabellaria* (93%), *Pinnularia* (79%), *Stenopterobia* (79%), *Navicula* (64%), *Brachysira* (50%), and *Gomphonema* (50%).

Most diatom species were rarely encountered and were found in low abundance. In 2002, 53% of 89 species were found at only one of fourteen sites. Fifty-nine percent of the 94 species collected in 2003 were also found at a single site. Less than ten and twelve percent of all species occurred at fifty percent or more of all sites in 2002 and 2003, respectively. Over the two-year period, 65 (49%) of the 132 species collected occurred at only a single site. Most of the single-occurrence species were found at developed/agricultural sites (37%). The percentage of single-occurrence species at cranberry, abandoned-bog, and forest sites was 25%, 14%, and 25%, respectively. Only 13% of all species were found in all four stream classes.

Over the two-year period, seventeen species were found at more than half of the fourteen sites. Only 22 (17%) of the 132 species comprised more than five percent of a sample (24 species when *Eunotia exigua, E. paludosa, and E. tenella* were considered separately). The most abundant taxa, comprising more than 50% of all cells at one or more sites, were the composite *Eunotia* species (91%), *Tabellaria quadraceptata* (86%), and *Gomphonema parvulum* (81%). The composite *Eunotia* species was most abundant in one forest stream, one abandoned-bog stream, and all four cranberry streams. *Tabellaria quadraceptata* was most abundant in two forest streams, and *Gomphonema parvulum* was most abundant in two developed/agricultural streams.

Species Richness

Taxonomic richness at the fourteen sites ranged from 12 to 44 species and 5 to 25 genera. Mean species richness for stream types ranged from 23.8 for forest streams to 31.3 for developed/agricultural streams (Table 3). Mean genus richness ranged from 10.8 at forest sites to 15.3 at developed/agricultural sites. Analysis of variance revealed no significant difference in species richness ($p = 0.83$) or genus richness ($p = 0.93$) between stream types.

Community Patterns

The first axis of the DCA ordination based on mean relative-abundance data for the two-year period clearly contrasted the developed/agricultural sites from the other sites (Figure 2). The first division of the TWINSPAN classification also separated the developed/agricultural streams from the other streams. The second DCA axis contrasted forest sites with cranberry sites. The two-dimensional diagram shows that sites were generally clustered with most other streams in the same class.

Nine taxa associated with one extreme end of the first DCA axis of the species ordination were found only at forest sites, and all but *Adlafia bryophila* occurred at a single site. Thirty-two of thirty-seven taxa associated with the other extreme end of the first axis were found only at developed/altered sites. Twenty-four of the thirty-two taxa occurred at a single site. The remaining eight taxa, which included *Achnanthes pusilla*, *Brachysira vitrea*, *Caloneis hyalina*, *Fragilaria vaucheriae*, *Gomphonema truncatum* var. *turgidum*, *Navicula lanceolata*, *Synedra ulna*, and an unidentified species of *Fragilaria* were found at from two to three developed/agricultural sites. Although also found at other site types, *Eunotia pectinalis* var. *minor*, *Gomphonema parvulum*, and *Eunotia rhomboidea* were found at all four developed/agricultural sites and were more abundant in these streams.

The second DCA axis contrasted taxa found at a single forest site with taxa occurring at a single cranberry site. The taxa found only at forest sites included *Eunotia curvata* var. *subarcuata*, *Stephanocyclus meneghiniana,* and unidentified species of *Desmogonium*, *Stenopterobia*, and *Gyrosigma*. Species limited to the cranberry sites were *Eunotia praerupta, Navicula rynchocephala, Nitzschia acicularis Nitzschia inconspicua, Pleurosira laevis, Rhoicosphenia curvata,* and unidentified species of *Stephanodiscus* and *Tryblionella.*

The order of sites along the first and second DCA axes using all species and one derived by ordinating only species found at two or more sites were nearly identical. Correlations were very high and significant when correlating the first (Spearman r = 0.99, $p < 0.001$) and second (Spearman r = -0.99, $p < 0.001$) DCA axes of the site ordinations. As with the ordination of all taxa, including single-occurrence species, *Achnanthes pusilla*, *Brachysira vitrea*, *Caloneis hyalina*, *Fragilaria vaucheriae*, *Gomphonema truncatum* var. *turgidum*, *Navicula lanceolata*, *Synedra ulna*, and an unidentified species of *Fragilaria* characterized the developed/agricultural side of the first DCA axis of the ordination derived using only species found at two or more sites.

The MRPP analysis of the mean relative-abundance data revealed a significant difference between stream types (A = 0.260, $p < 0.001$). Initial p values suggested that a difference in sample composition existed between cranberry and forest sites and between developed/agricultural sites and abandoned bogs, but the differences were not significant following the Bonferroni adjustment. A significant difference existed between the developed/agricultural sites and both cranberry and forest sites (Table 4).

Environmental Relationships

The first DCA axis of the site ordination was correlated with pH and specific conductance and the second axis was correlated with the combined area of wetlands and water (Table 5). Although not significant following the Bonferroni correction, altered land (developed land and upland agriculture) and wetland agriculture appeared to be associated with the first and second axis, respectively. Neither axis was associated with variations in basin area, canopy cover, or discharge.

pH Categories

Eighty-two (61%) of the 134 diatom species, including *Eunotia exigua*, *E. paludosa*, and *E. tenella* as separate species, collected at fourteen sites over the two-year period were assigned a pH category (Table 6). Forty-one species are classified as acidobiontic-acidophilous and 26 are classified as alkalibiontic-alkaliphilous. Fourteen species were classified as indifferent. van Dam et al. (1994) classifies one species, *Eunotia bilunaris,* as truly indifferent (i.e., insensitive to pH). One species, *Neidium affine*, was assigned contrasting pH preferences, ranging from acidophilous to alkaliphilous, by the different sources.

Twenty-one species represented dominant taxa comprising more than 75% of a sample. All but three species were assigned a pH category. The exceptions represented 16% of one sample and four percent of another sample. Fourteen species were classified as acidobiontic-acidophilous, two as indifferent, and two as alkalibiontic-alkaliphilous. The dominant acidobiontic-acidophilous species included *Eunotia incisa, E. pectinalis, E. pectinalis var. minor, E. rhomboidea, E. septentrionalis,* the composite *Eunotia* species (*E. exigua, E. paludosa*, and *E. tenella)*, *Frustulia amphipleuroides*, *Frustulia rhomboides*, *Frustulia saxonica*, *Pinnularia biceps* f. *petersenii*, *P. subcapitata*, *Semiorbis hemicyclus*, *Tabellaria flocculosa*, and *T. quadraceptata*. The two indifferent species were *Achnanthidium minutissimum* and *Gomphonema parvulum*, and the two alkalibiontic-alkaliphilous species were *Aulacoseira ambigua* and *Cocconeis placentula*.

The MRPP analyses of the percentage of dominant species in each of the three pH categories revealed a significant difference between the developed/agricultural streams and both the cranberry (A = 0.540, $p = 0.006$) and forest streams (A = 0.508, $p = 0.006$). Although the composition of the abandoned-bog streams appeared to differ from the developed/agricultural streams (A = 0.397, $p = 0.016$), the difference was not significant following the Bonferroni correction. Acidobiontic and acidophilous diatoms characterized the dominant species at forest, abandoned-bog, and cranberry sites. Indifferent species dominated the developed/agricultural samples (Table 6).

Discussion

Although the composition of diatom assemblages at our study sites varied considerably between years and most diatom species were rarely encountered and found in low abundance, clear community patterns were evident. The DCA ordination and TWINSPAN classification contrasted the circumneutral developed/agricultural streams with the more acid forest, abandoned-bog, and cranberry streams. The community gradient was associated with variations in pH and specific conductance.

Most species and genera associated with the contrast between the circumneutral streams and sites on the opposite end of the primary community gradient represented by the first DCA axis were single occurrences, but deleting these species did not substantially change the order of stream sites along the first or second DCA axes. Although differences between cranberry, abandoned-bog, and forest sites were less apparent, and all four classes where characterized by acid-water diatoms, species composition also varied between these classes.

We found no difference in species richness between stream types. Researchers have reported different effects of human activity on taxa richness. Chessman et al. (1999) associated an increase in genus richness with increasing alkalinity, specific conductance, hardness, and pH related with human activity, and Hill et al. (2003) reported that diatom-species richness was positively correlated with total phosphorus and nitrogen. Cuffney et al. (1997) found that taxa richness of benthic-algal communities with diatoms as a dominant component did not show a strong relationship with land use or water quality. Hill et al. (2001) concluded that diatom-taxa richness is not consistently or predictably related to human-related watershed disturbances. Perhaps the most relevant study is that conducted by Morgan (1987) who collected 53 periphyton species over a one-year period at six Pinelands streams, including three undisturbed streams and three disturbed streams. The disturbed streams were characterized by elevated pH and nutrients. All six streams were within the same major drainage basins as those in our study. As in our study, the disturbed basins had a higher percentage of developed land and upland agriculture than the undisturbed-forested basins. Two of the three undisturbed streams drained land with both active-cranberry bogs and abandoned bogs. Twenty-five of the 53 species were diatoms, which is much lower than the number of taxa found in our study of 16 streams. Our results, based solely on diatom assemblages, do not fully agree with Morgan's (1987) major conclusion that periphyton-taxonomic richness increases with disturbance. In our study, species and genus richness was highest in developed/agricultural sites compared to the other three classes, but the differences were not statistically significant.

Morgan (1987) identified nine diatom species as restricted to disturbed sites and nine species as restricted to undisturbed sites. We collected eight of these species in our study, and the distribution of only two species is consistent with his designations. Morgan (1987) included *Actinella punctata, Gomphonema parvulum, Synedra ulna,* and *Tabellaria flocculosa* in the disturbed-only category and *Eunotia exigua, E. flexuosa, Frustulia saxonica,* and *Pinnularia viridis* in the undisturbed-only category. In our study, *Actinella punctata* was found only in forest and abandoned-bog streams, *Gomphonema parvulum* and *Tabellaria flocculosa* were found in developed/agricultural, cranberry, and forest streams, and *Eunotia exigua, E. flexuosa*, and *Frustulia saxonica* were found in all-four stream types. The distributions of *Synedra ulna*, which was found only in developed/agricultural sites, and *Pinnularia viridis*, which was collected from cranberry and abandoned-bog sites, are consistent with Morgan's (1987) classification. The between-year variability in restricted species in our study and the difference between our results and those of Morgan (1987) suggest that it may be difficult to identify reliable indicator species based on presence or absence.

Specific conductance and pH differed between the developed/agricultural sites and the three other site types, and diatom composition was related to both environmental variables and the combined percentage of wetlands and water in a drainage area. Initial *p* values also suggested that altered land (developed land and upland agriculture) and wetland agriculture were associated with variations in diatom composition. Basin area, canopy cover, and stream discharge did not vary along the community gradient.

Several other studies also demonstrate the association of pH, specific conductance, and land use with variations in the composition of diatom assemblages. Geology is also a factor in some areas. Pan et al. (1999) concluded that in mid-Atlantic streams, broad spatial patterns of benthic-algal assemblages dominated by diatoms could be predicted by both site-specific factors, such as riparian conditions, and coarse-scale factors, such as land use in a drainage basin. Kutka and Richards (1996) point out that variations in diatom assemblages may be related to basin geology, chemistry, and land use rather than to proximate habitat factors. In a study of thirty-eight lakes in the Adirondack Mountains, Charles (1985) found strong relationships between pH-related factors (pH, alkalinity, Ca, Mg, Na, Al, and conductivity), the composition of diatom assemblages, and the distribution of individual taxa. Leland and Porter (2000) reported that the composition of benthic-algal assemblages in the Illinois River basin was related to variations in specific conductance (Na-Cl type salinity) and nutrients associated with agricultural and urban land uses.

Pan et al. (1996) demonstrated that diatom species composition in mid-Atlantic region streams shifted along a pH gradient and concluded that pH was the most important environmental factor affecting diatom species composition in the streams studied. They attributed the high pH, which ranged from 6.4 to 8.7, to watershed geology and land-use activities such as liming and nutrient enrichment associated with agriculture. In the Yakima River basin in Washington, water chemistry and the composition of algal assemblages dominated by diatoms varied with geology in areas where timber harvest and grazing were the dominant land uses, whereas in agricultural areas, differences in algal assemblages were associated with nutrient enrichment (Leland 1995). Carpenter and Wait (2000) identified pH, specific conductance, percent open canopy, and drainage area as significant factors describing patterns of algal taxa in the Oregon streams. Distinct diatom assemblages and water quality characteristics were found in streams draining forested basins compared to streams in basins with a high percentage of urban or agricultural land.

Where altered lands are more extensive, urban and agricultural land uses can overshadow the effect of geology (Leland and Porter 2000). In our study area, where all drainage areas are associated with the same underlying geology (Rhodehamel 1979a), developed land and upland agriculture are the primary factors influencing water quality (Zampella 1994, Zampella et al. 2001, 2003). Unlike most freshwater systems, weathering of sediments is not a major source of dissolved solids in Pinelands streams. An increase in specific conductance and pH in relation to land-use related watershed disturbance has been demonstrated in all the major Pinelands watersheds (Dow and Zampella 2000).

Experimental evidence supports the assumption that alkalinization associated with human activity can influence the composition of diatom assemblages. In a study of two acidic, darkwater Michigan lakes, Ohl et al. (1990) observed of a series of changes in diatom-species composition in a limed lake compared to the control. Similarly, diatoms in an acid-water Finnish lake neutralized with powdered lime changed to a diatom community more characteristic of alkaline conditions (Simola 1986).

Although diatoms from all pH categories were found in each stream class, acidobiontic and acidophilous diatoms characterized the dominant species at forest, abandoned-bog, and cranberry sites. Indifferent (circumneutral) species dominated the developed/agricultural samples. In a study of Idaho rivers, Fore and Grafe (2002) indicated that many diatom species designated as eutrophic were also alkaliphilic. Similarly, van Dam et al. (1994) classify most of the alkalibiontic and alkaliphilous diatoms collected in our study as mesotrophic-eutrophic or eutrophic (meso-eutrophentic and eutraphentic), whereas they classify most of the acidobiontic and acidophilous diatoms as oligotrophic (oligotraphentic). Indifferent species are assigned a range of trophic states. Using abundance-weighted averages of diatom indicator values, Denys (2004) found that trophic status provided a measure of pH rather than nutrient levels or productivity. In our study, the relationship between diatom composition, pH, and trophic status is probably not spurious since pH and nutrients are positively correlated in Pinelands waters (Zampella 1994), and enhanced primary production associated with nutrient enrichment may also contribute to elevated pH in Pinelands waters (Morgan 1985). Zampella et al. (2001) reported a median nitrate-N concentration less than 0.05 mg L^{-1} for both Papoose Branch and East Branch Bass River, whereas median nitrate-N concentrations for the four developed/agricultural sites ranged from 0.51 to 2.25 mg L^{-1}. At all six sites, total phosphorus was less than 0.01 mg L^{-1}.

Variations in pH and specific conductance were not associated with differences in diatom assemblages between forest, abandoned-bog, and cranberry sites. Cranberries do not require excessive fertilization and nitrogen and phosphorus concentrations (Eck 1990), and Howes and Teal (1995) concluded that nitrogen and phosphorus in discharges from cranberry bogs in Massachusetts are generally low in comparison to other land uses. Although the direct effect of cranberry agriculture on nutrients has not been studied in the Pinelands, the possible effect of nutrient enrichment on diatom assemblages cannot be discounted. Zampella et al. (2001) reported a median total phosphorus concentration of 0.01 mg L^{-1} and 0.02 mg L^{-1} for the Oswego River and Wading River, respectively. The Oswego River and Wading River basins are the center of the Pinelands cranberry industry.

The composition of diatom assemblages is influenced by factors other than water chemistry (Fore 2003). Many species found in Pinelands streams are also present in cranberry bogs and other wetland habitats (Moul and Buell 1979), so it is possible that proximal or watershed-wide landscape features influence the composition of stream-diatom assemblages.

The results of our study demonstrate that developed land and upland agriculture are associated with diatom assemblages that differ from those found in streams draining forested land with or without abandoned bogs and active-cranberry agriculture. Several factors, including taxonomic problems, the large number of diatoms, and incomplete pH classifications (Arzet et al. 1986b, Kelly et al. 1995, Hill et al. 2001) are obstacles to the use of diatoms for environmental monitoring. These factors, year-to-year variability, and the unreliability of indicator species may limit the utility of diatoms species as indicators of watershed conditions in the Pinelands.

Assessments based on genus-level diatom identifications may provide a reliable alternative to the analysis of species-level data (Kelly et al. 1995, Hill et al. 2001). Several genera, including *Achnanthes, Achnanthidium, Caloneis, Cymbella, Fragilaria, Fragilariforma, Gomphonema, and Synedra* were associated with our developed/agricultural streams in both 2002 and 2003. Another approach is to compare the composition of monitoring sites to that of minimally disturbed reference sites. Even though species composition varied between years, the developed/agricultural streams contrasted with the less disturbed, more acid forest, abandoned-bog, and cranberry streams. Because pH classifications are not available for all species, weighting of only dominant species may provide a third alternative.

Acknowledgments

We thank Nicholas Procopio, Christina Burns, Jason Shvanda, and Jim Rutherford for collecting water quality, stage, and discharge data and assisting with diatom sample collections. The New Jersey Division of Parks and Forestry authorized the state-lands research permits. Joseph Darlington granted permission to access Pole Bridge Branch on his property. Funding for this study was provided by the U. S. Environmental Protection Agency (State Wetlands Grant Program, Grant No. CD-99298001-1) and the Pinelands Commission.

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Table 1. Environmental characteristics of study streams. Land-use values are expressed as percentages. Altered land includes developed land and upland agriculture. Median values are shown for pH, specific conductance, and flow rank (1 = low).

Land-use type/Stream name	Basin Area (km^2)	Developed	Upland agriculture	Altered land	Wetland agriculture	Upland forest	Water	Wetlands	Barren land	% Canopy cover	pH	Specific conductance (μS cm^{-1})	Flow rank
Forest													
Buck Run	7.8	0	0	0.0	0	86.5	0.2	13.3	0	7.3	4.8	26.5	--
East Branch Bass River	21.1	2.0	0	2.0	0	82.7	1.0	14.0	0.2	42.0	4.4	37.4	9.0
Papoose Branch	11.4	0	0	0.0	0	87.5	0	12.4	0.1	7.3	4.7	29.9	4.5
Skit Branch	13.0	0.1	0.2	0.3	0	80.3	0	19.4	0	21.3	4.7	24.2	3.0
Mean ± SD	**13.3±5.6**	**0.5±1.0**	**0.1±0.1**	**0.6±1.0**	**0.0±0**	**84.3±3.3**	**0.3±0.5**	**14.8±3.2**	**0.1±0.1**	**19.4±16.4**	**4.7**	**28.2**	**4.5**
Abandoned-cranberry bog													
N. Br. Mt. Misery Brook	29.4	1.7	1.6	3.3	0.1	86.1	1.4	9.2	0	13.0	4.6	31.3	2.0
Shane Branch	5.0	0.4	0.1	0.4	0	50.8	0	48.8	0	0.0	4.2	39.4	1.0
Mean ± SD	**17.2±17.3**	**1.1±0.9**	**0.9±1.1**	**1.8±2.0**	**0.1±0.1**	**68.5±25.0**	**0.7±1.0**	**29.0±28.0**	**0.0±0.0**	**6.5±9.2**	**4.4**	**35.4**	**1.5**
Active-cranberry bog													
Batsto River	4.0	0.3	0.2	0.5	8.4	47.6	1.7	41.6	0.2	44.0	4.5	45.1	1.0
Hospitality Brook	4.9	1.6	6.8	8.4	34.3	24.7	6.9	23.0	2.7	0.0	4.7	46.2	6.5
Little Hauken Run	15.6	0.5	1.8	2.3	25.1	32.9	7.5	31.8	0.3	11.0	4.6	49.1	7.5
Pole Bridge Branch	34.8	7.1	1.3	8.4	3.9	56.5	1.1	29.4	0.8	59.0	5.1	49.4	4.0
Mean ± SD	**14.8±14.3**	**2.4±3.2**	**2.5±2.9**	**4.9±4.1**	**17.9±14.2**	**40.4±14.3**	**4.3±3.4**	**31.5±7.7**	**1.0±1.2**	**28.5±27.6**	**4.6**	**47.7**	**5.3**
Developed/Upland agriculture													
Albertson Brook	50.5	19.4	24.9	44.3	0.1	42.2	1.9	10.3	1.1	53.5	6.8	64.6	9.0
Great Swamp Branch	20.9	12.6	49.7	62.3	1.2	22.6	2.4	10.6	0.9	6.8	6.3	118.2	--
Hays Mill Creek	18.4	36.7	10.1	46.8	0.9	32.8	1.3	15.0	3.3	49.8	6.8	95.5	5.5
Sleeper Branch	46.6	21.3	8.0	29.3	0.5	43.3	1.1	24.4	1.4	0.0	6.8	63.2	9.0
Mean ± SD	**34.1±16.8**	**22.5±10.2**	**23.2±19.2**	**45.7±13.5**	**0.7± 0.5**	**35.2± 9.6**	**1.7±0.6**	**15.1± 6.6**	**1.7±1.1**	**27.5±28.0**	**6.8**	**80.0**	**9.0**

Table 2. Diatom species collected in 2002 and 2003 at fourteen Pinelands stream sites.

Achnanthes pusilla (Grun.) DeT. *
Achnanthidium minutissimum (Kütz.) Czarn.
Actinella punctata Lewis
Adlafia bryophila (Peters.) Lange-Bertalot
Adlafia sp.
Amphora ovalis (Kütz.) Kütz.
Amphora perpusilla (Grun.) Grun.
Asterionella ralfsii W. Sm.
Aulacoseira sp.
Aulacoseira ambigua (Grun.) Simonsen *
Brachysira serians (Bréb. ex Kütz.) Round & D.G.Mann
Brachysira vitrea (Grun.) Ross
Caloneis hyalina Hust.
Caloneis sp.
Cocconeis pediculus Ehr.
Cocconeis placentula
Cyclotella ocellata Pant.
Cyclotella sp.
Cymbella aspera (Ehr.) H. Perag.
Cymbella cuspidata Kütz.
Cymbella inaequalis (Ehr.) Rabh.
Cymbella sp.
Desmogonium sp.
Diatoma mesodon (Ehr.) Kütz.
Encyonema lunatum (W. Sm. in Grev.) VanHeurck
Encyonema minutum (Hilse ex Rabh.) D. G. Mann
Eunotia arcus Ehr.
Eunotia bidentula W. Sm.
Eunotia bigibba Kütz.
Eunotia bilunaris (Ehr.) Mills
Eunotia carolina Patr.
Eunotia curvata (Kütz.) Lagerst.
Eunotia curvata var. *subarcuata* (Naeg ex . Kütz.) Woodhead & Tweed
Eunotia diadon Ehr.
Eunotia elegans Østrup
Eunotia exigua (Bréb. ex Kütz.) Rabh.
Eunotia fallax A. Cl.
Eunotia flexuosa Bréb ex Kütz.
Eunotia formica Ehr.
Eunotia incisa W. Sm.
Eunotia indica Grun.
Eunotia lapponica Grun.
Eunotia major (W. Sm.) Rabh.
Eunotia meisteri Hust.
Eunotia muscicola var. *tridentula* Norpel & Lange-Bertalot
Eunotia naegelii Migula
Eunotia paludosa Grun.
Eunotia pectinalis (O. F. Müll) Rabh.
Eunotia pectinalis var. *minor* (Kütz.) Rabh.
Eunotia praerupta Ehr.
Eunotia rhomboidea Hust.
Eunotia rostellata Hust.
Eunotia septentrionalis Østrup
Eunotia serra Ehr.
Eunotia soleirolii (Kütz.) Rabh.
Eunotia sp.
Eunotia steineckii Petersen
Eunotia sudetica (O. F. Müll)
Eunotia suecica A. Cl.
Eunotia tenella (Grun.) Hust.
Eunotia vanheurckii Patr.
Fragilaria vaucheriae (Kütz.) J. B. Petersen
Fragilaria sp.
Fragilariforma constricta (Ehr.) Williams & Round
Fragilariforma sp.
Fragilariforma virescens (Ralfs) Williams & Round
Frustulia amphipleuroides (Grun.) Cleve-Euler
Frustulia crassinervia (Bréb) Lange-Bertalot & Krammer
Frustulia pseudomagaliesmontana Camburn & Charles
Frustulia rhomboides (Ehr.) DeT.
Frustulia saxonica Rabh.
Gomphonema affine Kütz.
Gomphonema olivaceum (Lyngb.) Kütz.
Gomphonema parvulum (Kütz.) Kütz.
Gomphonema truncatum var. *turgidum* (Ehr.) Patr.
Gyrosigma sp.
Hippodonta hungarica (Grun.) Lange-Bert. Metzeltin & Witkowski
Lemnicola hungarica (Grun.) Round & Basson
Meridion circulare (Grev.) C. Agardi
Navicula angusta Grun.
Navicula cryptocephala Kütz.
Navicula cryptotenella Lange-Bert.
Navicula exilis Kütz.
Navicula lanceolata (Ag.) Kütz. *
Navicula minima Grun.
Navicula rynchocephala Kütz.
Navicula seminulum Grun.
Navicula sp.
Navicula tripunctata (O. F. Müll) Bory
Navicula tripunctata var. *schizonemoides* (VanHeurck) Patr.

Table 2. (Continued)

Neidium affine (Ehr.) Pfitz.
Neidium dubium (Ehr.) Cl.
Neidium iridis (Ehr.) Cl.
Neidium ladogense var. *densistriatum* (Østrup) Foged
Neidium sp.
Nitzschia acicularis (Kütz.) W. Sm.
Nitzschia amphibia Grun.
Nitzschia dissipata (Kütz.) Grun.
Nitzschia fasciculata Grun.
Nitzschia inconspicua Grun.
Nitzschia palea (Kütz.) W. Sm.
Nitzschia sp.
Pinnularia abaujensis (Pant.) Ross
Pinnularia biceps f. *petersenii* Ross
Pinnularia biceps Greg.
Pinnularia borealis (Ehr.)
Pinnularia brebissonii (Kütz.) Rabh.
Pinnularia burkii Patr.
Pinnularia divergens var. *bacillaris* (M. Perag.) Mills
Pinnularia sp.
Pinnularia subcapitata Greg.
Pinnularia viridis (Nitz.) Ehr.
Placoneis sp.
Planothidium lanceolatum (Bréb.) Bukht. & Round
Pleurosira laevis (Ehr.) Compére
Rhoicosphenia curvata (Kutz.) Grun.
Semiorbis hemicyclus (Ehr.) Patr.
Stauroneis cf smithii Grun.
Stauroneis phoenicenteron (Nitz.) Ehr.
Stauroneis prominula (Grun.) (Ehr.)
Staurosirella pinnata (Ehr.) Williams & Round
Stenopterobia anceps (Lewis) Bréb.
Stenopterobia cruvula (W. Sm.) Krammer
Stenopterobia delicatissima (Lewis) Bréb. ex VanHeurck
Stenopterobia sp.
Stephanocyclus meneghiniana (Kutz.) Skabitschevsky
Stephanodiscus sp.
Surirella sp.
Synedra sp.
Synedra ulna (Nitz.) Ehr.
Tabellaria flocculosa (Roth) Kütz.
Tabellaria quadraceptata Knudson
Tetracyclus rupestris (Braun) Grun.
Tryblionella sp

*2003 *Achnanthes* cf. *pusilla* (Grun.) DeT.
2002 *Aulacoseira* cf. *ambigua* (Grun.) Simonsen
2003 *Navicula* cf. *lanceolata* (Ag.) Kütz.

Table 3. Species and genus richness for four stream types sampled in 2002 and 2003. Analysis of variance revealed no significant difference in species richness or genus richness between stream types. For all stream types except abandoned bog (n = 2), n = 4.

	Species richness			Genus richness		
Stream type	Mean (± 1 SD)		Median	Mean (± 1 SD)		Median
Developed/Agricultural	31.3	± 15.6	34.5	15.3	± 8.9	15.5
Active-cranberry	24.8	± 5.7	26.5	12.3	± 3.9	11.0
Abandoned-bog	30.5	± 4.9	30.5	12.0	± 0.0	12.0
Forest	23.8	± 7.5	20.0	10.8	± 3.1	10.0

Table 4. MRPP comparison of species composition between stream types based on 2-year (2002-2003) mean relative-abundance samples (14 sites and 132 species). Stream types include forest (F), abandoned-bog (A), active-cranberry (C), and developed/agricultural (D) streams. Comparisons are listed in order of decreasing *p* values. Tests significant after the Bonferroni adjustment are indicated with an asterisk. For all stream types except abandoned bog (n = 2), n = 4.

Stream type comparison			A	Initial *p* value
D	vs.	C	0.337	0.008*
D	vs.	F	0.128	0.010*
C	vs.	F	0.235	0.014
D	vs.	A	0.150	0.035
C	vs.	A	0.181	0.090
A	vs.	F	0.045	0.259

Table 5. Relationship of species-level diatom-assemblage gradients, based on composite 2002-2003 samples (14 sites and 132 species), to environmental factors. Spearman rank correlations significant after the Bonferroni adjustment are indicated with an asterisk.

		DCA Axis 1			DCA Axis 2		
Factor	N	r	*p*		r	*P*	
pH	14	0.83	< 0.001	*	-0.39	0.169	
Specific conductance	14	0.75	0.002	*	0.25	0.383	
Altered land	14	0.64	0.014		0.18	0.537	
Wetland agriculture	14	0.37	0.191		0.65	0.012	
Basin area (km^2)	14	0.42	0.131		-0.42	0.135	
Canopy cover	14	0.23	0.434		-0.12	0.684	
Discharge rank	12	0.43	0.163		-0.50	0.094	
Wetlands and water	14	-0.17	0.553		0.70	0.006	*

Table 6. The mean percentage composition (± 1 SD) of dominant-diatom taxa by pH class. Dominant-diatom taxa are those comprising more than 75% of a sample. The pH classes are acidobiontic-acidophilous, indifferent (circumneutral), and alkalibiontic-alkaliphilous. For all stream types, except abandoned bog (n = 2), n = 4.

	Stream Type				No of species per class
pH category	Developed/ Agriculture	Active cranberry	Abandoned bog	Forest	
Acidobiontic-acidophilous	29.5 ± 19.9	79.8 ± 7.8	73.2 ± 9.1	77.9 ± 12.2	14
Indifferent (circumneutral)	47.4 ± 22.6	--	--	--	2
Alkalibiontic-alkaliphilous	--	2.6 ± 5.2	10.5 ±14.8	--	2
Not classified	1.0 ± 1.9	--	--	3.9 ± 7.9	3
Number of dominant species	4.0 ± 2.9	1.8 ± 1.0	5.0 ± 0.0	3.3 ± 2.2	
% Sample	77.9 ± 2.1	82.4 ± 6.4	83.7 ± 5.8	81.8 ± 6.2	

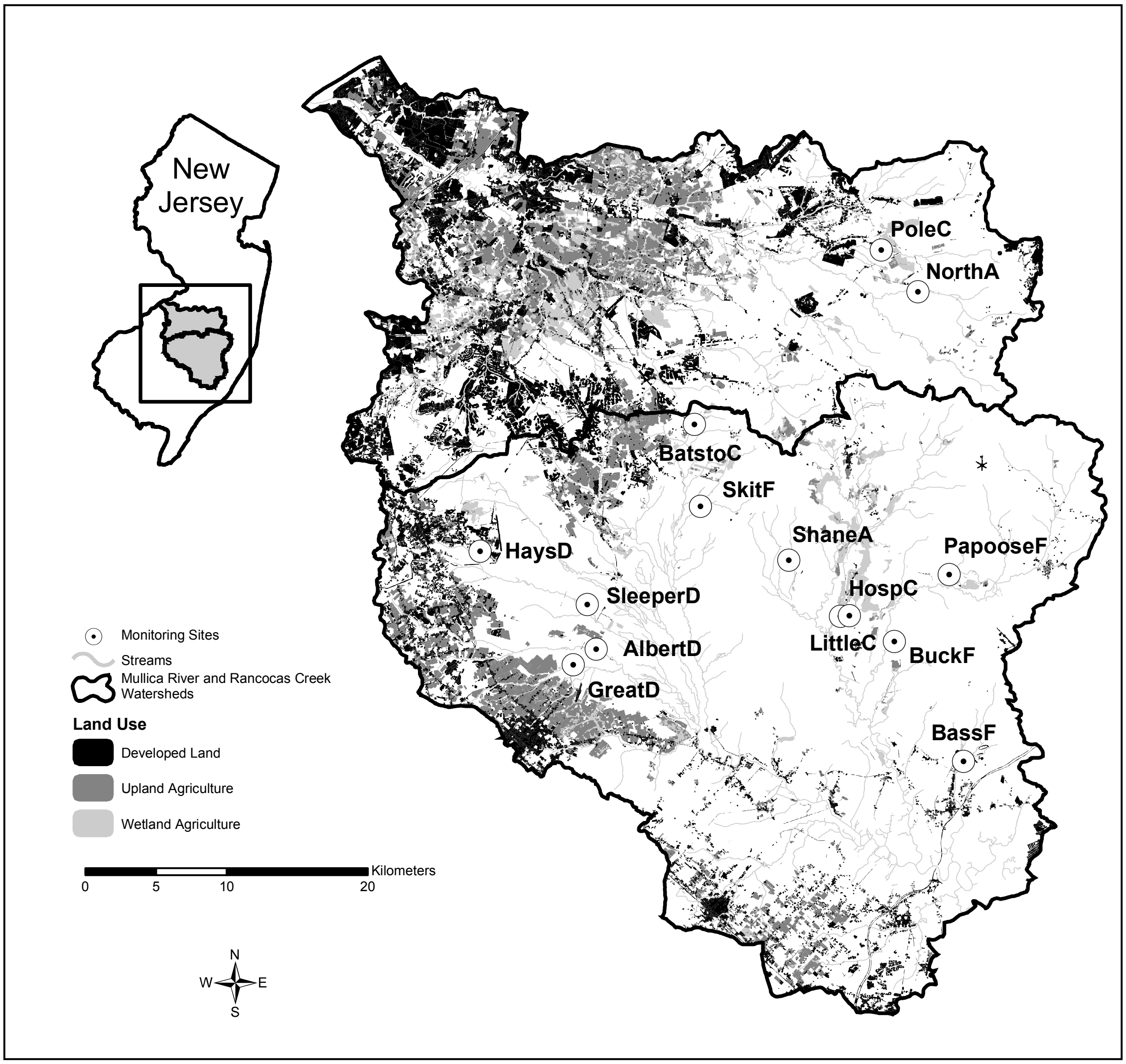

Figure 1. Location of 14 diatom sampling sites in the Mullica River and Rancocas Creek basins, including forest (F), abandoned-bog (A), active-cranberry (C), and developed/agricultural (D) stream types. The first few letters of each site name are shown. The last capital letter refers to the stream type. Refer to Table 1 for complete site names.

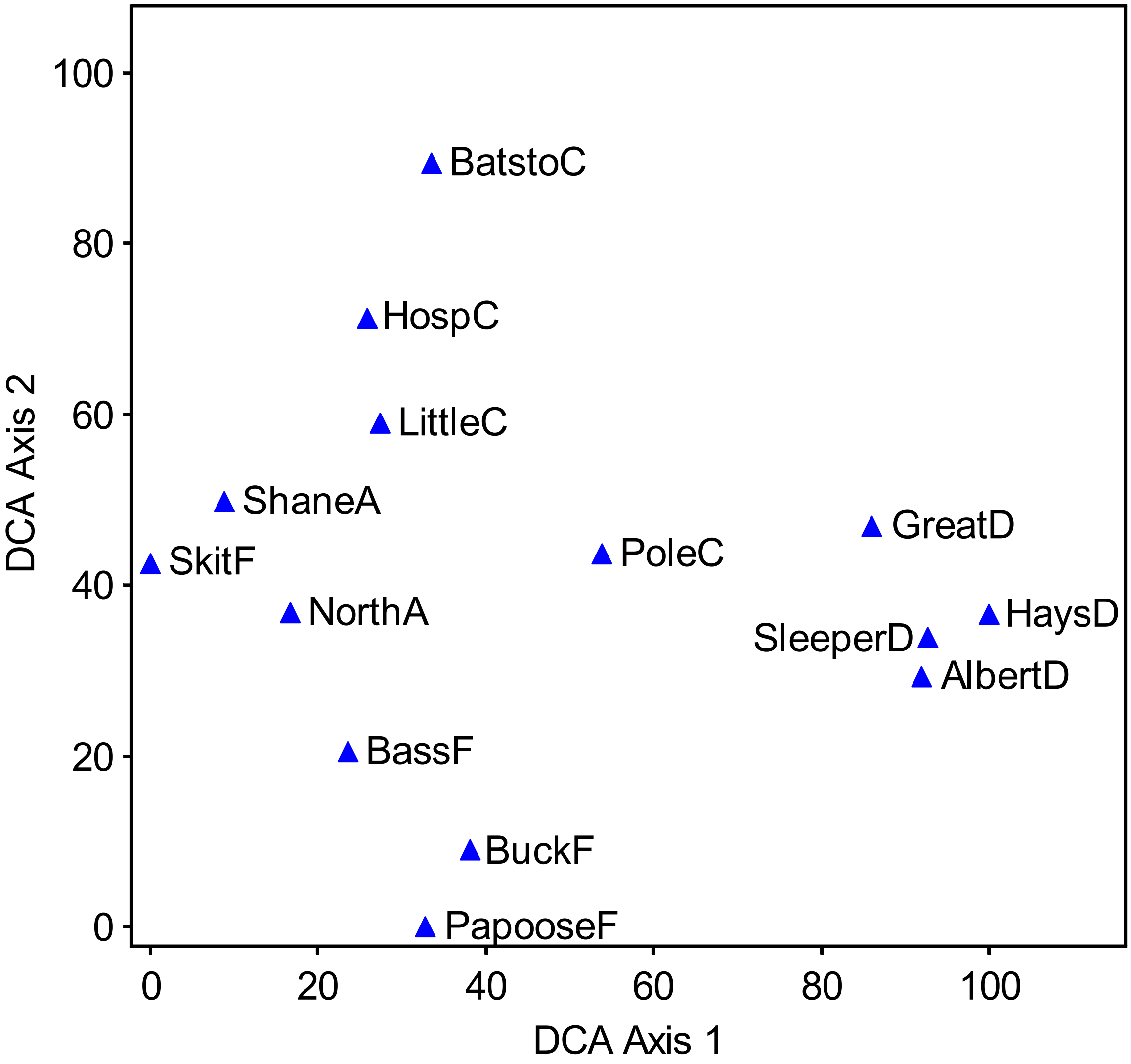

Figure 2. Species-level DCA site ordination based on composite samples collected in 2002 and 2003 at 14 sites, including forest (F), abandoned-bog (A), active-cranberry (C), and developed/agricultural (D) stream types. The first few letters of each site name are shown. The last capital letter refers to the stream type. Refer to Table 1 for complete site names.

PART 4. VEGETATION IN PINELANDS STREAMS DRAINING ACTIVE-CRANBERRY BOGS, ABANDONED-CRANBERRY BOGS, AND FOREST LAND

Kim J. Laidig

Abstract

Channel and bank vegetation from eleven Pinelands streams draining forest land, abandoned-cranberry bogs, and active-cranberry bogs were compared. The objectives were to determine if channel and bank plant-species composition was related to differences in upstream land use (forest land, abandoned-cranberry bogs, and active-cranberry bogs) and environmental factors, including water temperature, dissolved oxygen, pH, specific conductance, basin area, channel-vegetation cover, bank-vegetation cover, substrate texture (muck or sand), total-canopy cover, canopy-species cover, bankfull-channel depth, bankfull-channel width, and discharge rank. Detrended correspondence analysis and TWINSPAN were used to ordinate and classify the eleven stream sites and channel and bank vegetation using presence-absence, relative-cover, and absolute-cover data. Nonparametric multi-response permutation procedures (MRPP) were used to compare the same three measures of channel and bank vegetation composition between stream types. The study sites were characterized by low pH, specific conductance, dissolved oxygen, and discharge values with muck as the dominant bank and channel sediment. Channel and bank-vegetation quadrats yielded 114 vascular plant species, including 83 herbaceous and 31 woody species, with the majority of species considered native to the Pinelands. Total channel and bank-vegetation cover and channel and bank species richness did not differ significantly between forest, cranberry, and abandoned-bog sites. Ordination of channel and bank vegetation based on presence-absence, relative-cover, and absolute-cover data produced similar results. However, presence-absence data most clearly contrasted forest, cranberry, and abandoned-bog site groups. Ordination and classification of channel-vegetation presence-absence data revealed a distinct cranberry to abandoned-bog to forest site gradient. This gradient was correlated with increasing Atlantic white cedar-canopy cover and dissolved oxygen and decreasing red maple-canopy cover and specific conductance. Ordination and classification of bank-vegetation presence-absence data revealed a cranberry and abandoned-bog to forest site gradient. This gradient was correlated with increasing cedar-canopy cover and decreasing maple-canopy cover and specific conductance. Although the MRPP analysis of channel-vegetation presence-absence data indicated an overall significant difference, post-hoc comparisons indicated no significant differences between the three site groups. For bank vegetation, MRPP analysis of presence-absence data indicated significant differences between the three site groups. Differences in bank-vegetation and channel-vegetation composition between site groups appear to be most closely related to the type of canopy cover at the site. Whether canopy type is determined by land use is not known.

Introduction

Several studies have compared the aquatic and wetland plants in Pinelands streams draining forested watersheds with streams draining lands with a high percentage of development and upland agriculture (Morgan and Philipp 1986, Zampella and Laidig 1997, Zampella et al. 2001, 2003). Forested Pinelands streams are characterized by acid waters that are low in nutrients and other dissolved solids, whereas streams degraded by upland agriculture and development are generally characterized by elevated pH and dissolved-solid concentrations (Morgan and Good 1988, Zampella 1994). A major difference between sites in forested watersheds and those in heavily farmed and developed watersheds is the occurrence of nonnative plants in the degraded streams.

Sites surveyed in forested watersheds by Zampella and Laidig (1997) and Zampella et al. (2001, 2003) included active-cranberry agriculture and abandoned-cranberry bogs. No major differences in native plant species composition, based on presence-absence data, were observed between watersheds with past or present cranberry agriculture and those with no history of wetland agriculture. A number of streams in cranberry drainages were described as reference sites, which are sites located in drainages with a high percentage of forest and native plant communities and minimal developed or upland agricultural land. The assumption that drainages with cranberry bogs can represent reference watersheds is important because such benchmarks are used to assess the integrity of other sites.

In this study, I compared channel and bank vegetation from Pinelands streams draining three different land uses, including forest, abandoned-cranberry bogs, and active-cranberry bogs. All three land-use types represent acid-water streams with minimal upland agriculture or developed lands. I address two major questions. First, is channel and bank plant-species composition related to differences in upstream land use within the associated drainage basin? Second, is channel and bank plant-species composition related to environmental factors, including water quality, channel and basin morphology, and tree-canopy cover?

Methods

Land Use and Study Site Selection

Three to four streams representing each of the three land-use types, including forest, abandoned-cranberry bog (abandoned-bog), and active-cranberry bog (cranberry) were selected (Figure 1, Table 1). All eleven streams were included in earlier water-quality, stream-vegetation, fish or anuran studies and land-use profiles were completed as part of those studies (Zampella et al. 2001, 2003). The data set used to create the land-use profiles uses a modified Anderson et al. (1976) system. In this study, I refer to the Anderson-type land-use classes of urban land, agriculture, and agricultural wetlands as developed land, upland agriculture, and wetland agriculture, respectively. Collectively, developed land and upland agriculture is referred to as altered land. The combined area of upland forest, water, wetlands, and barren land is described as forest. Wetland agriculture includes cranberry bogs and blueberry fields. Most wetland agriculture in the study basins is cranberry agriculture.

The percentage of developed land and upland agriculture was low in all eleven drainage areas (Table 1). Altered land, which was generally highest in the cranberry drainage areas, did not exceed ten percent in any basin. The four forest sites were located in watersheds with no apparent agricultural history. Abandoned-bog sites were located in streams draining abandoned-cranberry bogs and forest. The three cranberry sites were located immediately downstream from active-cranberry farms and were bordered by abandoned bogs. All abandoned bogs have succeeded to emergent, shrub, or forested wetlands types. The percentage of wetland agriculture in the cranberry drainage basins ranged from 8.4 to 34.3% and the percentage of forest ranged from 57% to 91%.

Environmental Factors

From May through November 2001 and April through November 2002, pH, specific conductance, dissolved oxygen, and temperature were measured monthly at road or trail crossings in the vicinity of vegetation sampling sites. All water-quality measurements were completed under baseflow conditions. Specific conductance was measured with an Orion model-122 meter, pH was measured using an Orion model-250A meter, and temperature and dissolved oxygen were measured with a YSI 52 dissolved-oxygen meter. All available data were used to calculate median values for each sampling site.

Stream discharge was monitored at seven vegetation-sampling sites on 63 to 64 dates between October 2000 and October 2003. The Batsto River and Skit Branch sites were monitored for a shorter period (March 2002 to October 2003 and October 2000 to October 2001, respectively). Median discharge values for the period of record at these sites were less than 17 cfs. Discharge was not measured at Buck Run and Deep Run. To allow a comparison of all sites where discharge was measured, including Batsto River and Skit Branch, available discharge values for each date were ranked and these ranks were used to calculate a median discharge rank for each site.

Stream habitat was evaluated at cross-sectional transects placed at 25-m intervals. The number of transects established along each stream, which depended on the length of accessible habitat, ranged from 5 to 42 with a mean (± 1 SD) of 15 ± 11. Bankfull-channel depth and bankfull-channel width were measured at each transect. Depth was recorded at 10-cm intervals. At five points along each transect, including the right and left bank, the right and left side of the channel, and the thalweg (deepest point in the channel), I subjectively described streambed substrate texture as muck or sand. To obtain an estimate of shading and canopy composition above each transect, I used a spherical densiometer to measure canopy cover and identify the dominant canopy-tree species. If a single tree species was not clearly dominant, canopy composition was recorded as mixed.

Using the data from each transect, mean bankfull-channel depth, bankfull-channel width, and canopy-cover values were calculated for each stream. Sediment values represent the number of points, given as a percentage of total points, where each type of substrate was found in a stream. Similarly, canopy composition is expressed as the percentage of transects where a dominant, individual canopy-tree species was found.

Vegetation Sampling

I estimated total plant cover and the cover of individual vascular-plant species in 0.5-m by 0.5-m quadrats set at five points along each transect, including the right and left bank, the right and left side of the channel, and the thalweg. Cover estimates were limited to vegetation <

1.0 m tall. Sampling was conducted in July and August, 2001 and in August and September, 2002. Taxonomic nomenclature follows Gleason and Cronquist (1991).

Using the percentage-cover data for each species from the two bank quadrats and the three channel quadrats, I calculated average bank and channel percentage-cover values for each transect and grand averages for each stream. I used the same procedure and total plant-cover data to calculate mean channel-vegetation and bank-vegetation cover. Percentage-cover data was used to calculate total, bank, and channel species richness for each stream.

Data Analysis

I used detrended correspondence analysis (DCA, Hill 1979a, Hill and Gauch 1980) and TWINSPAN (Hill 1979b) to ordinate and classify stream vegetation and the eleven stream sites. Separate channel and bank vegetation ordinations were completed using presence-absence, relative-cover, and absolute-cover values. Untransformed data were used in the ordinations because preliminary ordinations using untransformed data and log, arcsine, and arcsine-squareroot transformed data yielded similar results. Default settings were used in the TWINSPAN and DCA analyses. To limit the effect of rare species on the ordinations, only species occurring at two or more sites were included in the analyses. With two exceptions, plant specimens that were identified only to genus were eliminated from the analyses if the genus was represented by known species. Panic-grasses that were difficult to identify in the field were lumped into a composite species (*Panicum* sp.). *Utricularia* sp. was another composite species that included *U. fibrosa*, among other aquatic bladderworts.

Spearman rank correlations were used to relate the first and second DCA axes of the channel and bank ordinations to water quality (pH, specific conductance, temperature, and dissolved oxygen), channel and basin (bankfull-channel depth, bankfull-channel width, channel and bank muck frequency, drainage area, discharge rank), and canopy variables, including total-canopy cover, Atlantic white cedar (*Chamaecyparis thyoides*) cover, red maple (*Acer rubrum*) cover, pitch pine (*Pinus rigida*) cover, and mixed species cover. Within these groups of related correlations, the alpha level was corrected for multiple comparisons using the sequential Bonferroni method (Rice 1989, 1990).

Separate nonparametric multi-response permutation procedures (MRPP, McCune and Mefford 1999) were used to compare vegetation composition between stream types based on presence-absence, relative-cover, and absolute-cover data for channel vegetation and bank vegetation. The MRPP analyses were based on Euclidean distance, and the alpha levels of the multiple tests were adjusted using the sequential Bonferroni method (Rice 1989, 1990). I report the p and A values for each analysis. The p value describes the likelihood that an observed difference is due to chance. The A statistic (chance-corrected within-group agreement) describes agreement within groups (i.e., stream type). $A = 1$ when all attributes within a group are identical, $A = 0$ when within group heterogeneity equals that expected by chance, and $A < 0$ when within-group heterogeneity is greater than expected by chance. I used separate Kruskal-Wallis ANOVA tests to compare species richness and total plant cover for both channel and bank vegetation.

An alpha level of 0.05 was used to assess significance for all tests. Ordinations, TWINSPAN classifications, and MRPP analyses were performed using PC-ORD for Windows 4.27 (MjM Software, Gleneden Beach, OR). Kruskal-Wallis ANOVAs and correlation analyses were performed using Statistica 7.1 (StatSoft, Inc., Tulsa, OK).

Results and Discussion

Environmental Factors

The eleven stream sites were acidic (<4.9) and, with the exception of Deep Run, had very low conductance values (<50 μS cm^{-1}) (Table 2). All sites where stream flow was measured exhibited low median discharge values (<17 cfs). Dissolved oxygen concentrations were also low with percent-saturation values ranging from 30% to 72%. Bankfull-channel depth at the eleven sites ranged from 17 to 63 cm and bankfull-channel width ranged from 2.5 to 6.1 m. Muck was the dominant channel and bank sediment at all but one of the sites. When present, canopy cover was dominated by Atlantic white cedar, red maple and other hardwoods, and mixed cedar and maple forests. Pitch pine canopy occurred at two of the sites. Drainage basin area ranged from 4.0 to 56.6 km^2. Forest sites generally exhibited higher dissolved oxygen, lower water temperature, higher cedar-canopy cover, and lower maple-canopy cover values. Total-canopy cover was highest in forest sites and lowest in the more open abandoned-bog sites.

Stream-vegetation Inventory

A total of 114 vascular plant species, including 83 herbaceous and 31 woody species, were found at the eleven study sites (Appendix). Based on a plant classification scheme described in Zampella et al. (2001, 2003), the majority of these species are considered native to the Pinelands. *Ludwigia palustris* and *Carex lurida*, species that are considered indicators of land-use related watershed disturbance (Zampella and Laidig 1997), were each found at a single cranberry site. Ninety plant species were found in channel plots and one hundred and nine species were associated with bank plots. Total plant-species richness at the eleven sites ranged from 20 to 54. The cranberry site group had the highest mean channel species richness. However, analysis of variance indicated no significant difference in bank-, channel-, or total-species richness between forest, abandoned-bog, and cranberry sites.

The lowest (5%) and highest (47%) channel-plant cover occurred at cranberry sites (Table 2). With the exception of one site, total channel-plant cover was lower than the adjacent banks. Total plant cover on the stream banks ranged from 10% to 65%. The forest site group had the lowest mean bank-plant cover. However, analysis of variance revealed no significant difference in total channel-plant cover and total bank-plant cover between the stream types.

Total cover for the majority of individual species was low (< 5%) for both bank and channel habitats (Appendix). Fourteen bank species and eight channel species reached average cover values of greater than 5% at one or more sites. For plants occurring on stream banks, the greatest cover values were obtained for several shrub species, including *Chamaedaphne calyculata*, *Clethra alnifolia*, and *Vaccinium macrocarpon*, and six wetland-herbaceous plants, including *Sparganium americanum*, *Leersia oryzoides*, *Eleocharis tenuis*, *Carex striata*, *Carex* *exilis*, and *Peltandra virginica*. Aquatic and wetland plants with the highest cover values in stream channels included *Sparganium americanum*, *Scirpus subterminalis*, *Utricularia* sp., and *Eleocharis robbinsii*.

Channel-vegetation Composition

The first DCA axis of the presence-absence ordination contrasted forest sites, shown on the right side of the site diagram, with cranberry sites shown on the left side of the diagram (Figure 2, Table 3). Abandoned-bog sites were more centrally located along the first axis. The first division of the TWINSPAN classification separated forest sites and two abandoned-bog sites (Tulpehocken Creek and Shane Branch) from cranberry sites and the remaining two abandoned-bog sites. The species ordination contrasted plants absent from forest sites and encountered most frequently at cranberry sites with species generally absent from cranberry sites and encountered most frequently at forest sites (Table 3). The MRPP analysis of presence-absence data indicated an overall significant difference in channel-vegetation composition between stream types (A = 0.056, $p = 0.009$). Post-hoc tests revealed a significant difference only between forest and cranberry site types, but this difference was not significant after the Bonferroni correction.

The first DCA-axis site scores of the ordinations based on presence-absence, relative-cover values, and absolute-cover data were strongly correlated ($r = 0.91$, $p < 0.001$ for presence-absence vs. relative cover, $r = 0.92$, $p < 0.001$ for presence-absence vs. absolute cover, and $r = 0.89$, $p < 0.001$ for relative cover vs. absolute cover). The second axes of the different ordinations were not correlated. The first DCA axis of all three ordinations generally contrasted forest sites with most cranberry and abandoned-bog sites (Figure 2). However, the presence-absence ordination more clearly separated the cranberry and abandoned-bog sites and represented a cranberry to abandoned-bog to forest gradient. The more pronounced contrast between site types in the presence-absence ordination compared to the relative and absolute-cover ordinations was due in part to variations in species cover between sites. Where two sites with the same species are considered identical based on presence-absence data, they appear less similar when differences in percentage cover are considered. Results of the MRPP analyses based on relative cover and absolute cover revealed no significant difference between site types.

The first DCA-axis site scores of the presence-absence ordination were correlated with increasing cedar-canopy cover and decreasing maple-canopy cover (Table 4). Cedar-canopy cover was also correlated with the first axis of both the relative-cover and absolute-cover ordinations. The forest sites and two abandoned-bog sites (Tulpehocken Creek and Shane Branch) had relatively high cedar-canopy values, whereas the other two abandoned-bog sites and most cranberry sites had higher maple-canopy cover. The first axes of all three ordinations were correlated with both specific conductance and dissolved oxygen (Table 4). Specific conductance decreased along these axes. The opposite trend was observed for dissolved oxygen. Statistical significance varied for the individual correlations following the Bonferroni correction.

The contrast between species associated with the forest and cranberry ends of the vegetation gradient based on presence-absence data may be directly related to the forest types that border the study streams. Of the ten plants associated with the forest end of the presence-absence vegetation gradient, only one species, *Sparganium americanum*, was not reported by Laidig and Zampella (1999) as occurring in the understory of Pinelands cedar swamps. Conversely, only five of the ten plants associated with the cranberry end of the gradient were found in the understory of cedar swamps (Laidig and Zampella 1999). The five plants not associated with cedar swamps included *Scirpus cyperinus*, *Itea virginica*, *Juncus effusus*, *Panicum virgatum*, and *Panicum verrucosum.* Unlike *Sparganium americanum*, which is an aquatic macrophyte, the five exceptions are wetland species.

Bank-vegetation Composition

The first DCA axis of the bank-vegetation presence-absence ordination contrasted forest sites, shown on the right side of the site diagram, with cranberry sites and abandoned-bog sites on the left side of the diagram (Figure 2, Table 5). The first division of the TWINSPAN classification also separated the four forest streams from the cranberry and abandoned-bog sites. Cranberry sites and a single abandoned-bog site (N. Br. Mt. Misery Brook) were separated from the remaining abandoned-bog sites in the second TWINSPAN division. The species ordination contrasted plants absent from forest sites and generally encountered most frequently at cranberry sites with species generally absent from cranberry sites and encountered most frequently at forest sites (Table 5).

The major patterns displayed by the presence-absence and absolute-cover ordinations were more similar to each other than to the relative-cover ordination (Figure 2). The first DCA-axis site scores of the ordination based on absolute-cover values were correlated with site scores of the ordinations based on presence-absence ($r = 0.94$, $p < 0.001$) and relative cover ($r = 0.74$, $p = 0.010$). The first DCA-axis site scores of the presence-absence and relative-cover ordinations were not correlated ($r = 0.51$, $p = 0.105$). The second axes of only the presence-absence and absolute-cover ordinations were correlated ($r = 0.89$, $p < 0.001$). The first DCA axis of the presence-absence and absolute-cover ordinations contrasted forest sites with a mix of cranberry and abandoned-bog sites. Both ordinations revealed a cranberry and abandoned-bog to forest site gradient (Figure 2).

MRPP analyses of presence-absence data indicated an overall significant difference in bank-vegetation composition between the three site classes ($A = 0.073$, $p = 0.001$). Post-hoc comparisons showed a significant difference between cranberry and forest sites ($A = 0.091$, $p = 0.014$), cranberry and abandoned-bog sites ($A = 0.045$, $p = 0.039$), and forest and abandoned-bog sites ($A = 0.044$, $p = 0.007$). MRPP analyses based on relative cover and absolute cover revealed overall significant differences between the three site types ($A = 0.104$, $p = 0.005$ for relative cover; $A = 0.110$, $p = 0.011$ for absolute cover). Post-hoc tests indicated that, for relative cover, only abandoned-bog and forest site types ($A = 0.094$, $p = 0.013$) and cranberry and abandoned-bog site types ($A = 0.100$, $p = 0.020$) were significantly different. For absolute cover, only cranberry and forest site types were significantly different ($A = 0.087$, $p = 0.010$). The greater contrast between sites based on presence-absence data compared to the cover-data analyses were due in part to the variation in species cover between sites. Where two sites with the same species are considered identical based on presence-absence data, they appeared less similar when differences in percentage cover are considered.

The first axes of the bank-vegetation and channel-vegetation ordinations were correlated (r = 0.90, $p < 0.001$). With two exceptions, the first-axis site scores of the three bank-vegetation ordinations were correlated with increasing cedar-canopy cover, decreasing maple-canopy cover, and decreasing specific conductance (Table 4). The two exceptions were the correlations between presence-absence scores and maple-canopy cover and relative-cover scores and cedar-canopy cover. Second-axis scores of the absolute-cover and presence-absence ordinations were correlated with increasing total-canopy cover, which reflected the higher total-canopy cover at cranberry and forest sites compared to abandoned-bog sites. Statistical significance varied for the individual correlations following the Bonferroni correction.

As noted in the channel-vegetation results, the contrast between species associated with the forest and cranberry ends of the bank-vegetation gradient based on presence-absence data may be directly related to the forest types that border the study streams. All ten species associated with the forest end of the bank-vegetation gradient were reported to occur in the understory of cedar swamps by Laidig and Zampella (1999). Conversely, only three of the ten plants associated with the cranberry end of the gradient were listed as occurring in the cedar understory. The seven species not associated with cedar swamps studied by Laidig and Zampella (1999) included an aquatic macrophyte, *Nuphar variegata*, and six wetland species, including *Itea virginica*, *Juncus effusus*, *Panicum virgatum*, *Panicum verrucosum*, *Eleocharis tenuis, and Cladium mariscoides.*

Summary

1. Bank and channel vegetation found in eleven Pinelands streams draining three different land uses, including forest land, abandoned-cranberry bogs, and active-cranberry bogs, were compared and related to environmental factors.

2. Environmental variables measured included water temperature, dissolved oxygen, pH, specific conductance, basin area, channel-vegetation cover, bank-vegetation cover, muck, sand, total-canopy cover, canopy-species cover, bankfull-channel depth, bankfull-channel width, and discharge rank.

3. The eleven streams were characterized by low pH, specific conductance, dissolved oxygen, and discharge values. Muck was the dominant bank and channel sediment at most sites.

4. One hundred and fourteen vascular plant species, including 83 herbaceous and 31 woody species were found at the eleven stream sites. The majority of these species are considered native to the Pinelands.

5. Channel, bank, and total-species richness did not differ significantly between forest, cranberry, and abandoned-bog sites.

6. Total channel and bank vegetation cover did not differ significantly between forest, cranberry, and abandoned-bog sites.

7. Ordination of channel and bank vegetation based on presence-absence, relative-cover, and absolute-cover data produced similar results. However, in both cases, presence-absence data most clearly distinguished forest, cranberry, and abandoned-bog site groups.

8. Ordination of channel-vegetation presence-absence data revealed a cranberry to abandoned-bog to forest site gradient. Although the MRPP analysis of channel-vegetation presence-absence data indicated an overall significant difference, post-hoc comparisons indicated no significant differences between the three site groups.

9. Ordination and classification of bank vegetation clearly separated forest sites from cranberry and abandoned-bog sites. Bank-vegetation composition based on presence-absence data differed significantly between all site groups. Ordination of the presence-absence data revealed a cranberry and abandoned-bog to forest site gradient.

10. The first DCA axis of the channel-vegetation ordination based on presence-absence data was correlated with increasing cedar-canopy cover and dissolved oxygen and decreasing maple-canopy cover and specific conductance. The first axis of the bank-vegetation ordination based on presence-absence data was correlated with increasing cedar-canopy cover, decreasing maple-canopy cover and decreasing specific conductance.

11. Differences in bank-vegetation and channel-vegetation composition between site groups appear to be most closely related to the type of canopy cover at the site. Whether canopy type is determined by land use is not known.

Acknowledgements

Robert Zampella, Nicholas Procopio, John Bunnell, Jennifer Ciraolo, Christina Burns, and Jason Shvanda provided valuable assistance with various aspects of the study. The New Jersey Division of Parks and Forestry authorized the state-lands research permits. Funding for this study was provided by the U. S. Environmental Protection Agency (State Wetlands Grant Program, Grant No. CD-99298001-1), the Pinelands Commission, and the National Park Service.

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Table 1. Land-use characteristics of forest, abandoned-bog, and cranberry streams. Land-use values are expressed as a percentage of basin area. Altered land includes developed land and upland agriculture.

Site Type and Stream Name	Altered land	Wetland agric.	Upland forest	Water	Wetlands	Barren land
Forest Streams						
Buck Run	0.0	0.0	86.5	0.2	13.3	0.0
E. Br. Bass River	2.0	0.0	82.7	1.0	14.0	0.2
Papoose Branch	0.0	0.0	87.5	0.0	12.4	0.1
Skit Branch	0.3	0.0	80.3	0.0	19.4	0.0
Mean	**0.6**	**0.0**	**84.3**	**0.3**	**14.8**	**0.1**
SD	**1.0**	**0.0**	**3.3**	**0.5**	**3.1**	**0.1**
Median	**0.2**	**0.0**	**84.6**	**0.1**	**13.7**	**0.0**
Abandoned-bog Streams						
Deep Run	0.2	0.0	15.9	4.2	79.7	0.0
N. Br. Mt. Misery Brook	3.3	0.1	86.1	1.4	9.2	0.0
Shane Branch	0.4	0.0	50.8	0.0	48.8	0.0
Tulpehocken Creek	0.2	0.1	61.3	1.0	37.4	0.0
Mean	**1.0**	**0.0**	**53.5**	**1.7**	**43.8**	**0.0**
SD	**1.5**	**0.0**	**29.1**	**1.8**	**29.2**	**0.0**
Median	**0.3**	**0.0**	**56.0**	**1.2**	**43.1**	**0.0**
Cranberry Streams						
Batsto River	0.5	8.4	47.6	1.7	41.6	0.2
Hospitality Brook	8.4	34.3	24.7	6.9	23.0	2.7
Little Hauken	2.3	25.1	32.9	7.5	31.8	0.3
Mean	**3.7**	**22.6**	**35.1**	**5.4**	**32.1**	**1.1**
SD	**4.1**	**13.1**	**11.6**	**3.2**	**9.3**	**1.4**
Median	**2.3**	**25.1**	**32.9**	**6.9**	**31.8**	**0.3**

Table 2. Basin size, canopy cover, and in-stream characteristics of forest, abandoned-bog, and cranberry streams. Plant-cover, canopy-cover, and substrate values are percentages.

Site Type and Stream Name	Basin area (km^2)	Bankfull-channel depth (cm)	Bankfull-channel width (m)	Dis-charge rank	pH	SC (µScm^{-1})	DO (mgL^{-1})	DO (%)	Temp (°C)	Channel-plant cover	Bank-plant cover	Total-canopy cover	Cedar-canopy cover	Maple-canopy cover	Pine-canopy cover	Mixed-canopy cover	Channel muck	Channel sand	Bank muck	Bank sand
Forest Streams																				
Buck Run	7.8	42.9	4.0	-	4.8	26.5	6.0	63.5	18.9	26.8	34.1	73.5	100.0	0.0	0.0	0.0	73.3	26.7	100.0	0.0
E. Br. Bass River	21.1	60.9	5.3	9.0	4.4	37.4	6.8	67.7	18.9	14.1	22.4	52.9	100.0	0.0	0.0	0.0	52.4	47.6	100.0	0.0
Papoose Branch	11.4	52.5	5.2	5.0	4.7	29.9	7.1	68.6	17.6	8.7	9.6	86.4	50.0	5.6	0.0	44.4	74.1	25.9	100.0	0.0
Skit Branch	13.0	39.8	6.1	4.0	4.7	24.2	5.9	69.4	23.3	23.4	32.6	33.2	100.0	0.0	0.0	0.0	81.0	19.0	100.0	0.0
Mean	**13.3**	**49.0**	**5.1**	**6.0**	**4.6**	**29.5**	**6.5**	**67.3**	**19.7**	**18.2**	**24.6**	**61.5**	**87.5**	**1.4**	**0.0**	**11.1**	**70.2**	**29.8**	**100.0**	**0.0**
SD	**5.6**	**9.6**	**0.9**	**2.6**	**0.2**	**5.8**	**0.6**	**2.6**	**2.5**	**8.3**	**11.3**	**23.4**	**25.0**	**2.8**	**0.0**	**22.2**	**12.4**	**12.4**	**0.0**	**0.0**
Median	**12.2**	**47.7**	**5.2**	**5.0**	**4.7**	**28.2**	**6.4**	**68.2**	**18.9**	**18.7**	**27.5**	**63.2**	**100.0**	**0.0**	**0.0**	**0.0**	**73.7**	**26.3**	**100.0**	**0.0**
Abandoned-bog Streams																				
Deep Run	4.6	30.7	2.5	-	4.0	89.6	2.9	36.8	27.0	19.5	45.1	2.8	0.0	0.0	30.8	7.7	94.9	5.1	100.0	0.0
N. Br. Mt. Misery Brook	29.4	35.2	4.8	3.0	4.6	31.3	4.8	44.5	16.0	37.9	43.8	32.4	0.0	87.5	0.0	5.4	88.1	11.9	100.0	0.0
Shane Branch	4.6	17.1	2.5	1.0	4.2	39.4	4.7	57.6	27.2	16.6	36.3	39.8	24.2	31.2	0.0	30.4	51.2	48.8	100.0	0.0
Tulpehocken Creek	56.6	47.3	4.7	7.0	4.9	23.9	7.6	71.7	21.4	20.1	14.5	14.9	80.0	0.0	0.0	10.0	13.3	86.7	15.0	85.0
Mean	**23.8**	**32.6**	**3.6**	**3.7**	**4.4**	**46.0**	**5.0**	**52.6**	**22.9**	**23.5**	**34.9**	**22.5**	**26.1**	**29.7**	**7.7**	**13.4**	**61.9**	**38.1**	**78.8**	**21.3**
SD	**24.8**	**12.5**	**1.3**	**3.1**	**0.4**	**29.7**	**1.9**	**15.3**	**5.3**	**9.7**	**14.1**	**16.7**	**37.7**	**41.3**	**15.4**	**11.5**	**37.6**	**37.6**	**42.5**	**42.5**
Median	**17.0**	**32.9**	**3.6**	**3.0**	**4.4**	**35.4**	**4.7**	**51.1**	**24.2**	**19.8**	**40.0**	**23.7**	**12.1**	**15.6**	**0.0**	**8.8**	**69.6**	**30.4**	**100.0**	**0.0**
Cranberry Streams																				
Batsto River	4.0	37.8	3.5	1.0	4.5	45.1	2.6	29.6	22.0	20.8	32.7	71.4	1.3	31.3	0.0	67.5	91.7	8.3	97.5	2.5
Hospitality Brook	4.9	62.5	4.5	6.0	4.7	46.2	6.5	63.5	22.9	47.2	65.4	9.8	0.0	50.9	31.0	12.5	72.2	27.8	66.7	33.3
Little Hauken Run	15.6	63.0	4.4	8.0	4.6	49.1	4.4	40.6	21.3	5.3	26.3	57.3	0.0	100.0	0.0	0.0	68.1	31.9	93.5	6.5
Mean	**8.2**	**54.4**	**4.2**	**5.0**	**4.6**	**46.8**	**4.5**	**44.6**	**22.1**	**24.4**	**41.5**	**46.2**	**0.4**	**60.7**	**10.3**	**26.7**	**77.3**	**22.7**	**85.9**	**14.1**
SD	**6.4**	**14.4**	**0.6**	**3.6**	**0.1**	**2.1**	**2.0**	**17.3**	**0.8**	**21.2**	**21.0**	**32.3**	**0.7**	**35.4**	**17.9**	**35.9**	**12.6**	**12.6**	**16.8**	**16.8**
Median	**4.9**	**62.5**	**4.4**	**6.0**	**4.6**	**46.2**	**4.4**	**40.6**	**22.0**	**20.8**	**32.7**	**57.3**	**0.0**	**50.9**	**0.0**	**12.5**	**72.2**	**27.8**	**93.5**	**6.5**

Table 3. Channel-vegetation species scores based on ordination of presence-absence data. Species are ordered by raw DCA axis 1 scores. Frequency of occurrence (%) and mean percentage-cover values are presented for species found at forest (F), abandoned-bog (A), and cranberry (C) stream sites.

			Frequency			Cover		
Species	Ax1	Ax2	F	A	C	F	A	C
Scirpus cyperinus	-179	69	-	-	67	-	-	0.1
Itea virginica	-144	-11	-	-	67	-	-	0.2
Panicum virgatum	-125	83	-	25	67	-	<0.1	0.2
Juncus effusus	-125	83	-	25	67	-	0.7	0.8
Cuscuta sp.	-101	7	-	-	67	-	-	<0.1
Nyssa sylvatica	-101	7	-	-	67	-	-	<0.1
Panicum verrucosum	-77	100	-	25	33	-	<0.1	<0.1
Smilax rotundifolia	-77	100	-	25	33	-	<0.1	<0.1
Decodon verticillatus	-73	41	-	25	67	-	0.4	0.2
Glyceria obtusa	-68	204	-	50	100	-	0.7	0.1
Carex stricta	-50	-119	-	25	33	-	<0.1	<0.1
Nuphar variegata	-40	98	-	50	100	-	2.5	1.2
Vaccinium corymbosum	-27	-88	-	25	67	-	<0.1	0.9
Rhexia virginica	-25	-41	-	50	67	-	<0.1	<0.1
Sagittaria engelmanniana	-19	-32	25	50	100	0.1	<0.1	0.1
Eleocharis tenuis	-11	373	-	50	67	-	0.1	0.2
Woodwardia virginica	-8	-99	-	25	33	-	<0.1	<0.1
Aster nemoralis	0	-18	25	-	67	<0.1	-	<0.1
Leersia oryzoides	23	19	50	25	100	0.2	0.2	3.8
Lachnanthes caroliniana	26	-173	-	25	33	-	<0.1	<0.1
Gaylussacia frondosa	26	-173	-	25	33	-	<0.1	<0.1
Schizachyrium scoparium	32	4	25	-	33	<0.1	-	<0.1
Acer rubrum	37	-23	50	50	100	<0.1	0.1	0.2
Hypericum canadense	37	248	25	50	33	<0.1	<0.1	<0.1
Lysimachia terrestris	39	39	25	25	67	<0.1	<0.1	0.1
Carex striata	51	-90	-	50	-	-	0.5	-
Triadenum virginicum	64	100	50	100	100	<0.1	0.2	0.3
Dulichium arundinaceum	75	100	50	100	100	0.2	0.8	0.1
Eleocharis robbinsii	82	158	25	100	33	3.3	1.8	0.7
Eleocharis flav. v. olivacea	89	240	25	75	33	0.2	1.0	<0.1
Nymphaea odorata	90	9	50	75	67	0.6	0.8	0.3
Rubus hispidis	93	14	25	-	67	0.1	-	0.1
Chamaedaphne calyculata	95	123	50	100	67	0.2	3.4	1.7
Panicum spp.	95	14	50	25	67	0.1	<0.1	0.2
Chamaecyparis thyoides	115	-50	50	25	67	<0.1	<0.1	0.2
Ilex glabra	117	25	50	25	33	0.5	<0.1	<0.1
Cladium mariscoides	119	248	-	50	-	-	<0.1	-
Panicum longifolium	119	248	-	50	-	-	<0.1	-
Peltandra virginica	121	-9	50	25	67	0.1	0.2	0.9
Clethra alnifolia	139	-6	100	50	100	0.9	0.8	2.7
Vaccinium macrocarpon	148	136	50	100	33	0.1	0.2	0.1
Rhododendron viscosum	153	91	25	-	33	0.4	-	0.1
Utricularia spp.	170	89	75	75	67	0.4	4.1	0.1
Carex exilis	173	-176	25	25	-	0.2	<0.1	-
Carex trisperma	173	-176	25	25	-	<0.1	<0.1	-
Kalmia angustifolia	179	385	25	50	-	<0.1	<0.1	-
Scirpus subterminalis	186	25	100	75	67	7.2	4.0	0.8
Drosera intermedia	191	-42	50	50	-	0.1	<0.1	-
Carex atlantica	192	-97	50	25	33	<0.1	<0.1	<0.1
Bartonia paniculata	212	-18	25	-	33	<0.1	-	<0.1
Eubotrys racemosa	226	-17	75	50	33	0.5	0.2	0.2
Juncus pelocarpus	244	121	100	100	-	0.1	0.1	-
Sparganium americanum	246	51	50	-	33	0.1	-	7.5
Carex collinsii	258	-125	25	25	-	<0.1	<0.1	-
Drosera rotundifolia	263	83	75	50	-	0.1	<0.1	-
Rhynchospora alba	342	-21	50	-	-	<0.1	-	-
Gaylussacia dumosa	342	-21	50	-	-	0.3	-	-
Orontium aquaticum	358	141	50	25	-	0.2	0.1	-
Eriocaulon aquaticum	425	52	75	-	-	2.2	-	-

Table 4. Relationship of channel and bank-vegetation DCA axes to environmental variables. Spearman rank (r) correlations significant following the Bonferonni correction are noted with an asterisk.

		Presence-absence Ordination				Relative-cover Ordination				Absolute-cover Ordination			
		Axis 1		Axis 2		Axis 1		Axis 2		Axis 1		Axis 2	
	N	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Channel Vegetation													
Channel and Basin Variables													
Basin area	11	0.24	0.484	0.56	0.071	0.30	0.370	0.04	0.915	0.28	0.401	-0.38	0.247
Discharge rank	9	0.22	0.574	0.64	0.061	0.23	0.559	-0.01	0.983	0.23	0.559	-0.22	0.574
Bankfull-channel width	11	0.33	0.326	0.09	0.790	0.49	0.125	0.29	0.385	0.36	0.272	-0.18	0.593
Bankfull-channel depth	11	-0.05	0.873	0.18	0.593	0.11	0.750	0.02	0.958	0.07	0.832	0.18	0.593
Muck	11	-0.24	0.484	0.03	0.937	-0.32	0.340	0.18	0.593	-0.33	0.326	0.39	0.235
Canopy Variables													
Total-canopy cover	11	0.35	0.298	-0.55	0.077	0.44	0.180	-0.44	0.180	0.61	0.047	0.35	0.298
Cedar-canopy cover	11	0.86	0.001*	-0.35	0.295	0.81	0.003*	-0.19	0.570	0.91	0.000*	-0.62	0.042
Maple-canopy cover	11	-0.80	0.003*	-0.09	0.802	-0.56	0.072	-0.04	0.911	-0.61	0.046	0.71	0.015
Mixed-canopy cover	11	-0.23	0.500	-0.36	0.279	-0.06	0.860	0.17	0.623	-0.22	0.518	0.52	0.100
Water-quality Variables													
pH	11	0.37	0.259	0.02	0.958	0.57	0.066	0.31	0.355	0.45	0.170	-0.26	0.433
Specific conductance	11	-0.69	0.019	0.15	0.670	-0.79	0.004*	-0.12	0.729	-0.75	0.008*	0.58	0.060
Dissolved oxygen conc.	11	0.61	0.047	0.14	0.689	0.78	0.004*	0.35	0.285	0.55	0.077	-0.35	0.298
Temperature	11	-0.29	0.392	-0.25	0.466	-0.43	0.184	0.13	0.709	-0.41	0.205	-0.22	0.509
Bank Vegetation													
Channel and Basin Variables													
Basin area	11	0.12	0.719	-0.13	0.709	0.15	0.650	-0.02	0.958	0.28	0.401	-0.16	0.631
Discharge rank	9	0.03	0.932	0.01	0.983	-0.18	0.651	0.14	0.715	0.10	0.797	0.13	0.731
Bankfull-channel width	11	0.40	0.228	0.15	0.650	0.06	0.853	0.01	0.979	0.44	0.180	0.25	0.450
Bankfull-channel depth	11	0.00	0.989	0.52	0.102	-0.45	0.160	0.09	0.790	-0.12	0.729	0.49	0.125
Muck	11	0.47	0.145	-0.16	0.643	0.40	0.223	0.47	0.141	0.45	0.162	0.09	0.782
Canopy Variables													
Total-canopy cover	11	0.52	0.098	0.65	0.029	-0.22	0.519	0.52	0.102	0.32	0.340	0.80	0.003*
Cedar-canopy cover	11	0.94	0.000*	-0.18	0.599	0.57	0.065	0.08	0.826	0.94	0.000*	0.16	0.639
Maple-canopy cover	11	-0.60	0.050	0.60	0.051	-0.76	0.006*	-0.06	0.867	-0.74	0.009*	0.24	0.480
Mixed-canopy cover	11	-0.23	0.504	0.32	0.343	-0.36	0.279	-0.09	0.786	-0.33	0.321	0.10	0.775
Water-quality Variables													
pH	11	0.38	0.245	0.05	0.873	0.33	0.326	-0.01	0.979	0.47	0.142	0.05	0.894
Specific conductance	11	-0.72	0.012*	0.22	0.519	-0.62	0.043	0.06	0.853	-0.85	0.001*	0.10	0.770
Dissolved oxygen conc.	11	0.51	0.113	0.01	0.979	0.25	0.450	0.08	0.811	0.53	0.096	0.03	0.937
Temperature	11	-0.25	0.465	-0.49	0.124	0.16	0.630	-0.68	0.020	-0.22	0.518	-0.47	0.141

Table 5. Bank-vegetation species scores based on ordination of presence-absence data. Species are ordered by raw DCA axis 1 scores. Frequency of occurrence (%) and mean percentage-cover values are presented for species found at forest (F), abandoned-bog (A), and cranberry (C) stream sites.

			Frequency			Cover						Frequency			Cover		
Species	Ax1	Ax2	F	A	C	F	A	C	Species	Ax1	Ax2	F	A	C	F	A	C
Carex bullata	-234	212	-	25	33	-	0.1	0.2	*Xyris difformis*	108	161	-	50	-	-	<0.1	-
Panicum virgatum	-178	-265	-	-	67	-	-	1.5	*Pinus rigida*	126	117	50	50	67	<0.1	<0.1	0.1
Itea virginica	-152	107	-	25	67	-	<0.1	0.2	*Osmunda cinnamomea*	128	0	25	50	33	0.1	0.1	0.1
Cuscuta sp.	-115	-234	-	-	100	-	-	<0.1	*Chamaecyparis thyoides*	132	4	100	75	100	0.3	1.4	0.6
Nuphar variegata	-90	85	-	50	100	-	<0.1	0.4	*Vaccinium corymbosum*	137	-31	100	50	100	0.4	1.7	2.1
Panicum verrucosum	-79	-11	-	50	67	-	0.3	0.2	*Gaylussacia frondosa*	138	-38	50	25	67	0.4	<0.1	0.1
Eleocharis tenuis	-77	169	-	75	67	-	0.4	3.0	*Aronia arbutifolia*	139	31	25	-	33	0.1	-	0.2
Juncus effusus	-61	-43	-	50	100	-	0.3	0.9	*Nymphaea odorata*	140	144	25	50	-	<0.1	<0.1	-
Cladium mariscoides	-53	413	-	50	-	-	0.1	-	*Ilex glabra*	149	7	75	50	67	1.4	0.6	<0.1
Decodon verticillatus	-50	20	-	25	67	-	0.3	0.5	*Kalmia angustifolia*	152	224	50	75	-	0.4	0.1	-
Panicum longifolium	-48	326	-	75	-	-	0.2	-	*Rhododendron viscosum*	153	-13	100	50	67	0.7	0.1	0.2
Sagittaria engelmanniana	-48	131	-	100	67	-	0.2	0.2	*Juncus pelocarpus*	166	230	75	100	-	0.1	1.0	-
Glyceria obtusa	-38	90	25	50	100	<0.1	1.5	0.3	*Panicum spp.*	172	62	75	50	67	0.7	<0.1	1.0
Hypericum canadense	-27	168	-	50	33	-	<0.1	0.1	*Orontium aquaticum*	174	104	25	25	-	<0.1	<0.1	-
Leersia oryzoides	-25	-130	25	25	100	0.3	<0.1	6.9	*Muhlenbergia uniflora*	178	186	25	50	-	0.1	0.1	-
Lysimachia terrestris	-25	-130	25	25	100	<0.1	<0.1	0.2	*Mitchella repens*	181	-51	25	25	33	0.1	<0.1	<0.1
Cyperus dentatus	-22	178	-	25	33	-	<0.1	<0.1	*Smilax glauca*	197	1	50	-	33	<0.1	-	0.1
Lachnanthes caroliniana	-4	-105	-	50	67	-	<0.1	<0.1	*Scirpus subterminalis*	201	108	25	50	-	0.2	0.4	-
Peltandra virginica	-1	-91	25	50	67	0.1	0.8	3.7	*Eubotrys racemosa*	207	-5	75	50	33	2.5	0.2	0.3
Nyssa sylvatica	1	50	-	25	33	-	<0.1	<0.1	*Carex exilis*	219	143	25	25	-	1.8	0.3	-
Eleocharis flav. v. olivacea	30	350	25	75	-	0.2	0.4	-	*Rhynchospora alba*	225	144	50	50	-	0.1	<0.1	-
Carex striata	34	4	-	50	33	-	2.8	<0.1	*Carex atlantica*	233	78	50	50	-	1.0	<0.1	-
Dulichium arundinaceum	44	132	50	100	100	1.1	2.9	0.6	*Magnolia virginiana*	251	7	25	25	-	<0.1	<0.1	-
Rhexia virginica	46	84	-	75	33	-	0.1	<0.1	*Schizaea pusilla*	252	178	50	25	-	0.1	<0.1	-
Triadenum virginicum	57	103	75	100	100	0.2	0.6	0.5	*Bartonia paniculata*	255	15	100	25	33	0.1	<0.1	<0.1
Drosera intermedia	60	167	50	100	33	0.1	0.2	<0.1	*Carex folliculata*	260	62	50	-	33	0.3	-	<0.1
Smilax rotundifolia	66	-78	50	50	67	<0.1	0.1	0.1	*Carex collinsii*	262	47	75	25	-	0.5	<0.1	-
Bartonia virginica	72	-71	-	25	33	-	<0.1	<0.1	*Drosera rotundifolia*	264	95	100	50	-	0.5	0.1	-
Vaccinium macrocarpon	74	138	75	100	67	0.7	4.4	0.3	*Aster nemoralis*	284	44	75	-	33	0.1	-	<0.1
Eleocharis robbinsii	75	329	25	75	-	<0.1	0.5	-	*Carex trisperma*	292	120	50	25	-	0.5	<0.1	-
Chamaedaphne calyculata	82	119	75	100	100	0.8	11.8	3.1	*Gaylussacia dumosa*	299	154	75	25	-	3.3	0.1	-
Acer rubrum	93	-44	75	50	100	0.2	0.1	0.7	*Smilax laurifolia*	305	-61	50	-	-	<0.1	-	-
Clethra alnifolia	93	-44	75	50	100	2.5	1.9	5.5	*Carex livida*	328	81	75	-	-	0.1	-	-
Gaylussacia baccata	97	-36	25	-	67	<0.1	-	0.2	*Eriocaulon aquaticum*	398	31	50	-	-	0.5	-	-
Rubus hispidis	97	32	25	50	67	0.1	<0.1	0.1	*Myrica pensylvanica*	398	31	50	-	-	1.5	-	-
Hypericum densiflorum	100	162	25	-	33	<0.1	-	<0.1	*Sabatia difformis*	398	31	50	-	-	<0.1	-	-
Andropogon v. abbreviatus	104	162	25	50	33	<0.1	0.5	0.3									

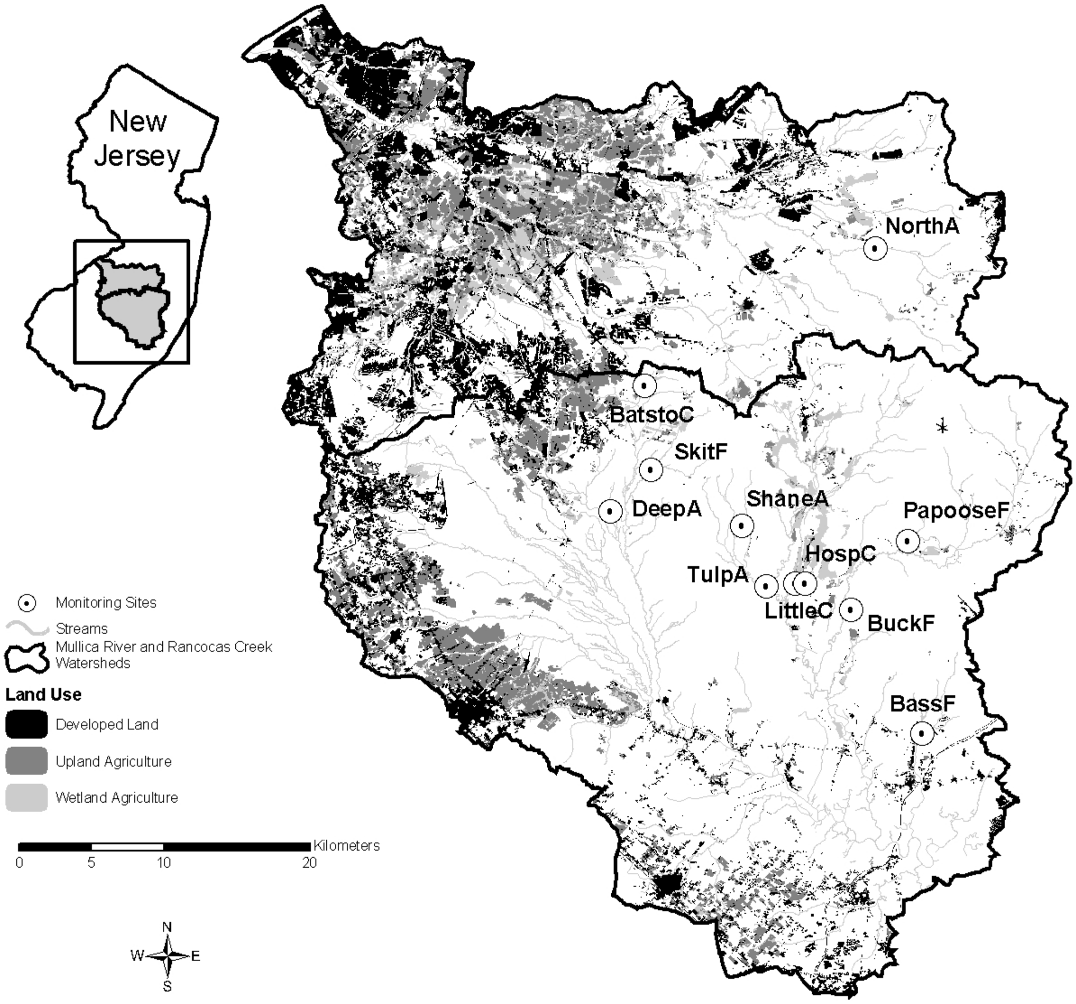

Figure 1. Location of 11 stream-vegetation monitoring sites in the Mullica River and Rancocas Creek watersheds. Site types include forest (F), abandoned-bog (A), and cranberry (C) streams. The last letter in each site code refers to the stream type. Refer to Table 1 for complete site names.

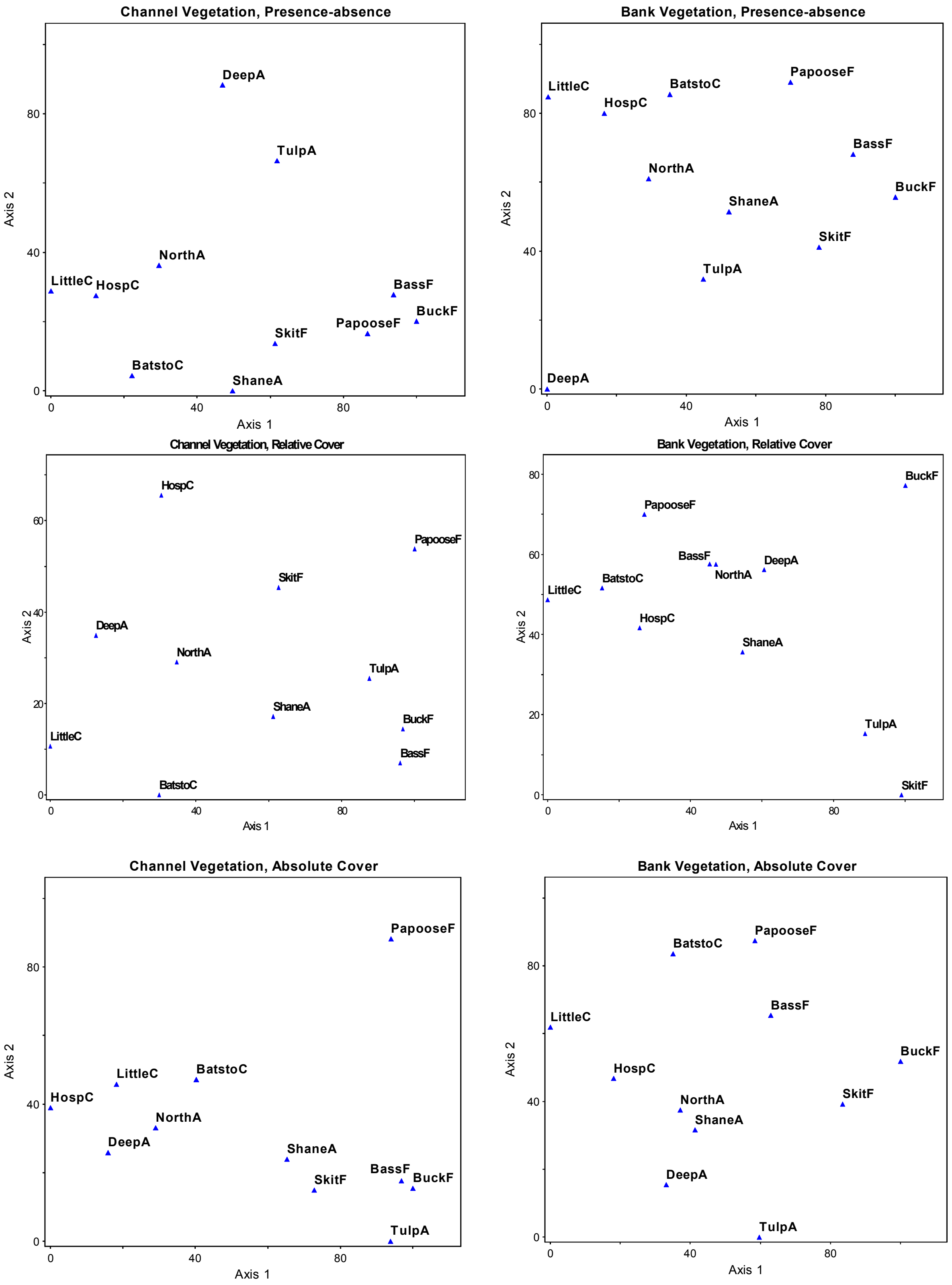

Figure 2. DCA ordinations of channel (left) and bank (right) sites based on presence-absence (top), relative cover (middle), and absolute cover (bottom) of vegetation species in forest (F), abandoned-bog (A), and cranberry (C) streams. The last letter in each site code refers to the stream type. Refer to Table 1 for complete site names and Tables 3 and 5 for channel- and bank-species presence-absence DCA scores.

Appendix. Mean bank (B) and channel (C) percentage-cover values for herbaceous and woody plants found at forest, abandoned-bog, and cranberry streams. Total, channel, and bank-species richness values are presented at the bottom of the table.

	Forest Streams								Abandoned-bog Streams								Cranberry Streams					
	Buck Run		E. Br. Bass River		Papoose Branch		Skit Branch		Deep Run		N. Br. Mt. Misery Brook		Shane Branch		Tulpehocken Creek		Batsto River		Hospitality Brook		Little Hauken Run	
Species	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
Herbaceous species:																						
Amphicarpum purshii	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
Andropogon v. abbreviatus	-	-	-	-	-	-	0.04	-	-	-	-	-	0.89	-	1.03	-	-	-	1.00	0.19	-	-
Aster nemoralis	0.20	-	0.18	-	-	-	0.18	0.02	-	-	-	-	-	-	-	-	0.10	0.01	-	0.02	-	-
Aster novi-belgii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.08	-	-
Bartonia paniculata	0.15	0.03	0.04	-	0.22	-	0.04	-	-	-	-	-	0.01	-	-	-	0.03	0.01	-	-	-	-
Bartonia virginica	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	0.01	-	-	-	-	-
Calamogrostis cinnoides	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex atlantica	3.90	0.10	-	-	0.03	-	-	0.02	-	-	-	-	0.05	0.01	0.03	-	-	0.01	-	-	-	-
Carex atlantica v. capillacea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	-	-	-	-	-
Carex bullata	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	-	-	-	-	-	-	0.72	0.01
Carex collinsii	-	-	0.04	-	1.81	0.19	0.04	-	-	-	-	-	0.01	<0.01	-	-	-	-	-	-	-	-
Carex exilis	-	-	-	-	-	-	7.36	0.90	-	-	-	-	1.20	0.01	-	-	-	-	-	-	-	-
Carex folliculata	1.00	0.20	-	-	-	-	0.07	-	-	-	-	-	-	-	-	-	0.06	-	-	-	-	-
Carex intumescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.30	0.01	-	-	-	-
Carex livida	0.10	-	-	-	0.33	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	0.30	-	-
Carex lurida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	0.01	-	-	-	-
Carex striata	-	-	-	-	-	-	-	-	-	-	3.80	0.77	7.25	1.05	-	-	0.06	-	-	-	-	-
Carex stricta	-	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	0.22	0.01
Carex trisperma	0.80	-	-	-	-	-	1.07	0.14	-	-	-	-	0.01	<0.01	-	-	-	-	-	-	-	-
Chasmanthium laxum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.11	0.05	-	-	-	-
Cladium mariscoides	-	-	-	-	-	-	-	-	0.54	0.18	-	-	0.05	0.02	-	-	-	-	-	-	-	-
Cuscuta sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.01	0.13	0.05	0.01	-
Cyperus dentatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.18	-	-	-	0.06	-	-	-
Danthonia sericea v. epilis	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Decodon verticillatus	-	-	-	-	-	-	-	-	-	-	1.25	1.57	-	-	-	-	0.25	0.01	1.28	0.63	-	-
Dioscorea villosa	-	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera filiformis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.60	-	-	-	-	-	-	-
Drosera intermedia	-	-	0.25	0.07	-	-	0.25	0.24	0.02	-	0.16	0.05	0.52	0.12	0.23	-	-	-	-	-	0.01	-
Drosera rotundifolia	0.50	0.10	0.50	-	0.42	0.06	0.57	0.10	-	0.01	-	-	0.14	0.01	0.13	-	-	-	-	-	-	-

Appendix. Mean bank (B) and channel (C) percentage-cover values for herbaceous and woody plants found at forest, abandoned-bog, and cranberry streams. Total, channel, and bank-species richness values are presented at the bottom of the table.

	Forest Streams								Abandoned-bog Streams								Cranberry Streams					
	Buck Run		E. Br. Bass River		Papoose Branch		Skit Branch		Deep Run		N. Br. Mt. Misery Brook		Shane Branch		Tulpehocken Creek		Batsto River		Hospitality Brook		Little Hauken Run	
Species	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
Dulichium arundinaceum	0.05	0.03	-	-	-	-	4.32	0.86	3.42	1.00	0.36	0.56	4.85	1.44	2.85	0.25	0.50	0.12	0.43	0.20	0.80	0.09
Eleocharis flavescens v. olivacea	-	-	-	-	-	-	0.61	0.83	0.17	0.41	0.29	2.38	-	-	1.08	1.05	-	0.01	-	-	-	-
Eleocharis microcarpa	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eleocharis robbinsii	-	-	-	-	-	-	0.04	13.05	0.71	0.82	-	0.01	0.07	0.18	1.15	6.10	-	-	-	2.15	-	-
Eleocharis tenuis	-	-	-	-	-	-	-	-	0.73	0.23	-	-	0.01	-	0.80	0.12	-	-	7.42	0.67	1.66	0.03
Eleocharis tuberculosa	-	-	-	-	-	-	0.04	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Erianthus giganteus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.48	-	-
Eriocaulon aquaticum	2.00	2.80	0.07	0.62	-	5.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eupatorium resinosum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.22	-	-	-
Glyceria obtusa	-	-	0.04	-	-	-	-	-	2.27	0.42	3.75	2.33	-	-	-	-	0.38	0.12	0.22	0.11	0.41	0.14
Hypericum canadense	-	-	-	-	-	-	-	0.02	-	0.03	0.04	0.01	-	-	0.13	-	-	-	0.18	0.01	-	-
Juncus canadensis	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	0.07	-	-
Juncus effusus	-	-	-	-	-	-	-	-	-	-	1.02	2.62	-	-	0.03	-	0.01	-	2.03	2.28	0.65	0.12
Juncus militaris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.30	-	-	-	-	-	-
Juncus pelocarpus	0.10	0.07	0.18	0.02	-	0.04	0.07	0.12	3.54	0.24	0.09	0.01	0.05	0.19	0.33	0.02	-	-	-	-	-	-
Lachnanthes caroliniana	-	-	-	-	-	-	-	-	-	-	-	-	0.07	0.01	0.05	-	0.06	0.02	-	-	0.01	-
Leersia oryzoides	-	-	-	-	1.17	0.07	-	0.81	-	-	0.20	0.82	-	-	-	-	9.46	7.86	3.08	1.32	8.05	2.28
Lobelia nuttallii	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ludwigia palustris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.28	0.19	-	-
Lycopus uniflorus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	0.04	-	-
Lysimachia terrestris	-	-	-	-	0.14	0.02	-	-	-	-	0.02	0.05	-	-	-	-	0.10	0.09	0.18	0.13	0.18	-
Mitchella repens	-	-	0.21	-	-	-	-	-	-	-	-	-	0.03	<0.01	-	-	0.13	-	-	-	-	-
Muhlenbergia uniflora	-	-	-	-	-	-	0.46	0.05	-	-	-	-	0.02	-	0.40	-	-	-	-	-	-	-
Nuphar variegata	-	-	-	-	-	-	-	-	0.15	7.90	-	-	0.03	2.10	-	-	0.38	2.44	0.28	0.31	0.65	0.81
Nymphaea odorata	-	-	-	-	-	0.07	0.04	2.26	-	-	0.02	0.81	0.04	2.25	-	0.08	-	0.85	-	-	-	0.01
Orontium aquaticum	-	0.17	-	-	0.17	0.76	-	-	-	-	-	-	-	-	0.05	0.20	-	-	-	-	-	-
Osmunda cinnamomea	-	-	0.29	-	-	-	-	-	-	-	0.36	-	0.03	-	-	-	0.15	0.03	-	-	-	-
Osmunda regalis	-	-	2.18	1.71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxypolis rigidior	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panicum longifolium	-	-	-	-	-	-	-	-	0.60	0.03	0.04	-	0.36	0.02	-	-	-	-	-	-	-	-

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	Forest Streams								Abandoned-bog Streams								Cranberry Streams					
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Species	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
Panicum sp.	0.40	0.07	0.21	-	-	-	2.25	0.19	-	-	0.05	0.01	0.02	-	-	-	2.15	0.28	0.79	0.34	-	-
Panicum verrucosum	-	-	-	-	-	-	-	-	-	-	0.21	0.01	-	-	0.98	-	-	-	0.49	0.08	0.02	-
Panicum virgatum	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	1.44	0.11	3.04	0.49
Peltandra virginica	-	-	-	0.05	0.50	0.37	-	-	-	-	0.29	-	2.75	0.69	-	-	-	-	5.75	2.59	5.42	0.25
Polygala cruciata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-
Potamogeton confervoides	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Proserpinaca pectinata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-
Rhexia virginica	-	-	-	-	-	-	-	-	-	-	0.27	0.01	0.04	<0.01	0.20	-	0.10	0.03	-	0.07	-	-
Rhynchospora alba	-	0.03	0.07	-	-	-	0.14	0.12	-	-	-	-	0.04	-	0.08	-	-	-	-	-	-	-
Sabatia difformis	0.05	-	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sagittaria engelmanniana	-	-	-	-	-	-	-	0.21	0.19	-	0.07	0.18	0.03	0.02	0.40	-	0.15	0.08	-	0.04	0.43	0.09
Sarracenia purpurea	-	-	0.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schizachyrium scoparium	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	0.04	-	-
Schizaea pusilla	-	-	0.14	-	-	-	0.07	-	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-
Scirpus cyperinus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.30	1.09	0.03
Scirpus subterminalis	-	19.93	0.89	7.88	-	0.93	-	0.10	-	-	-	0.01	0.07	4.97	1.60	10.98	-	1.60	-	0.70	-	-
Sparganium americanum	-	0.30	-	-	-	0.28	-	-	-	-	-	-	-	-	-	-	-	-	16.89	22.59	-	-
Triadenum virginicum	-	-	0.43	-	0.11	0.02	0.32	0.17	1.02	0.18	1.00	0.56	0.15	0.02	0.10	0.02	0.29	0.17	1.13	0.60	0.07	0.04
Utricularia cornuta	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	-	-	-	-	-	-	-	-
Utricularia sp.	-	1.20	-	0.50	-	0.02	-	-	0.13	0.58	-	14.45	-	1.29	-	-	-	0.05	-	0.37	-	-
Woodwardia areolata	-	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-	-	-	-	-	-	-	-
Woodwardia virginica	-	-	-	-	-	-	-	-	-	-	-	-	0.40	0.05	-	-	-	-	-	0.15	-	-
Xyris difformis	-	-	-	-	-	-	-	-	-	-	-	-	0.02	0.02	0.03	-	-	-	-	-	-	-
Zizania aquatica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-
Woody species:																						
Acer rubrum	-	-	0.11	-	0.33	0.04	0.18	0.02	-	-	0.04	0.07	0.52	0.13	-	-	0.44	0.08	1.03	0.53	0.64	0.05
Aronia arbutifolia	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50	0.11	-	-
Chamaecyparis thyoides	0.05	-	0.29	0.02	0.25	-	0.75	0.17	-	-	0.04	-	5.40	0.10	0.13	-	0.28	0.13	1.28	0.44	0.17	-
Chamaedaphne calyculata	1.20	0.27	0.86	-	-	-	1.21	0.57	27.31	7.82	11.93	5.62	6.89	0.22	1.20	0.13	0.05	-	8.44	4.80	0.73	0.35
Clethra alnifolia	-	0.03	6.29	0.95	2.47	1.26	1.25	1.31	-	-	6.75	2.81	1.02	0.26	-	-	12.45	4.73	3.39	3.22	0.72	0.07

Appendix. Mean bank (B) and channel (C) percentage-cover values for herbaceous and woody plants found at forest, abandoned-bog, and cranberry streams. Total, channel, and bank-species richness values are presented at the bottom of the table.

	Forest Streams								Abandoned-bog Streams								Cranberry Streams					
	Buck Run		E. Br. Bass River		Papoose Branch		Skit Branch		Deep Run		N. Br. Mt. Misery Brook		Shane Branch		Tulpehocken Creek		Batsto River		Hospitality Brook		Little Hauken Run	
Species	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
Eubotrys racemosa	6.05	0.53	1.64	1.05	2.50	0.33	-	-	-	-	0.14	0.86	0.64	0.06	-	-	0.78	0.53	-	-	-	-
Gaylussacia baccata	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	0.25	-	0.28	0.04	-	-
Gaylussacia dumosa	4.30	0.27	1.14	-	-	-	7.64	0.83	-	-	-	-	-	-	0.50	-	-	-	-	-	-	-
Gaylussacia frondosa	-	-	1.43	-	0.11	-	-	-	-	-	-	-	0.18	0.05	-	-	0.26	0.03	0.11	-	-	-
Hypericum densiflorum	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	0.11	0.15	-	-
Ilex glabra	1.40	0.40	0.04	-	-	-	4.29	1.67	-	-	0.36	0.05	-	-	2.00	-	0.03	-	-	-	0.02	0.14
Ilex laevigata	-	-	1.00	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilex opaca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.21	0.07	-	-	-	-
Itea virginica	-	-	-	-	-	-	-	-	0.15	-	-	-	-	-	-	-	0.28	0.17	-	-	0.43	0.35
Kalmia angustifolia	0.30	-	1.14	0.19	-	-	-	-	0.02	0.03	0.36	0.14	0.05	-	-	-	-	-	-	-	-	-
Kalmia latifolia	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-	-	-	-
Lyonia mariana	-	-	-	-	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-
Magnolia virginiana	-	-	0.07	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
Myrica pensylvanica	5.70	0.67	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nyssa sylvatica	-	-	-	-	-	-	-	-	-	-	-	-	0.02	-	-	-	-	0.05	0.11	0.07	-	-
Pinus rigida	0.05	-	-	-	-	-	0.04	-	-	-	0.02	-	-	-	0.03	-	0.01	-	0.22	-	-	-
Quercus ilicifolia	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
Rhododendron viscosum	0.20	-	2.07	1.57	0.42	-	0.14	-	-	-	0.11	-	0.15	-	-	-	-	-	0.61	0.38	0.07	-
Rubus hispidis	0.55	0.27	-	-	-	-	-	-	-	-	0.14	-	0.02	-	-	-	0.23	0.12	0.22	0.13	-	-
Smilax glauca	-	-	-	-	0.11	-	0.04	-	-	-	-	-	-	-	-	-	0.24	-	-	-	-	-
Smilax laurifolia	-	-	0.07	-	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Smilax rotundifolia	-	-	0.04	-	0.14	-	-	-	-	-	0.07	0.06	0.14	-	-	-	-	-	0.25	0.08	0.05	-
Smilax walteri	-	-	-	-	-	-	-	-	-	-	-	-	0.01	-	-	-	-	-	-	-	-	-
Vaccinium corymbosum	0.15	-	0.64	-	0.56	-	0.14	-	-	-	3.38	-	3.40	0.02	-	-	0.80	0.38	5.47	2.41	0.02	-
Vaccinium macrocarpon	2.45	0.13	-	-	0.06	-	0.29	0.10	4.52	0.21	8.86	0.46	3.83	0.11	0.55	0.02	-	-	0.50	0.23	0.26	-
Viburnum n. nudum	-	-	0.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Channel-species Richness	22		14		16		28		16		29		34		12		33		46		19	
Bank-species Richness	24		37		23		36		18		34		51		32		38		39		28	
Total-species Richness	31		40		29		42		20		38		54		33		44		51		29	

PART 5. MACROINVERTEBRATE ASSEMBLAGES IN PINELANDS STREAMS DRAINING ACTIVE-CRANBERRY BOGS, ABANDONED-CRANBERRY BOGS, AND FOREST LAND

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Abstract

We compared the composition of macroinvertebrate assemblages collected from three habitats (muck, vegetated muck, and woody debris) in twelve New Jersey Pinelands blackwater streams draining forest land, abandoned-cranberry bogs, and active-cranberry bogs. We address two questions. First, are variations in macroinvertebrate assemblages related to differences in past and present land uses within the associated drainage basin? Secondly, do macroinvertebrate assemblages vary between habitats? Although the primary focus is family-level assemblages, we also evaluate community patterns at the genus level. All twelve streams were relatively slow moving and acidic, with low conductance values and dissolved-oxygen concentrations. Muck was the dominant sediment at most sites. Although no single environmental variable clearly separated the three stream types, higher dissolved-oxygen levels, lower water temperatures and specific conductance values, and a higher percentage of woody debris generally characterized the forest streams. Family richness was significantly different between forest and abandoned-bog streams. We found no statistically significant difference in mean genus richness between individual stream types. Mean family and genus richness was similar among muck, vegetated-muck, and woody-debris habitats. Cranberry and forest sites shared more families in common than each shared with abandoned-bog sites, and muck and vegetated-muck habitats shared more taxa in common than either shared with woody debris. Compared to abandoned-bog and cranberry sites, the highest number of genera restricted to a single stream type was found at forest sites. Both family-level and genus-level macroinvertebrate composition differed significantly between the cranberry streams and the other two stream classes, regardless of habitat type (muck, vegetated muck, and woody debris). Overall, the effect of stream type appears to overshadow that of habitat. Tubificidae, Chironomidae, and Asellidae were the most abundant and widespread families. Ephemeroptera, Plecoptera, and Trichoptera (EPT) composition differed significantly between each of the three stream types, with mayflies, stoneflies, and caddisflies occurring more frequently at forest sites. Genus-level chironomid composition differed significantly between cranberry and both forest and abandoned-bog streams. Because many of the taxa that we encountered are adapted to lentic habitats and slow-moving lotic habitats or low-oxygen environments, we attributed some of the variation in community composition to subtle differences in dissolved-oxygen levels. Although not conclusive, our results suggest that variations in macroinvertebrate composition may be related to a complex environmental gradient involving dissolved oxygen, temperature, specific conductance, stream width, and woody debris. The relationship between reduced canopy cover and both lower woody-debris cover and higher stream temperatures, which can influence dissolved-oxygen levels, is most likely related to deforestation associated with historic and active cranberry agriculture.

Introduction

Urban and agricultural land uses within a drainage basin may strongly influence the composition of stream-macroinvertebrate communities (Jones and Clark 1987, Lenat and Crawford 1994, Delong and Brusven 1998, Kennen 1999, Sponseller et al. 2001, Stephenuck et al. 2002, Stewart et al. 2003). Although present-day land uses may explain appreciable variation in stream-macroinvertebrate composition, the long-term effect of historic land uses, especially agriculture, must also be considered (Foster et al. 2003, Harding et al. 1998).

Cranberry agriculture, which involves clearing land to construct bogs, damming streams to establish reservoirs, and controlling the flow of water by channelizing stream segments and creating extensive ditch networks (Eck 1990), is a major land use in parts of the New Jersey Pinelands (Pine Barrens). The native cranberry was first cultivated in New Jersey in the mid-19th century. Since that time, the industry has been an important landscape-shaping factor. Harvested cranberry acreage, estimated to be about 3,100 acres in 2002 (U.S. Department of Agriculture 2003), represents less than one-third of the 11,200 acres that existed at the peak of bog cultivation in 1919 (Eck 1990). Abandoned-cranberry bogs are now a common feature of the Pinelands landscape.

New Jersey Pinelands streams are representative of blackwater coastal plain streams found along the east coast and Gulf Coast of the United States (Patrick 1996). Previous studies have compared the composition of fish, frog, and plant assemblages in Pinelands streams draining basins with active-cranberry agriculture, abandoned-cranberry bogs, and developed and upland-agricultural land (altered land) to basins with no altered land or evidence of past or present cranberry cultivation. A major difference between the forested and altered-land watersheds is the occurrence of nonnative species in the altered basins (Hastings 1979, 1984, Morgan and Philipp 1986, Zampella and Laidig 1997, Zampella and Bunnell 1998, 2000). Although these studies have demonstrated that streams draining basins with active-cranberry and abandoned-cranberry bogs support native fish, frog, and plant assemblages similar to those found in forested basins, a comparison of the macroinvertebrate communities found in these three stream types has not been conducted.

In this study, we compare the composition of macroinvertebrate assemblages collected from central-Pinelands blackwater streams draining forest land, abandoned-cranberry bogs, and active-cranberry bogs. All three land-use types represent acid-water streams with minimal upland agriculture or developed lands. Within each stream we sampled muck, vegetated-muck, and woody-debris habitats. We address two major questions. First, are variations in macroinvertebrate assemblages related to differences in past and present land uses within the associated drainage basin? Secondly, do macroinvertebrate assemblages vary between habitats? Although the primary focus is family-level assemblages, we also evaluate community patterns at the genus level.

Methods

Land Use and Study Site Selection

We selected four streams representing each of the three stream types, including forest, abandoned-cranberry bog (abandoned-bog), and active-cranberry bog (cranberry) streams (Figure 1, Table 1). All twelve streams were included in earlier water-quality, stream-vegetation, fish, or anuran studies and land-use profiles were completed as part of those studies (Zampella et al. 2001, 2003). The data set used to create the land-use profiles is based on a modified Anderson et al. (1976) system. In this paper, we refer to the Anderson-type land-use classes of urban land, agriculture, and agricultural wetlands as developed land, upland agriculture, and wetland agriculture, respectively. Collectively, we refer to developed land and upland agriculture as altered land. Wetland agriculture includes cranberry bogs and blueberry fields. Most wetland agriculture in the study basins is cranberry agriculture.

The percentage of altered land (developed land and upland agriculture) was low in all twelve drainage areas (Table 1). Altered land, which was generally highest in the cranberry drainage areas, did not exceed ten percent in any basin. The four forest sites were located in undeveloped watersheds with no apparent agricultural history. Abandoned-bog sites were located in streams draining abandoned-cranberry bogs and forest. The four cranberry sites were located immediately downstream from cranberry bogs. Abandoned bogs bordered three of these sites. All abandoned bogs have succeeded to emergent, shrub, or forested wetlands. The percentage of wetland agriculture in the cranberry drainage basins ranged from 3.9 – 34.3%.

Environmental Factors

From May through November 2001 and April through November 2002, we measured pH, specific conductance, dissolved oxygen, and temperature monthly at road or trail crossings near each macroinvertebrate sampling site. All water-quality measurements were completed under baseflow conditions. Specific conductance was measured with an Orion model-122 meter, pH was measured using an Orion model-250A meter, and temperature and dissolved oxygen were measured with a YSI 52 dissolved-oxygen meter. All available data were used to calculate median values for each sampling site.

We monitored stream discharge at or near eight macroinvertebrate-sampling sites on 63 to 64 dates between October 2000 and October 2003. The Batsto River and Skit Branch sites were monitored for a shorter period (March 2002 to October 2003 and October 2000 to October 2001, respectively). We did not measure discharge at Buck Run and Deep Run. To allow a comparison of all sites where we measured discharge, including the Batsto River and Skit Branch, we ranked available discharge values for each date and used these ranks to calculate a median discharge rank for each site (Table 1).

With one exception (Pole Bridge Branch), we evaluated stream habitat within 100-m to 200-m stream reaches at each site. Bankfull stream depth and width were measured along transects established at 25-m intervals. Using a 0.25-m^2 quadrat, we estimated channel-vegetation and woody-debris cover at three points along each transect, including the right and left side of the channel and the thalweg (deepest point in the channel). We also subjectively described the streambed substrate at the same three points as muck or sand. To obtain an estimate of shading, we used a spherical densiometer to measure canopy cover over the center of each transect. Using the data from each transect, we calculated mean bankfull depth and width and channel-vegetation, woody-debris, and canopy-cover values for each stream. Sediment values represent the number of points, given as a percentage of total points measured, where each type of substrate was found in a stream.

Macroinvertebrate Sampling

We sampled macroinvertebrates in three different habitats, including bare muck, vegetated muck, and woody debris. Using a 46 X 23 cm kick net, we completed from one to five one-meter long sweeps of bare muck at each site. The multiple sweeps were pooled as one sample. The same approach was used to sample muck with floating-leaved aquatic-macrophyte patches composed of *Nuphar variegata* and/or *Nymphaea odorata* (vegetated muck). At one site (Tulpehocken Creek), separate samples collected from *Nymphaea odorata* and *Scirpus subterminalis* patches were combined as one. At each site, we used the same number of sweeps for the muck and vegetated-muck sampling. Woody debris was sampled by cutting ten 30-cm sections of submerged wood and removing all visible macroinvertebrates. No woody debris was found at Hospitality Brook, a cranberry site, and two abandoned-bog sites, Shane Branch and Deep Run. We collected all bare muck and vegetated-muck samples within the same 100-m stream reach. At three sites, we sampled woody debris in an adjacent, 100-m stream reach. All sampling was conducted over a five-week period in June and July 2002.

Each sample was sieved in the field and preserved with 10% formalin. Personnel of the New Jersey Department of Environmental Protection, Bureau of Freshwater and Biological Monitoring, sorted and identified all specimens. Specimens were evenly distributed in a light-colored pan marked with grids of equal sizes and removed from randomly selected grids until a total of at least 100 organisms were sampled. Three of thirty-three samples analyzed had less than 100 organisms. With a few exceptions, the individuals were then identified at least to family using 7 to 30X stereo zoom and 40 to 400X compound magnification. Most specimens were identified to genus.

Data Analysis

We used detrended correspondence analysis (DCA, Hill 1979a, Hill and Gauch 1980) and TWINSPAN (Hill 1979b) to ordinate and classify macroinvertebrate families and the 12 stream sites based on relative-abundance data. We averaged the relative-abundance data of the different habitats from each site and analyzed the composite samples. Because we found no woody debris at three sites, we also ordinated composite samples composed of muck and vegetated-muck samples only. Log-transformed relative-abundance data were used in all DCA analyses. We also analyzed genus-level relative-abundance data using the composite samples. Using Spearman rank correlation, we correlated the first and second DCA axes of the family-level and genus-level ordinations with each environmental variable. To describe relationships among environmental variables, we constructed a correlation matrix using Spearman rank correlation.

We used nonparametric multi-response permutation procedures (MRPP, McCune and Mefford 1999) to compare family-level and genus-level composition between stream types based on composite samples that included all habitats, and between stream types based on separate analyses of three different habitats. We also use MRPP to compare genus-level macroinvertebrate, EPT (Ephemeroptera, Plecoptera, and Trichoptera), and chironomid composition between stream types. Composite-habitat samples were used in all genus-level comparisons. The MRPP analyses were based on Euclidean distance, and significance levels of the multiple tests were adjusted using the sequential Bonferroni method (Rice 1989, 1990). We report the p and A values for each analysis. The p value describes the likelihood that an observed difference is due to chance. The A statistic (chance-corrected within-group agreement) describes agreement within groups (i.e., stream type). $A = 1$ when all attributes within a group are identical, $A = 0$ when within group heterogeneity equals that expected by chance, and $A < 0$ when within-group heterogeneity is greater than expected by chance. We used separate Kruskal-Wallis ANOVA tests to assess differences in family and genus richness between stream types. Post-hoc comparisons were conducted using multiple comparisons of mean ranks (Siegel and Castellan 1988).

We used an alpha level of 0.05 to assess significance for all statistical tests, and adjusted significance levels of multiple tests using the sequential Bonferroni method (Rice 1989, 1990). Ordinations, TWINSPAN classifications, and MRPP analyses were performed using PC-ORD for Windows 4.27 (MjM Software, Gleneden Beach, OR). ANOVAs and correlation analyses were performed using Statistica 7.1 (StatSoft, Inc., Tulsa, OK).

Results

Environmental Factors

All twelve streams were relatively slow moving and acidic (Table 1). Sand was the dominant sediment at one site. Muck dominated the streambeds at the remaining sites. Dissolved-oxygen concentrations were low, with mean concentrations ranging from 4.7 mg L^{-1} for the cranberry streams to 6.5 mg L^{-1} for the forest streams. Median specific conductance values, which were <50 μS cm^{-1} at all but one site, were lowest in forest sites and highest in cranberry sites. Mean drainage area ranged from 13.3 km^2 for forest streams to 23.8 km^2 for abandoned-bog streams. Higher dissolved-oxygen levels, lower temperatures, and a higher percentage of woody-debris cover generally characterized the forest streams.

The correlation matrix revealed strong relationships between channel vegetation and bankfull depth and channel muck, between basin area and channel muck, depth, and width, and between canopy cover and woody debris and temperature (Table 2). The negative relationship between muck and dissolved oxygen may be associated with variations in flow regimes. Due to the large number of comparisons, we cannot make conclusions regarding the statistical significance of these associations.

Macroinvertebrate Inventory

Specimens from all but two taxa, the phylum Nematoda (roundworms) and the insect order Collembola (springtails), were identified to family. More than 90% of all specimens were also identified to genus. Fifty-three families, comprising 20 orders and represented by 110 genera, were collected from the 12 stream sites (Tables 3 and 4). The orders were represented by insects (Coleoptera, Diptera, Ephemeroptera, Hemiptera, Lepidoptera, Megaloptera, Odonata, Plecoptera, Trichoptera), crustaceans (Decapoda, Amphipoda, Isopoda), leeches (Pharyngobdellida, Rhychobdellida), bristle worms (Haplotaxida, Lumbriculida, Tubificida), clams (Veneroida), snails (Basommatophora), and turbellarian flatworms (Tricladia).

Both stoneflies (Plecoptera) and caddisflies (Trichoptera) occurred more frequently and with higher relative abundances at forest sites (Table 5). Mayflies (Ephemeroptera) occurred more frequently at forest sites compared to cranberry sites and were absent from abandoned-bog sites. Fingernail clams (Veneroida) were found at two cranberry streams and two forest streams, with higher relative abundances in the latter. Pyralid moths (Lepidopterans) were found only at abandoned-bog sites.

Megalopterans were found in all stream types, but occurred more frequently at forest sites. Isopods were also found at all three stream types, but were much more abundant at the cranberry sites. Both odonates and coleopterans were found at all site types and were slightly more abundant at cranberry and abandoned-bog sites. Both the relative abundance and frequency of occurrence of tubificid worms was similar for the three stream types. The lower relative abundance of dipterans in cranberry streams was due to the high relative abundance of isopods at these sites.

For convenience, both nematodes and collembolans are referred to as “families” and are included in the family-level analysis. Nineteen families were represented by single-site occurrences. Sixteen families were found at a minimum of one-half of all sites. The family Chironomidae (midges) comprised five subfamilies, including Chironominae, Diamesinae, Orthocladiinae, Pseudochironomini, and Tanypodinae, represented by 41 genera (Table 4).

The most frequently occurring families were Tubificidae (100%), Chironomidae (100%), and Asellidae (92%). Seventy-eight percent of the families were found in low abundance, with each contributing less than five-percent to relative abundance at any site. Families with the highest maximum relative abundance were Chaoboridae (18.5%), Tubificidae (28.2%), Asellidae (65.0%), and Chironomidae (74.9%).

Family-level Comparison of Stream Types

Family richness at the twelve sites ranged from 11 to 25 taxa. A total of 36 families were found at the cranberry sites, 27 at abandoned-bog sites, and 38 at forest sites. Mean (± 1 SD) and median family richness was highest at the forest sites (22.8 ± 2.6 and 23.5) compared to the cranberry (16.8 ± 3.1 and 16) and abandoned-bog sites (13.0 ± 2.8 and 12). Analysis of variance revealed a significant overall difference in family richness among types ($p = 0.019$). Mean family richness was considerably higher for forest sites compared to cranberry sites, but the post-hoc tests revealed a significant difference only between abandoned bog and forest sites (*p* = 0.016). The highest number of families limited to one stream class was found at forest streams, followed by cranberry and abandoned-bog streams (Table 6). About one-third of the families occurred in all stream classes. Cranberry and forest sites shared more species in common than each shared with abandoned-bog sites.

Only four families, including three forest-site taxa, Aeshnidae, Heptageniidae, Odontoceridae, and one abandoned-bog taxon, Nematoda, were limited to woody debris habitats. Muck and vegetated-muck habitats shared more families in common than either shared with woody debris. Mean (± 1 SD) family richness was similar among woody debris (9.4 ± 2.0), vegetated muck (10.1 ± 2.5), and muck (10.8 ± 2.9) samples.

The first axis of the DCA ordination based on the three-habitat composite samples contrasted the forest streams and one abandoned-bog stream (Tulepehocken Creek), shown on the left side of the site diagram, with three abandoned-bog sites and all cranberry sites shown on the right side of the diagram (Figure 2). The first division of the TWINSPAN classification also separated the four forest streams and Tulpehocken Creek from the other sites. The two-dimensional diagram shows that sites were generally clustered with most other sites in the same class.

With two exceptions, Asellidae (isopods) and Coenagrionidae (damselflies), families shown on the far-right side of the family diagram were absent from the forest sites but present at the cranberry or abandoned-bog sites (Figure 2). Of these fourteen families, Ancylidae (snails), Corduliidae (dragonflies), Noteridae (beetles), Gerridae (true bugs), Caenidae (mayflies), Crangonyctidae (amphipods), Glossiphoniidae (leeches), and Planariidae (turbellarian flatworms) were found only in the cranberry samples, and Libellulidae (dragonflies) and Curculionidae (weevils) were found only in the abandoned-bog samples. Haliplidae (beetles), Lumbriculidae (oligochaetes), Chaoboridae (phantom midges), and the order Collembola (springtails) were associated with both cranberry and abandoned-bog sites. None of these families was found at more than two sites in each stream class and two-thirds occurred at only one of the eight sites. Crangonyctidae and Collembola were found in all habitats. The other twelve families were limited to muck or vegetated-muck habitats. The relative abundance of all these families except Crangonyctidae and Chaoboridae was less than one percent. Chaoboridae was the most frequently occurring and abundant family, occurring at two cranberry and two abandoned-bog sites with a mean (± 1 SD) relative abundance of 7.7% (± 8.1%). The most obvious difference between the three stream types was the high relative abundance of Asellidae for cranberry sites (45.7 ± 16) compared to abandoned-bog (8.6 ±13.5) and forest sites (0.8 ± 0.70). However, removing this family from the ordination did not reveal patterns much different than that obtained using the full data set. Three additional taxa, nematodes, Gomphidae (dragonflies), and Pyralidae (moths), were present only at abandoned bog sites.

Thirteen families shown on the extreme left side of the ordination diagram were present at forest sites but absent from the cranberry and abandoned-bog sites. Families associated only with forest sites included Brachycentridae, Limnephilidae, Molannidae, Odontoceridae (caddisflies), Ephemerellidae, Metretopodidae, Heptageniidae (mayflies), Empididae (true flies), Aeshnidae, Cordulegastridae (dragonflies), Calopterygidae (damselflies), Erpobdellidae (leeches), and Cambaridae (crayfish). Limnephilidae, Molannidae, Empididae, Calopterygidae, and Erpobdellidae were found at two or more of the forest sites. The other families occurred at only one forest site. Molannidae and Ephemerellidae, with a maximum relative abundance of 1.8% and 1.3%, respectively, were the only two families that comprised more than one percent of any forest sample. Habitat use among the thirteen families varied. Three families were found only on woody debris, two only in muck, and two only in vegetated-muck samples. The six other families were found in two or more habitats. Simuliidae (blackflies) larvae, also shown on the forest side of the ordination, were found on woody debris at the four forest sites and in muck at one cranberry site.

The patterns revealed by the MRPP analysis of the composite-sample based on all habitats were similar to those displayed by the associated DCA ordination (Table 7). We found a significant difference in family-level macroinvertebrate composition between the three groups of streams (A = 0.310, *p* = 0.003). A post-hoc comparison across all groups revealed a significant difference between the cranberry class and the other two stream classes but no difference between the abandoned-bog and forest classes.

We did not complete an MRPP analysis using the different habitats from each stream as separate samples because within-stream samples are not independent. However, comparison of the different stream classes based on separate MRPP analyses of each habitat type showed a significant difference in family-level composition between cranberry streams and both abandoned-bog and forest streams regardless of habitat (Table 8).

We obtained results similar to the three-habitat composite-sample analysis when ordinating either a two-habitat composite sample comprised of only muck and vegetated-muck samples or the three habitats from each stream site as separate samples (Figure 3). As with the three-habitat composite-sample data, the first axis of both DCA ordinations contrasted the forest sites and Tulpehocken Creek with the other sites. The ordering of sites and families along the first axis of the three ordinations was similar. Spearman rank correlations between the DCA axis 1 and axis 2 sites scores of the two-habitat and three-habitat composite-sample ordinations were significant ($r = 0.89$, $p < 0.001$ for axis 1 and $r = 0.74$, $p = 0.006$ for axis 2). The DCA axis 1 and axis 2 family scores for the three-sample and two-sample ordinations were also significantly correlated ($r = 0.85$, $p < 0.001$ for axis 1 and $r = 0.65$, $p < 0.001$ for axis 2), as were those for the three-sample and multiple-habitat ordinations ($r = 0.86$, $p < 0.001$ for axis 1 and $r = 0.58$, $p < 0.001$ for axis 2). Forest sites, where the composition of woody-debris samples contrasted with that of muck and vegetated-muck samples, displayed the most obvious difference between habitats (Figure 3). Overall, the effect of stream type appears to overshadow that of habitat.

Following the Bonferroni correction, we found no statistically significant correlation between the first two DCA axes based on the ordination of the three-habitat composite-sample data and environmental factors (Table 9). However, the correlation coefficient and initial *p* value suggest a negative relationship exists between the forest-to-cranberry/abandoned-bog community gradient, represented by the first DCA axis, and dissolved oxygen. The initial *p* value for specific conductance also suggests that the community gradient is positively correlated with this measure of dissolved solids.

Genus-level Comparison of Stream Types

Mean and median genus richness was highest at the forest sites compared to the cranberry and abandoned-bog sites (Table 10). Excluding the chironomids, the number of named genera per family ranged from 1 to 5, with a mean (± 1 SD) of 1.6 (± 0.95). Analysis of variance indicated a significant difference in genus richness among sites (p = 0.030). Although none of the individual post-hoc comparisons were significant, the greatest difference was found between forest sites and both cranberry (p = 0.07) and abandoned-bog (p = 0.06) sites. Mean genus richness was generally similar between habitats, and was consistently lower for woody debris (Table 10). Compared to abandoned-bog and cranberry sites, the highest number of genera restricted to a single stream type was found at forest sites. About one-quarter of the genera were found at all three stream types (Tables 11).

As with the family-level site ordination, the first axis of the genus-level DCA ordination contrasted the four forest sites and one abandoned-bog site (Tulpehocken Creek) with the other abandoned-bog streams and all cranberry streams (Figure 4). Sites within the same stream classes were clustered in the same general area of the two-dimensional site diagram. The first division of the genus-level TWINSPAN classification separated the four forest sites from the cranberry and abandoned-bog sites. The second division separated three cranberry sites from the remaining cranberry site and all four abandoned-bog sites.

Results of the MRPP analysis of the genus-level data showed a significant difference in macroinvertebrate composition between stream types (A = 0.23, p = 0.002). Post-hoc comparisons revealed a significant difference between the cranberry class and the other two stream classes, but no difference between the abandoned-bog and forest classes (Table 12).

The first DCA axis of the genus-level ordination, which represented a cranberry/abandoned-bog to forest community gradient, was positively correlated with dissolved-oxygen concentrations (Table 13). Although not significant following the Bonferroni correction due to the large number of tests, the analysis revealed a positive relationship between the first axis and both woody debris and stream width and a negative relationship between the community gradient and specific conductance and temperature.

The genus-level ordination contrasted genera associated with forest sites with those associated with cranberry or abandoned bog sites (Table 14). Thirty-three of 34 genera shown on one extreme end of the ordination were found only at forest sites. Nineteen of these taxa occurred at a single site, but deleting these taxa had little effect on the ordering of sites along the first and second DCA axes. The remaining fourteen genera were found at from one-half to all of the four forest sites. Mayflies, caddisflies, chironomids, oligochaetes, and odonates dominated the group of thirty-three forest-site genera. Seven of the eight species associated with the extreme end of the species gradient were found only on woody debris. However, muck, vegetated muck, and woody debris accounted for 37.5%, 23.6%, and 38.9% of the individual occurrences of the thirty-three genera, which suggests that habitat preference was not fully responsible for the contrast between forest streams and the other two stream types. EPT composition differed significantly between each of the three stream types (Table 15). The genus-level chironomid composition differed significantly between cranberry and both forest and abandoned-bog streams (Table 15).

The only plecopteran genus, *Leuctra*, was found at all forest sites, with a mean relative abundance of 5.6% (" 2.5%), as well as at a single cranberry site and a single abandoned-bog site. It occurred frequently in all three habitats. Ephemeropterans were represented by five genera, including *Eurylophella*, *Stenonema*, *Siphloplecton*, *Caenis*, and *Paraleptophlebia*. Most mayfly occurrences were associated with forest sites. Three genera, *Eurylophella*, *Stenonema*, and *Siphloplecton*, each occurred at a single forest site. *Eurylophella* was found in all three habitats, *Siphloplecton* inhabited muck and vegetated muck, and *Stenonema* was found only on woody debris. *Caenis* was found inhabiting muck in two cranberry streams. *Paraleptophlebia* was found inhabiting both muck and woody debris in forest streams and woody debris in a single cranberry stream.

Forest sites accounted for two-thirds of the genera-level tricopteran occurrences, which were equally distributed among the three habitats. Seven genera, *Brachycentrus*, *Cheumatopsyche*, *Hydroptila*, *Mystacides*, *Platycentropus*, *Molanna*, and *Psilotreta*, were found only at forest sites. The genera *Hydropsyche*, *Oecetis*, and *Neureclipsis* were found across stream types. *Polycentropus* was the only caddisfly that was not found at a forest site. The trichopteran genera *Hydropsyche* and *Hydroptila* were more frequently associated with woody debris compared to muck and vegetated-muck habitats, and *Nyctiophylax*, *Cheumatopsyche*, and *Psilotreta* were found only on woody debris. *Mystacides*, *Polycentropus*, *Brachycentrus*, *Molanna*, and *Platycentropus* were found only in muck or vegetated-muck samples.

Megalopterans included *Chauliodes*, *Nigronia*, and *Sialis*. *Nigronia* was collected from vegetated-muck and woody debris at one forest stream and from woody debris at a second forest stream. *Chauliodes* was found on woody debris at a single cranberry site. Sialis, which was found across stream types, was most frequently encountered in muck or vegetated-muck habitats.

Odonates comprised eight genera. *Ischnura* was found at four cranberry sites, a single forest site, and a single abandoned-bog site. *Boyeria*, *Calopteryx*, *Argria*, and *Cordulegaster* were found only in forest streams. Except for *Calopteryx*, which was found at two forest sites, all were found at a single site. *Gomphus* and *Sympetrum* were each found at a single abandoned-bog site and *Tetragoneuria* at one cranberry site. Most odonates were collected from muck or vegetated-muck habitats. Only two genera, *Boyeria* and *Ischnura*, were found on woody debris. Nine of the ten habitat samples where *Ischnura* was found were either muck or vegetated muck.

Twelve of the forty-one chironomid genera were found only at forest sites, with most limited to a single occurrence (Table 14). Only two genera were limited to the each of the other stream types. Sixteen chironomid genera were found across stream types. Three chironomid genera, *Tvetenia*, *Potthastia*, and *Xylotopus* were found only in woody debris. Six genera, including *Nilothauma*, *Harnischia*, *Paralauterborniella*, *Psectrotanypus*, and *Stempellinella*, were found only in muck samples, and four genera, including *Corynoneura*, *Guttipelopia*, *Cryptotendipes*, and *Kiefferulus* were found only in vegetated-muck samples. *Rheotanytarsus* and *Simulium* larvae, which were associated with forest sites, used contrasting habitats. *Simulium* larvae were found more frequently on woody debris, whereas *Rheotanytarsus* was absent in this habitat. All *Chaoborus* larvae were collected from muck or vegetated-muck habitats in cranberry and abandoned bog-sites.

Discussion

Taxon richness is often used as a measure of impairment, with decreasing richness associated with increasing perturbation (Barbour et al. 1999). Family-level richness was higher at forest sites compared to abandoned-bog and cranberry sites, but only forest and abandoned-bog site family richness was significantly different. Differences in mean genus richness between stream types were not significant. Mean family and genus richness was similar among muck, vegetated-muck, and woody-debris habitats. Both family-level and genus-level composition differed significantly between the cranberry streams and the other two stream classes, regardless of habitat type (muck, vegetated muck, and woody debris). The difference between cranberry and abandoned-bog sites is noteworthy because abandoned bogs bordered some cranberry sites.

Muck and vegetated-muck habitats had more families in common than each shared with woody debris, which can be attributed to the similarity between these two habitats. Our finding that mean family and genus richness was similar among habitats, and that genus richness was consistently lower for woody debris, is not consistent with those of other coastal plain stream studies where taxonomic richness and macroinvertebrate production is generally higher on snags than in less stable sand or silt habitats (Benke et al. 1984, 1985, Smock et al. 1985, Smock and Gilinsky 1992, Hax and Golladay 1998). We obtained similar family-level results when three-habitat composite samples, two-habitat (muck and vegetated-muck) composite samples, and individual-habitat samples were analyzed, indicating that the direct contribution of woody debris to contrasting site-type patterns was minimal. Forest sites displayed the most obvious difference between habitats and the influence of woody debris on macroinvertebrate composition, but overall, the effect of stream type appears to overshadow that of habitat. In the streams that we studied, woody debris may play a less direct but important role in shaping community composition by serving as a refuge and source of recolonizers following flow disturbances (Hax and Golladay 1998).

Our results suggest that variations in family-level and genus-level composition paralleled dissolved-oxygen gradients. Relatively low oxygen levels are not unusual in the groundwater-fed, low-turbulent waters of the Pinelands. During our study period, the median dissolved-oxygen concentration and percent saturation for McDonalds Branch, a U. S. Geological Survey Hydrologic Benchmark Network Station located in a Pinelands state forest (Mast and Turk 1999), was 2.8 mg L^{-1} and 29%, respectively (DeLuca et al. 2002, 2003). Because many of the taxa that we encountered are adapted to lentic habitats and slow-moving lotic habitats or low-oxygen environments, variations in community composition may be associated with subtle differences in dissolved-oxygen levels.

Tubificidae, Chironomidae, and Asellidae were the most abundant and widespread families. Chironomids are an important taxon in coastal plain streams, where they can be responsible for the majority of production (Smith and Smock 1992, Wright and Smock 2001). The dominance of Chironomids, which are relatively tolerant of organic pollution (Hilsenhoff 1988) and associated low oxygen levels, at forest, abandoned-bog, and cranberry streams suggests that this family is not an indicator of aquatic degradation in Pinelands streams. Similarly, Dougherty and Morgan (1991) found chironomids as the dominant benthic macroinvertebrates in both a dystrophic Pinelands lake and a degraded lake with fluctuating pH and elevated nutrients. However, we did find that differences in genus-level chironomid composition existed between stream types.

Neither the frequency of occurrence or the abundance of tubicid worms, which are generally among the most tolerant macroinvertebrates (Barbour et al. 1999), contributed to the differences between the three stream types. The family Asellidae, represented by the genus *Caecidotea*, was widespread and found in all habitats. Although the much greater relative abundance of this isopod at cranberry sites compared to the other two stream types cannot be directly attributed to any of the measured environmental variables, the family is considered to be very tolerant of conditions associated with organic pollution (Hilsenhoff 1988).

Chaoborus larvae (Chaoboridae) generally occur in lentic habitats and are often abundant in the low-oxygen environment of profundal zones (Hilsenhoff 2001, LaRow 1970). Tolerance of low-oxygen concentrations may explain why *Chaoborus* were found at cranberry and abandoned-bog sites that displayed some of the lowest dissolved-oxygen concentrations recorded for the twelve study streams.

Given the low pH of the study streams, it may appear unusual to find clams. Dougherty and Morgan (1991) described the presence of mollusks as one of the factors that distinguished the macroinvertebrate fauna of an enriched Pinelands lake from that of a dystrophic lake. Fingernail clams (Pisidiidae = Sphariidae) are among the few mollusks found in small, acidic coastal plain streams due to a greater tolerance to high acidity (Smock and Gilinsky 1992, Pennak 1978), yet the pH at which the clams were found is much more acidic than the lower pH limit of 6.0 reported by Pennak (1978). Like *Chaoborus* larvae, Pisidiid clams are generally adapted to waters with low oxygen levels (McMahon and Bogan 2001).

An increase in the number and relative abundance of EPT taxa is frequently associated with increasing levels of aquatic health. We found that EPT composition differed significantly between each of the three stream types and that stoneflies, caddisflies, and mayflies occurred more frequently at forest sites. Many of the caddisflies that we encountered, including *Nyctiophylax*, *Molanna, Neureclipsis*, *Platycentropus*, *Mystacides,* and *Oxyethira,* are found in lentic habitats or slow currents in streams, with the last four genera associated with aquatic macrophytes (Wiggins 1996a,b). *Brachycentrus*, *Hydropsyche*, *Psilotreta*, and *Cheumatopsyche* are generally associated with lotic habitats, and *Polycentropus, Hydroptila* and *Oecetis* are found in both lentic and lotic habitats (Wiggins 1996a,b). The lentic trichopterans represented 49% of the genus-level composite-sample occurrences, followed by lotic-lentic genera (27%), and lotic genera (24%), reflecting the slow currents that characterize the study streams. Most of the families encountered are considered moderately tolerant, although *Brachycentrus* and *Psilotreta*, two genera found only at forest sites, are included in families classified as intolerant by Hilsenhoff (1988).

Ephemeropterans, which are generally considered an intolerant group (Hilsenhoff 1988), occurred more frequently at forest sites and were absent at abandoned-bog sites. Most of the genera we encountered are associated with both lotic and lentic habitats (Edmunds and Waltz 1996). *Caenis*, the only mayfly genus limited to cranberry sites, usually inhabits stream pools or littoral sediments of lakes and ponds. This genus is one of the most tolerant mayflies (Hilsenhoff 1988). *Leuctra*, which was the only stonefly that we collected, was found across stream types but was more frequently encountered in forest streams. This intolerant stonefly (Hilsenhoff 1988) is generally associated with stream habitats (Stewart and Harper 1996).

Habitat use by odonates in a sand-bottomed coastal plain stream in Virginia varied among different species (Burcher and Smock 2002). Odonates were less abundant on snags compared to debris dams, silt, and sand. In our study, we collected most of the odonate genera from muck or vegetated-muck habitats, which are the habitats in which they are generally found (Westfall and Tennessen 1996). *Ishnura*, the most frequently encountered odonate, is associated with vegetated lentic or lotic-depositional habitats (Westfall and Tennessen 1996). The odonate families that we encountered display a range of tolerance values (Hilsenhoff 1988), which do not appear to be related to stream type.

Although not conclusive, our results suggest that variations in macroinvertebrate composition may be related to a complex environmental gradient involving dissolved oxygen, temperature, specific conductance, stream width, and woody debris. The relationship between reduced canopy cover and both lower woody-debris cover and higher stream temperatures, which influence dissolved-oxygen levels, is most likely related to deforestation and a higher percentage of open water associated with historic and active cranberry agriculture. Pesticide use in cranberry cultivation (Eck 1990, Szeto et al. 1990, Anderson and Davis 2000), which was not addressed in our study, may explain some of the variation in macroinvertebrate assemblages between stream types, but the actual effect is unknown and, as with other aquatic systems, may be difficult to determine (Sobiech and Henry 2003).

Acknowledgements

We thank Kim Laidig, Christina Burns, and Jason Shvanda for assisting with various aspects of the study. The New Jersey Division of Parks and Forestry authorized the state-lands research permits. Joseph Darlington granted permission to access Pole Bridge Branch on his property. Funding for this study was provided by the U. S. Environmental Protection Agency (State Wetlands Grant Program, Grant No. CD-99298001-1), the Pinelands Commission, the National Park Service, and the New Jersey Department of Environmental Protection.

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Table 1. Instream and land-use characteristics of study streams. Altered land includes developed land and upland agriculture. Dissolved oxygen (DO) and specific conductance (SC) are in mg L^{-1} and $\mu S\ cm^{-1}$, respectively. Land-use values are expressed as a percentage of basin area. Instream plant cover, canopy cover, wood-debris cover, muck, and sand are expressed as percentages.

Site Type and Stream Name	Basin area (km^2)	Bankfull depth (cm)	Bankfull width (m)	Dis-charge rank	pH	SC	DO	% DO	Temp (°C)	Instream plant cover	Canopy cover	Woody-debris cover	Muck	Sand	Altered land	Wetland agri-culture	Upland forest	Open water	Wetlands	Barren land
Forest streams																				
Buck Run	7.8	42.9	4.0	---	4.8	26.5	6.0	63.5	18.9	26.8	73.5	9.9	73.3	26.7	0.0	0.0	86.5	0.2	13.3	0.0
E. Br. Bass River	21.1	58.6	4.9	10.0	4.4	37.4	6.8	67.7	18.9	7.1	52.8	4.7	50.0	50.0	2.0	0.0	82.7	1.0	14.0	0.2
Papoose Branch	11.4	43.7	4.8	5.0	4.7	29.9	7.1	68.6	17.6	7.5	91.7	2.9	63.3	36.7	0.0	0.0	87.5	0.0	12.4	0.1
Skit Branch	13.0	47.9	6.0	4.0	4.7	24.2	5.9	69.4	23.3	29.1	35.7	2.7	93.3	6.7	0.3	0.0	80.3	0.0	19.4	0.0
Mean	**13.3**	**48.3**	**4.9**	**6.3**	**4.6**	**29.5**	**6.5**	**67.3**	**19.7**	**17.6**	**63.4**	**5.0**	**70.0**	**30.0**	**0.6**	**0.0**	**84.3**	**0.3**	**14.8**	**0.1**
SD	**5.6**	**7.2**	**0.8**	**3.2**	**0.2**	**5.8**	**0.6**	**2.6**	**2.5**	**11.9**	**24.4**	**3.3**	**18.3**	**18.3**	**1.0**	**0.0**	**3.3**	**0.5**	**3.1**	**0.1**
Median	**12.2**	**45.8**	**4.8**	**5.0**	**4.7**	**28.2**	**6.4**	**68.2**	**18.9**	**17.2**	**63.1**	**3.8**	**68.3**	**31.7**	**0.2**	**0.0**	**84.6**	**0.1**	**13.7**	**0.0**
Abandoned-bog streams																				
Deep Run	4.6	40.7	2.5	---	4.0	89.6	2.9	36.8	27.0	16.8	0.0	0.0	100.0	0.0	0.2	0.0	15.9	4.2	79.7	0.0
N. Br. Mt. Misery Brook	29.4	39.8	5.2	2.5	4.6	31.3	4.8	44.5	16.0	30.0	41.0	4.5	80.0	20.0	3.3	0.1	86.1	1.4	9.2	0.0
Shane Branch	4.6	17.9	3.3	2.0	4.2	39.4	4.7	57.6	27.2	20.1	9.2	0.0	73.3	26.7	0.4	0.0	50.8	0.0	48.8	0.0
Tulpehocken Creek	56.6	49.1	5.3	8.0	4.9	23.9	7.6	71.7	21.4	15.2	17.4	0.0	0.0	100.0	0.2	0.1	61.3	1.0	37.4	0.0
Mean	**23.8**	**36.9**	**4.1**	**4.2**	**4.4**	**46.0**	**5.0**	**52.6**	**22.9**	**20.5**	**16.9**	**1.1**	**63.3**	**36.7**	**1.0**	**0.0**	**53.5**	**1.7**	**43.8**	**0.0**
SD	**24.8**	**13.3**	**1.4**	**3.3**	**0.4**	**29.7**	**1.9**	**15.3**	**5.3**	**6.7**	**17.6**	**2.2**	**43.7**	**43.7**	**1.5**	**0.0**	**29.1**	**1.8**	**29.2**	**0.0**
Median	**17.0**	**40.2**	**4.2**	**2.5**	**4.4**	**35.4**	**4.7**	**51.1**	**24.2**	**18.4**	**13.3**	**0.0**	**76.7**	**23.3**	**0.3**	**0.0**	**56.0**	**1.2**	**43.1**	**0.0**
Cranberry streams																				
Batsto River	4.0	31.9	3.7	1.0	4.5	45.1	2.6	29.6	22.0	28.4	65.9	0.5	100.0	0.0	0.5	8.4	47.6	1.7	41.6	0.2
Hospitality Brook	4.9	27.8	3.0	7.0	4.7	46.2	6.5	63.5	22.9	49.7	7.9	0.0	86.7	13.3	8.4	34.3	24.7	6.9	23.0	2.7
Little Hauken Run	15.6	66.6	4.4	9.0	4.6	49.1	4.4	40.6	21.3	5.0	56.0	3.5	63.3	36.7	2.3	25.1	32.9	7.5	31.8	0.3
Pole Bridge Branch	34.8	---	---	4.0	5.1	49.4	5.2	55.3	19.6	---	---	---	---	---	8.4	3.9	56.5	1.1	29.4	0.8
Mean	**14.8**	**42.1**	**3.7**	**5.3**	**4.7**	**47.5**	**4.7**	**47.3**	**21.5**	**27.7**	**43.2**	**1.3**	**83.3**	**16.7**	**4.9**	**17.9**	**40.4**	**4.3**	**31.4**	**1.0**
SD	**14.3**	**21.3**	**0.7**	**3.5**	**0.3**	**2.1**	**1.6**	**15.1**	**1.4**	**22.3**	**31.0**	**1.9**	**18.6**	**18.6**	**4.1**	**14.2**	**14.3**	**3.4**	**7.7**	**1.2**
Median	**10.2**	**31.9**	**3.7**	**5.5**	**4.6**	**47.7**	**4.8**	**48.0**	**21.7**	**28.4**	**56.0**	**0.5**	**86.7**	**13.3**	**5.3**	**16.8**	**40.3**	**4.3**	**30.6**	**0.5**

Table 2. Environmental-factors correlation matrix. Correlations significant at an initial *p* value < 0.05 are shown in bold print.

	DO	Temp.	Instream plant cover	Woody-debris cover	Per-cent muck	Canopy cover	Bankfull depth	Bank-full width	pH	Specific conduc-tance	Basin area	Discharge rank
Dissolved oxygen (mg L^{-1})	1.00											
Temperature (^{o}C)	-0.39	1.00										
Instream plant cover (%)	-0.16	0.20	1.00									
Woody-debris cover (%)	0.13	**-0.77**	-0.20	1.00								
Muck (%)	**-0.70**	0.47	**0.67**	-0.29	1.00							
Canopy cover (%)	0.13	**-0.71**	-0.30	**0.74**	-0.29	1.00						
Bankfull depth (cm)	0.35	-0.39	**-0.70**	0.45	-0.60	0.35	1.00					
Bankfull width (m)	0.49	-0.47	-0.11	0.40	-0.46	0.31	**0.61**	1.00				
PH	**0.59**	-0.42	0.13	0.20	-0.38	0.37	0.29	0.55	1.00			
Specific conductance (μS cm^{-1})	**-0.64**	0.28	-0.08	-0.26	0.42	-0.31	-0.28	**-0.78**	-0.44	1.00		
Basin area (km^2)	0.51	-0.55	-0.28	0.39	**-0.66**	0.11	**0.70**	**0.81**	**0.58**	-0.30	1.00	
Discharge rank	0.58	-0.31	-0.54	0.32	**-0.72**	0.02	**0.77**	0.24	0.22	-0.01	0.54	1.00

Table 3. Taxonomy of macroinvertebrates collected at 12 Pinelands streams, including streams draining cranberry, abandoned-bog, and forest. Chironomids (Diptera) are listed in Table 4.

Phylum/Subphylum	Class	Order	Family	Genus
Arthropoda				
	Insecta			
		Coleoptera (beetles)		
			Curculionidae	Unknown
			Dytiscidae	*Desmopachria*
			Dytiscidae	*Hydroporus*
			Dytiscidae	*Ilybius*
			Dytiscidae	*Laccophilus*
			Dytiscidae	Unknown
			Elmidae	*Ancyronyx*
			Elmidae	*Oulimnius*
			Elmidae	*Stenelmis*
			Elmidae	*Unknown*
			Gyrinidae	*Dineutus*
			Gyrinidae	*Gyrinus*
			Haliplidae	*Peltodytes*
			Noteridae	*Hydrocanthus*
			Unknown	-----
		Collembola (springtails)		-----
		Diptera (true flies)		
			Ceratopogonidae	*Bezzia*
			Ceratopogonidae	*Culicoides*
			Ceratopogonidae	*Probezzia*
			Ceratopogonidae	Unknown
			Chaoboridae	*Chaoborus*
			Empididae	*Hemerodromia*
			Simuliidae	*Simulium*
			Tabanidae	*Chrysops*
			Tabanidae	Unknown
			Tipulidae	*Limnophila*
			Tipulidae	*Pseudolimnophila*
			Tipulidae	*Tipula*
			Tipulidae	Unknown
		Ephemeroptera (mayflies)		
			Caenidae	*Caenis*
			Ephemerellidae	*Eurylophella*
			Heptageniidae	*Stenonema*
			Leptophlebiidae	*Paraleptophlebia*
			Metretopodidae	*Siphloplecton*
		Hemiptera (true bugs)		
			Corixidae	Unknown
			Gerridae	Unknown
			Notonectidae	*Buenoa*
			Notonectidae	*Notonecta*
			Veliidae	*Microvelia*
			Veliidae	*Rhagovelia*
		Lepidoptera (butterlies and moths)		
			Pyralidae	Unknown
		Megaloptera (fishflies, alderflies, and dobsonfles)		
			Corydalidae	*Chauliodes*
			Corydalidae	*Nigronia*
			Sialidae	*Sialis*
		Odonata (damselflies and dragonflies)		
			Aeshnidae	*Boyeria*
			Cordulegastridae	*Cordulegaster*
			Corduliidae	*Tetragoneuria*
			Gomphidae	*Gomphus*
			Libellulidae	*Sympetrum*
			Calopterygidae	*Calopteryx*
			Coenagrionidae	*Argia*
			Coenagrionidae	*Ischnura*
			Gomphidae	Unknown
Arthropoda				
	Insecta			
		Plecoptera (stoneflies)		
			Leuctridae	Leuctra
		Trichoptera (caddisflies)		
			Brachycentridae	*Brachycentrus*
			Hydropsychidae	*Cheumatopsyche*
			Hydropsychidae	*Hydropsyche*
			Hydroptilidae	*Hydroptila*
			Hydroptilidae	*Oxyethira*
			Leptoceridae	Unknown
			Leptoceridae	*Mystacides*
			Leptoceridae	*Oecetis*
			Leptoceridae	Unknown
			Limnephilidae	*Platycentropus*
			Limnephilidae	Unknown
			Molannidae	*Molanna*
			Odontoceridae	*Psilotreta*
			Polycentropodidae	*Neureclipsis*
			Polycentropodidae	*Nyctiophylax*
			Polycentropodidae	*Polycentropus*
			Polycentropodidae	Unknown
Arthropoda/Crustacea				
	Malacostraca			
		Decapoda (crayfish)		
			Cambaridae	Unknown
		Amphipoda (scuds)		
			Crangonyctidae	*Synurella*
		Isopoda (sowbugs)		
			Asellidae	*Caecidotea*
Annelida				
	Hirudinea (leeches)			
		Pharyngobdellida		
			Erpobdellidae	*Mooreobdella*
		Rhychobdellida		
			Glossiphoniidae	*Placobdella*
	Oligochaeta (bristle worms)			
		Haplotaxida		
			Enchytraeidae	Unknown
			Naididae	*Dero*
			Naididae	*Nais*
			Naididae	*Slavina*
			Naididae	*Specaria*
			Naididae	*Vejdovskyella*
		Lumbriculida		
			Lumbriculidae	*Lumbriculus*
		Tubificida		
			Tubificidae	*Aulodrilus*
			Tubificidae	*Limnodrilus*
			Tubificidae	*Tubifex*
Mollusca				
	Bivalvia (clams)			
		Veneroida		
			Pisidiidae	Unknown
	Gastropoda (snails)			
		Basommatophora		
			Ancylidae	Unknown
Nematoda (roundworms)				-----
Platyhelminthes (flatworms)				
	Turbellaria			
		Tricladia		
			Planariidae	*Phagocata*

Table 4. Chironomids (Order Diptera, Family Chironomidae) collected at 12 Pinelands streams, including cranberry, abandoned-bog, and forest streams.

- Subfamily
  - Tribe
    - Genus
- Chironominae
  - Chironomini
    - *Chironomus*
    - *Cladopelma*
    - *Cryptochironomus*
    - *Cryptotendipes*
    - *Dicrotendipes*
    - *Harnischia*
    - *Hyporhygma*
    - *Kiefferulus*
    - *Nilothauma*
    - *Pagastiella*
    - *Parachironomus*
    - *Paralauterborniella*
    - *Paratendipes*
    - *Polypedilum*
    - *Stenochironomus*
    - *Tribelos*
  - Tanytarsini
    - *Paratanytarsus*
    - *Rheotanytarsus*
    - *Stempellinella*
    - *Tanytarsus*

- Subfamily
  - Genus
- Diamesinae
  - *Potthastia*
- Orthocladiinae
  - *Corynoneura*
  - *Cricotopus*
  - *Heterotrissocladius*
  - *Psectrocladius*
  - *Rheocricotopus*
  - *Thienemanniella*
  - *Tvetenia vitracies*
  - Unknown
  - *Xylotopus*
- Pseudochironomini
  - *Pseudochironomus*
- Tanypodinae
  - *Ablabesmyia*
  - *Alotanypus*
  - *Apectrotanypus*
  - *Clinotanypus*
  - *Guttipelopia*
  - *Labrundinia*
  - *Pentaneura*
  - *Procladius*
  - *Psectrotanypus*
  - *Tanypus*
  - *Thienemannimyia*

Table 5. Mean relative abundance and frequency of occurrence of macroinvertebrate orders in cranberry, abandoned-bog, and forest streams (n= 4 for each stream type). Taxa are listed in order of increasing frequency.

	Mean Relative Abundance (%)			Frequency (%)			
Order	Cranberry	Abandoned bog	Forest	Cranberry	Abandoned bog	Forest	All sites
Amphipoda	2	---	---	25	---	---	8
Decapoda	---	---	<1	---	---	25	8
Basommatophora	<1	---	---	25	---	---	8
Nematoda	---	1	---	---	25	---	8
Tricladia	<1	---	---	25	---	---	8
Rhychobdellida	<1	---	---	25	---	---	8
Pharyngobdellida	---	---	<1	---	---	50	17
Collembola	<1	<1	---	50	25	---	25
Lepidoptera	---	1	---	---	75	---	25
Lumbriculida	<1	<1	---	50	25	---	25
Veneroida	<1	---	3	50	---	50	33
Ephemeroptera	<1	---	1	50	---	100	50
Plecoptera	<1	2	6	25	25	100	50
Megaloptera	1	1	2	50	50	100	67
Odonata	3	1	1	100	50	75	75
Trichoptera	5	1	10	75	75	100	83
Haplotaxida	2	8	4	75	75	100	83
Coleoptera	1	1	0	100	100	75	92
Hemiptera	1	2	2	75	100	100	92
Isopoda	46	9	1	100	75	100	92
Diptera	31	71	63	100	100	100	100
Tubificida	8	4	6	100	100	100	100

Table 6. The number of families found only at forest (F), abandoned-bog (A), or cranberry (C) sites or at a combinations of stream types by habitat. Numbers include collembolans and nematodes.

Habitat	F	A	C	AF	CF	CA	CAF	Total
Woody debris only	3	1	-	-	-	-	-	4
Muck only	2	-	4	-	-	-	-	6
Vegetated muck only	2	3	3	-	-	-	-	8
Muck and woody debris	2	-	-	-	3	-	-	5
Vegetated muck and woody debris	-	-	-	-	1	-	1	2
Muck and vegetated muck	3	-	-	-	1	3	3	10
Muck, vegetated muck, and woody debris	1	1	1	1	2	1	13	20
Total Families	13	5	8	1	7	4	17	55

Table 7. MRPP comparison of macroinvertebrate family-level composition between stream types (12 sites and 55 taxa) based on composite samples that include muck, vegetated-muck, and woody-debris habitats. Stream types include cranberry, abandoned-bog, and forest streams. For each stream type, n = 4. An overall significant difference was found among streams (A = 0.310, *p* = 0.003). Tests significant after the Bonferroni adjustment are indicated with an asterisk.

Stream-type comparisons			A	Initial *p* value
Cranberry	vs.	Forest	0.40	0.007*
Cranberry	vs.	Abandoned bog	0.26	0.011*
Abandoned bog	vs.	Forest	0.01	0.295

Table 8. MRPP comparison of family-level macroinvertebrate composition between stream types based on separate analyses of muck, vegetated-muck, and woody-debris habitats. Stream types include cranberry, abandoned-bog, and forest streams. Overall and between-type tests significant after the Bonferroni adjustment are indicated with an asterisk.

Stream-type comparisons by habitat			A	Initial *p* value
Muck				
All groups			0.234	0.005*
Cranberry	vs.	Forest	0.290	0.010*
Cranberry	vs.	Abandoned bog	0.205	0.014*
Abandoned bog	vs.	Forest	-0.015	0.597
Vegetated muck				
All groups			0.386	0.001*
Cranberry	vs.	Abandoned bog	0.460	0.007*
Cranberry	vs.	Forest	0.350	0.007*
Abandoned bog	vs.	Forest	0.070	0.090
Woody Debris				
All groups			0.259	0.016*
Cranberry	vs.	Abandoned bog	0.046	<0.001*
Cranberry	vs.	Forest	0.390	0.009*
Abandoned bog	vs.	Forest	0.124	0.044

Table 9. Relationship of family-level macroinvertebrate-community gradients, based on composite-habitat samples, to environmental variables. No correlations are significant following the Bonferroni correction.

		DCA Axis 1		DCA Axis 2	
Environmental Variables	n	Spearman r	*p*	Spearman r	*p*
Instream plant cover (%)	11	0.15	0.670	0.25	0.450
Woody debris cover (%)	11	-0.52	0.100	0.30	0.366
Muck cover (%)	11	0.52	0.103	0.06	0.852
Canopy cover (%)	11	-0.45	0.160	0.35	0.285
Bankfull depth (cm)	11	-0.30	0.370	0.15	0.650
Bankfull width (m)	11	-0.55	0.077	0.11	0.750
pH	12	-0.42	0.175	0.50	0.101
Specific conductance (μS cm^{-1})	12	0.76	0.005	0.12	0.713
Dissolved oxygen (mg L^{-1})	12	-0.73	0.007	0.10	0.746
Temperature (^{o}C)	12	0.56	0.060	-0.20	0.541
Basin area (km^{2})	12	-0.39	0.208	0.13	0.681
Discharge rank	10	-0.26	0.463	0.21	0.564

Table 10. Mean genus-level richness by stream type and habitat. Median values for cranberry, abandoned bog, and forest streams are 28, 26, and 41.5, respectively.

	Cranberry	Abandoned bog	Forest	All sites
Muck	15.0 ± 3.9	13.5 ± 1.0	24.5 ± 6.6	17.7 ± 6.5
Vegetated muck	15.3 ± 4.4	20.8 ± 6.3	21.0 ± 4.7	19.0 ± 5.5
Woody debris	14.3 ± 3.0	12.5 ± 3.5	18.3 ± 3.5	15.6 ± 4.0
Total	26.0 ± 6.6	25.3 ± 6.2	41.5 ± 7.8	30.9 ± 10.0

Table 11. The number and percentage of genera found only at forest, abandoned-bog, or cranberry sites or at a combination of stream types.

Type	Number	Percentage
Forest	35	31.8
Abandoned bog	11	10.0
Cranberry	14	12.7
Abandoned bog and forest	6	5.5
Cranberry and forest	7	6.4
Cranberry and abandoned bog	8	7.3
Forest, abandoned bog, and cranberry	29	26.4
Total	110	100.0

Table 12. MRPP comparison of genus-level composition between three stream types (12 sites and 110 taxa). Stream types include cranberry, abandoned-bog, and forest streams. For each stream type, n = 4. A significant difference was found among streams (A = 0.233, *p* = 0.002). Tests significant after the Bonferroni adjustment are indicated with an asterisk.

Stream-type Comparison			A	Initial *p* value
Cranberry	vs.	Forest	0.339	0.007*
Cranberry	vs.	Abandoned bog	0.169	0.018*
Abandoned bog	vs.	Forest	0.059	0.046

Table 13. Relationship of genus-level macroinvertebrate-community gradients, based on composite-habitat samples, to environmental variables. Correlations significant following the Bonferroni correction are noted with an asterisk.

		DCA Axis 1		DCA Axis 2	
Environmental Variables	n	Spearman r	*p*	Spearman r	*P*
Instream plant cover (%)	11	-0.18	0.593	0.255	0.450
Woody debris cover (%)	11	0.62	0.042	0.098	0.775
Muck (%)	11	-0.55	0.080	0.247	0.464
Canopy cover (%)	11	0.59	0.056	-0.155	0.650
Depth (cm)	11	0.51	0.110	-0.391	0.235
Width (m)	11	0.65	0.032	0.055	0.873
pH	12	0.48	0.118	-0.538	0.071
Specific conductance (μS cm^{-1})	12	-0.73	0.007	-0.196	0.542
Dissolved oxygen (mg L^{-1})	12	0.80	0.002*	-0.266	0.404
Temperature (^{o}C)	12	-0.65	0.021	0.035	0.914
Basin area (km^{2})	12	0.43	0.167	-0.210	0.513
Discharge rank	10	0.51	0.129	-0.502	0.140

Table 14. Genus-level ordination. Genera are ordered by raw DCA axis 1 scores. Frequency of occurrence is given for forest (F), abandoned-bog (A), and cranberry (C) stream sites. High-positive axis-1 scores are associated with forest sites. Negative axis-1 scores are associated with abandoned-bog and cranberry sites.

Order	Family	Genus	F	A	C	AX1	AX2
Hemiptera	Notonectidae	*Buenoa*	--	25	--	-150	77
Diptera	Chironomidae	*Hyporhygma*	--	25	25	-124	119
Diptera	Chironomidae	*Parachironomus*	--	25	25	-123	57
Diptera	Chironomidae	*Kiefferulus*	--	25	--	-122	184
Trichoptera	Polycentropodidae	*Polycentropus*	--	25	--	-122	184
Odonata	Libellulidae	*Sympetrum*	--	25	--	-122	184
Diptera	Chaoboridae	*Chaoborus*	--	50	50	-118	114
Diptera	Chironomidae	*Guttipelopia*	--	25	25	-113	161
Coleoptera	Haliplidae	*Peltodytes*	--	25	25	-79	-45
Megaloptera	Corydalidae	*Chauliodes*	--	--	25	-78	199
Coleoptera	Elmidae	*Oulimnius*	--	--	25	-78	199
Hemiptera	Veliidae	*Rhagovelia*	--	--	25	-78	199
Diptera	Chironomidae	*Chironomus*	50	75	50	-63	237
Diptera	Tipulidae	*Tipula*	--	--	50	-60	-9
Odonata	Coenagrionidae	*Ischnura*	25	25	100	-38	-57
Coleoptera	Noteridae	*Hydrocanthus*	--	--	25	-34	14
Diptera	Chironomidae	*Paratanytarsus*	--	--	25	-34	14
Diptera	Chironomidae	*Psectrotanypus*	--	--	25	-34	14
Diptera	Tipulidae	*Pseudolimnophila*	--	--	25	-34	14
Odonata	Corduliidae	*Tetragoneuria*	--	--	25	-34	14
Hemiptera	Notonectidae	*Notonecta*	25	75	25	-34	105
Diptera	Chironomidae	*Paratendipes*	50	75	--	-32	214
Diptera	Ceratopogonidae	*Culicoides*	50	100	--	-28	253
Ephemeroptera	Caenidae	*Caenis*	--	--	50	-27	-107
Triclaidia	Planariidae	*Phagocata*	--	--	25	-21	-221
Rhychobdellida	Glossiphoniidae	*Placobdella*	--	--	25	-21	-221
Amphipoda	Crangonyctidae	*Synurella*	--	--	25	-21	-221
Coleoptera	Elmidae	*Stenelmis*	--	--	50	-20	-104
Diptera	Chironomidae	*Alotanypus*	25	50	50	-17	271
Diptera	Chironomidae	*Tanypus*	--	25	25	-13	373
Coleoptera	Dytiscidae	*Ilybius*	--	25	--	-8	412
Coleoptera	Dytiscidae	*Laccophilus*	--	25	--	-8	412
Haplotaxida	Naididae	*Vejdovskyella*	--	25	--	-8	412
Isopoda	Asellidae	*Caecidotea*	100	75	100	-5	53
Lumbriculida	Lumbriculidae	*Lumbriculus*	--	25	50	12	-123
Diptera	Chironomidae	*Stenochironomus*	50	25	75	14	-25
Trichoptera	Leptoceridae	*Oecetis*	50	25	75	24	-64
Diptera	Chironomidae	*Dicrotendipes*	25	--	75	28	-79
Coleoptera	Dytiscidae	*Hydroporus*	50	75	--	30	266
Diptera	Chironomidae	*Clinotanypus*	25	75	25	32	283
Haplotaxida	Naididae	*Dero*	50	75	75	44	212
Diptera	Chironomidae	*Polypedilum*	100	100	100	48	-2
Tubificida	Tubificidae	*Limnodrilus*	100	100	75	57	80
Diptera	Ceratopogonidae	*Bezzia*	75	75	75	79	244
Haplotaxida	Naididae	*Specaria*	--	25	25	79	-5
Diptera	Chironomidae	*Ablabesmyia*	100	100	100	99	135
Diptera	Tabanidae	*Chrysops*	50	75	25	102	260
Coleoptera	Dytiscidae	*Desmopachria*	25	25	--	110	204
Diptera	Chironomidae	*Cryptotendipes*	--	25	--	120	110
Odonata	Gomphidae	*Gomphus*	--	25	--	120	110
Coleoptera	Gyrinidae	*Gyrinus*	--	25	--	120	110
Diptera	Ceratopogonidae	*Probezzia*	--	25	--	120	110
Diptera	Chironomidae	*Procladius*	100	100	75	135	55
Coleoptera	Gyrinidae	*Dineutus*	25	25	25	153	-55
Diptera	Chironomidae	*Tribelos*	100	50	100	155	212
Diptera	Chironomidae	*Pentaneura*	50	25	25	160	113
Diptera	Chironomidae	*Cryptochironomus*	25	25	25	168	-8
Diptera	Chironomidae	*Potthastia*	25	--	--	173	143
Megaloptera	Sialidae	*Sialis*	100	50	50	173	229
Diptera	Chironomidae	*Cricotopus*	75	25	50	179	-48
Diptera	Chironomidae	*Cladopelma*	75	50	25	180	109
Diptera	Chironomidae	*Apectrotanypus*	100	75	75	192	72
Ephemeroptera	Leptophlebiidae	*Paraleptophlebia*	50	--	25	195	31
Diptera	Chironomidae	*Corynoneura*	25	--	25	199	-43
Trichoptera	Hydropsychidae	*Hydropsyche*	75	25	50	220	-11
Diptera	Chironomidae	*Labrundinia*	75	--	50	220	-53
Diptera	Chironomidae	*Tanytarsus*	100	75	25	223	267
Diptera	Chironomidae	*Thienemannimyia*	100	100	50	223	191
Diptera	Chironomidae	*Pagastiella*	50	--	--	224	165
Trichoptera	Polycentropodidae	*Neureclipsis*	75	25	25	237	129
Plecoptera	Leuctridae	*Leuctra*	100	25	25	263	104
Diptera	Chironomidae	*Psectrocladius*	100	50	75	266	237
Trichoptera	Hydroptilidae	*Oxyethira*	100	25	--	280	159
Tubificida	Tubificidae	*Aulodrilus pigueti*	50	--	50	289	82
Diptera	Simuliidae	*Simulium*	100	--	25	306	80
Trichoptera	Polycentropodidae	*Nyctiophylax*	25	--	25	309	67
Diptera	Chironomidae	*Rheotanytarsus*	100	--	--	314	152
Odonata	Coenagrionidae	*Argia*	25	--	--	319	119
Odonata	Cordulegastridae	*Cordulegaster*	25	--	--	319	119
Ephemeroptera	Ephemerellidae	*Eurylophella*	25	--	--	319	119
Diptera	Chironomidae	*Heterotrissocladius*	75	50	--	319	231
Megaloptera	Corydalidae	*Nigronia*	50	--	--	331	157
Diptera	Chironomidae	*Tvetenia*	75	--	--	333	72
Diptera	Chironomidae	*Nilothauma*	50	--	--	343	194
Pharyngobdellida	Erpobdellidae	*Mooreobdella*	50	--	--	346	201
Odonata	Calopterygidae	*Calopteryx*	50	--	--	346	64
Trichoptera	Hydroptilidae	*Hydroptila*	75	--	--	346	87
Trichoptera	Leptoceridae	*Mystacides*	50	--	--	346	64
Trichoptera	Molannidae	*Molanna*	75	--	--	351	116
Diptera	Chironomidae	*Rheocricotopus*	75	--	--	351	132
Diptera	Chironomidae	*Thienemanniella*	75	--	--	351	93
Hemiptera	Veliidae	*Microvelia*	50	--	--	352	54
Trichoptera	Brachycentridae	*Brachycentrus*	25	--	--	357	223
Diptera	Chironomidae	*Harnischia*	25	--	--	357	223
Diptera	Tipulidae	*Limnophila*	25	--	--	357	223
Diptera	Chironomidae	*Paralauterborniella*	25	--	--	357	223
Trichoptera	Limnephilidae	*Platycentropus*	25	--	--	357	223
Diptera	Chironomidae	*Pseudochironomus*	25	--	--	357	223
Ephemeroptera	Metretopodidae	*Siphloplecton*	25	--	--	357	223
Haplotaxida	Naididae	*Slavina*	25	--	--	357	223
Tubificida	Tubificidae	*Tubifex*	25	--	--	357	223
Diptera	Empididae	*Hemerodromia*	50	--	--	359	176
Haplotaxida	Naididae	*Nais*	50	--	--	361	99
Coleoptera	Elmidae	*Ancyronyx*	25	--	--	362	40
Odonata	Aeshnidae	*Boyeria*	25	--	--	362	40
Trichoptera	Hydropsychidae	*Cheumatopsyche*	25	--	--	362	40
Trichoptera	Odontoceridae	*Psilotreta*	25	--	--	362	40
Diptera	Chironomidae	*Stempellinella*	25	--	--	362	40
Ephemeroptera	Heptageniidae	*Stenonema*	25	--	--	362	40
Diptera	Chironomidae	*Xylotopus*	25	--	--	362	40

Table 15. Comparison of genus-level EPT (Ephemeroptera, Plecoptera, and Trichhoptera) and chironomid composition between stream types based on composite-habitat samples. Stream types include cranberry, abandoned-bog, and forest streams. Between-type comparisons for each habitat are listed in order of decreasing *p* values. Overall and between-type tests significant after the Bonferroni adjustment are indicated with an asterisk.

Stream-type comparison			A	Initial *p* value
EPT				
All Groups			0.206	0.005*
Cranberry	vs.	Forest	0.193	0.009*
Abandoned bog	vs.	Forest	0.159	0.022*
Cranberry	vs.	Abandoned bog	0.130	0.049*
Chironomids				
All Groups			0.079	0.007*
Cranberry	vs.	Forest	0.090	0.007*
Cranberry	vs.	Abandoned bog	0.068	0.026*
Abandoned bog	vs.	Forest	0.042	0.122

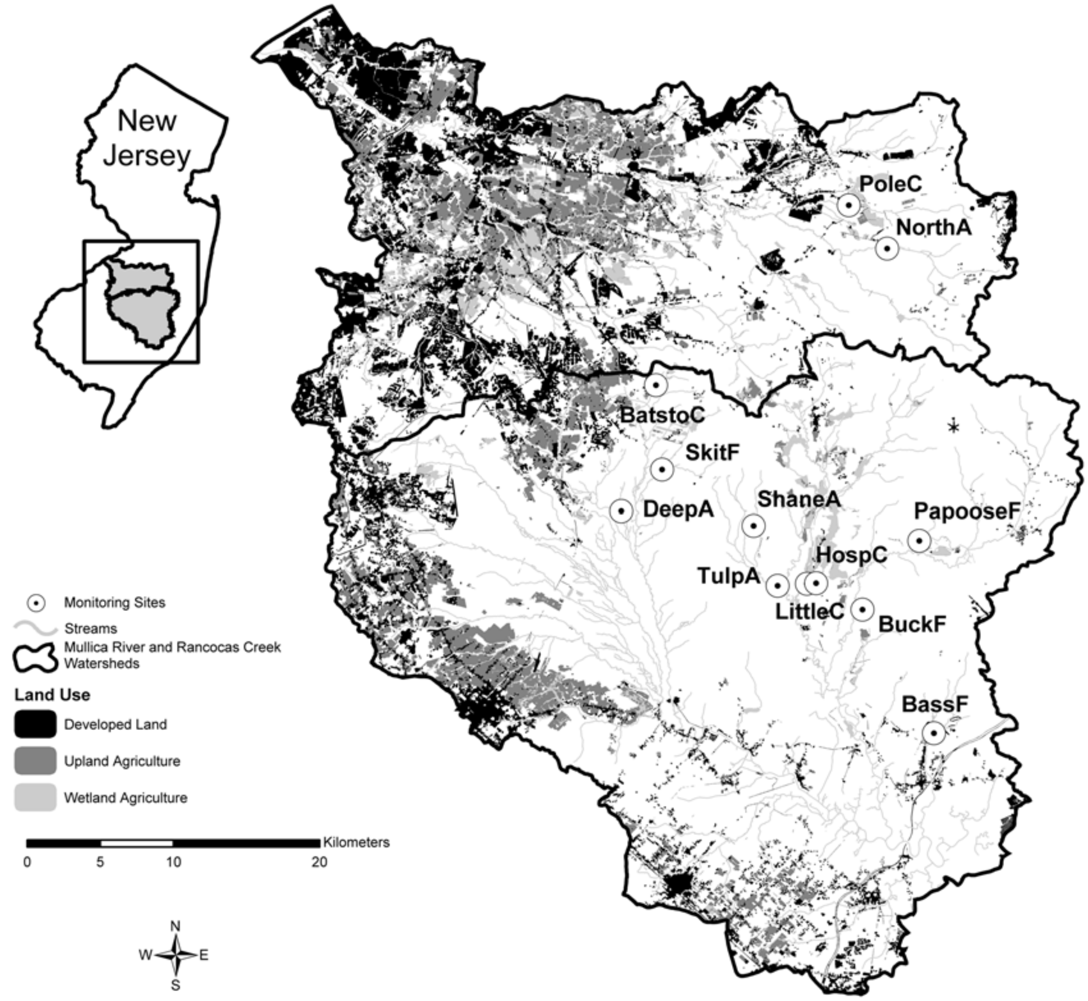

Figure 1. Location of 12 macroinvertebrate stream-monitoring sites in the Mullica River and Rancocas Creek watersheds. Site types include forest (F), abandoned-bog (A), and cranberry (C) streams. The first few letters of each site name are shown. The last capital letter in each site name refers to the stream type. Refer to Table 1 for complete site names.

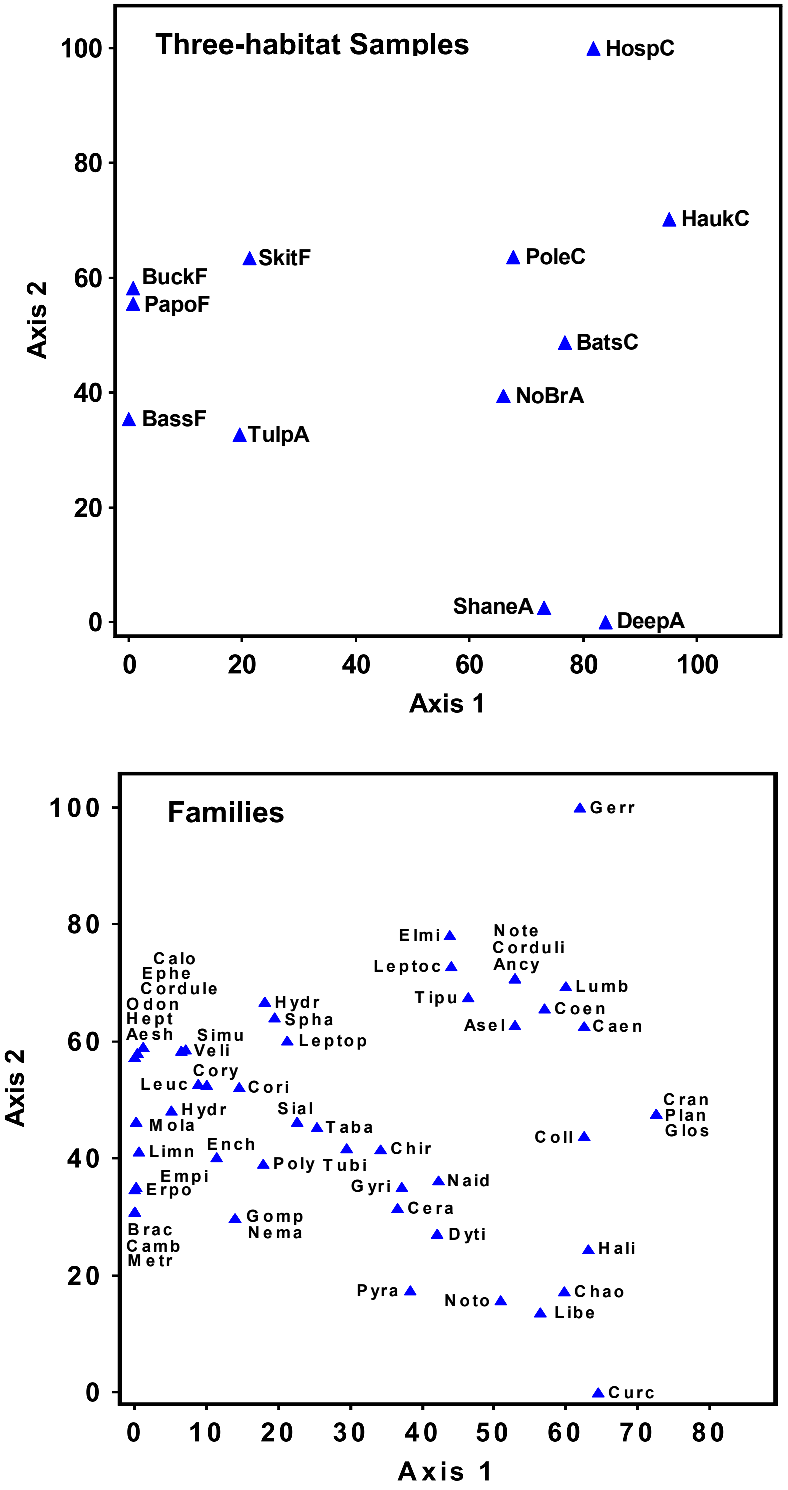

Figure 2. Family-level DCA ordination of three-habitat composite samples from forest (F), abandoned-bog (A), and cranberry (C) streams. The first few letters of each family and site name are shown. The last capital letter in each site name refers to the stream type. Refer to Tables 1 and 3 for complete site and family names.

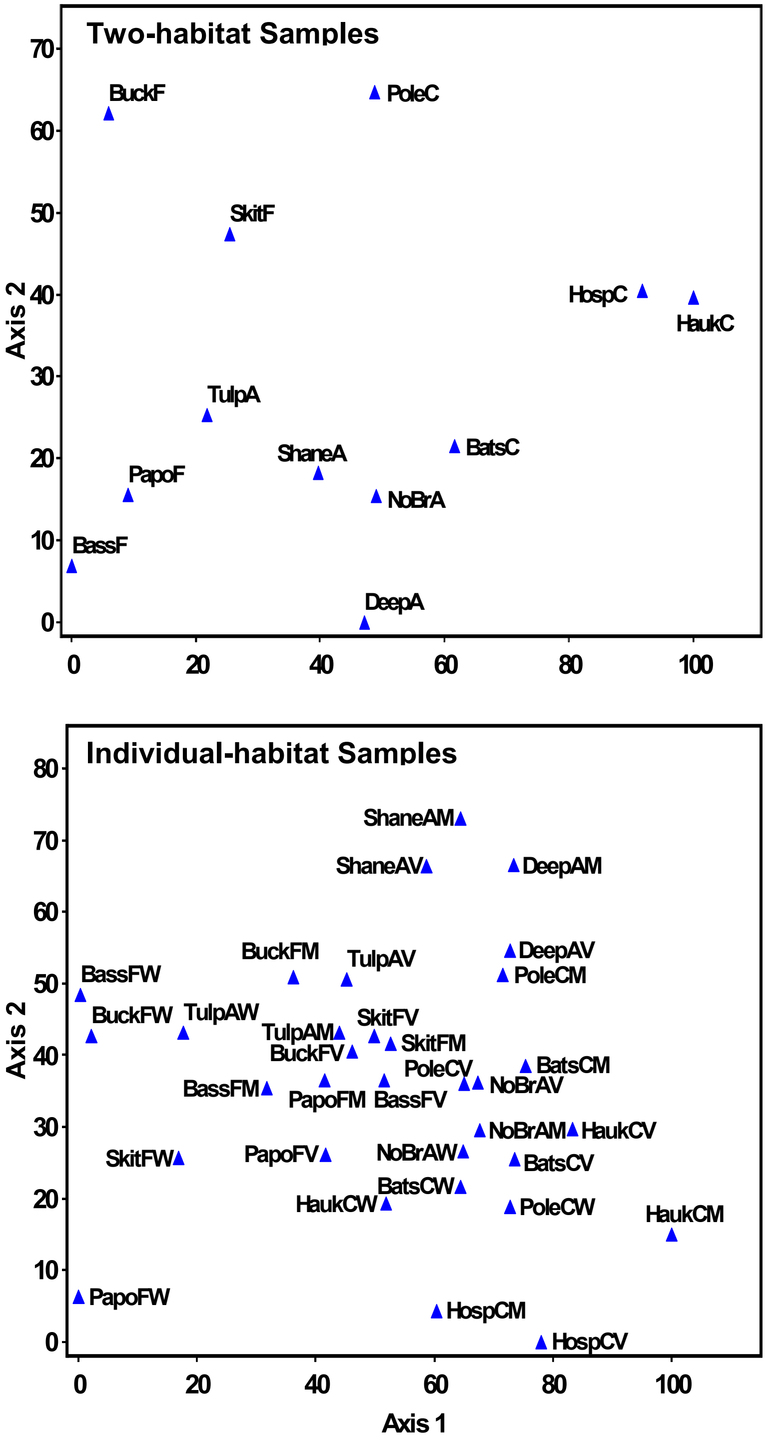

Figure 3. Family-level DCA ordinations of two-habitat composite samples comprised of muck and vegetated-muck samples and individual habitat samples, including muck (M), vegetated muck (V), and woody debris (W) from forest (F), abandoned-bog (A), and cranberry (C) streams. The first few letters of each site name are shown. Refer to Table 1 for complete site names.

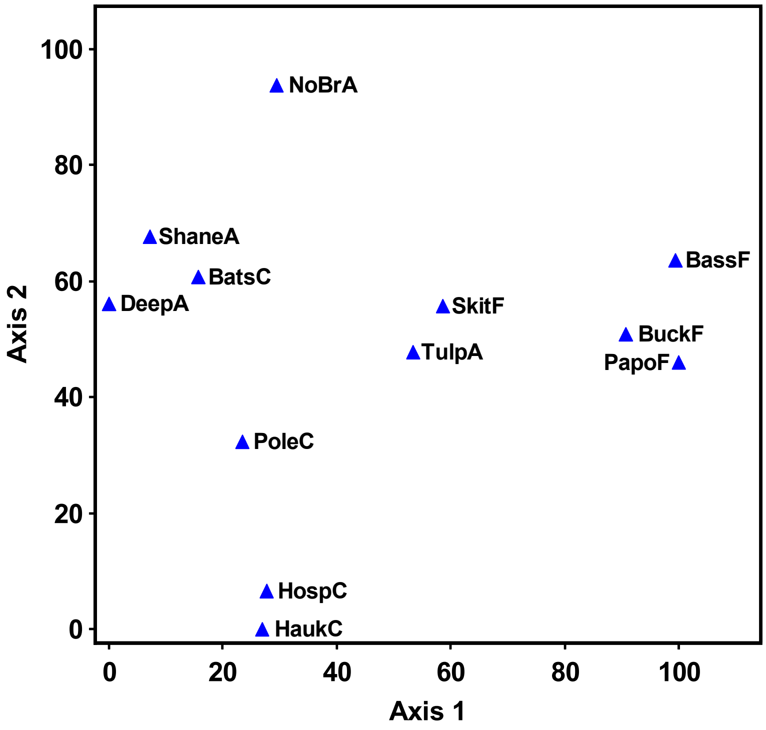

Figure 4. Genus-level DCA ordination of three-habitat composite samples from forest (F), abandoned-bog (A), and cranberry (C) streams. The first few letters of each family and site name are shown. The last capital letter in each site name refers to the stream type. Refer to Table 1 complete site names.

PART 6. FISH ASSEMBLAGES IN PINELANDS STREAMS DRAINING ACTIVE-CRANBERRY BOGS, ABANDONED-CRANBERRY BOGS, AND FOREST LAND

John F. Bunnell

Abstract

I evaluated whether there were differences in fish-assemblage composition, fish abundance, and fish biomass between Pinelands streams that drain active-cranberry bogs, abandoned-cranberry bogs, and forest land. All streams were shallow, relatively slow moving, and acidic, with low specific conductance and dissolved-oxygen values. Muck was the dominant sediment at most sites. Compared to forest streams, cranberry and abandoned-bog streams were generally characterized by less canopy cover, lower pH and dissolved-oxygen levels, and higher water temperature and specific conductance values. A total of twelve native Pinelands fish species were collected from the eleven streams. Although there was no difference in species richness between the three stream types, variations in species richness were related to several measures of stream size, including basin area, discharge, bankful-channel width, and bankful-channel depth. Fish-community gradients, generated from separate ordinations of presence-absence and relative-abundance data, did not distinguish stream types, but were related to species richness and the same four measures of stream size. The increase in species richness with stream size was primarily due to the addition of new species, rather than species replacement. The banded sunfish (*Enneacanthus obesus*) and eastern mudminnow (*Umbra pygmaea*) were the most frequently occurring species. Although there was no significant difference in the presence-absence or relative abundance of fish species between stream types, the swamp darter (*Etheostoma fusiforme*) was less abundant and the banded sunfish and eastern mudminnow were more abundant in cranberry and abandoned-bog streams compared to forest streams. Cranberry and abandoned-bog streams generally supported greater fish abundance and biomass (represented by the weight of six target species), which was primarily due to the higher abundance of banded sunfish and eastern mudminnows at streams in these two groups. Greater fish abundance and biomass for cranberry and abandoned-bog streams may be related to the lower pH and dissolved-oxygen levels at these sites, conditions that may favor the banded sunfish and eastern mudminnow. Reduced canopy cover, lower dissolved-oxygen levels, and higher water temperatures at cranberry and abandoned-bog streams are likely due to deforestation and the greater amount of open water in watersheds with past and present cranberry agriculture.

Introduction

Forested watersheds in the New Jersey Pinelands are characterized by acid-water conditions and native-fish assemblages, whereas basins that drain upland agriculture and developed land display elevated pH and support nonnative-fish species (Hastings 1979, 1984, Zampella and Bunnell 1998). As many as ten fish species usually distributed outside the Pinelands and three species introduced to the state have been collected from degraded waters in the region (Zampella et al. 2003). In contrast to upland-agricultural impacts, basins that drain both past and present wetland agriculture, including active-cranberry farms and abandoned-cranberry bogs, support a similar suite of native species as forested watersheds (Zampella et al.

2001, 2003). Due to the similarity in fish species present, streams that drain active-cranberry bogs, abandoned bogs, and forest land have all served as reference sites to assess the aquatic integrity of other sites in the region (Zampella and Bunnell 1998, Zampella et al. *in press*). Because regional-reference sites should represent minimally disturbed streams (Hughes et al. 1986) and wetland agriculture comprises a substantial portion of some Pinelands watersheds (Procopio and Bunnell 2006), a detailed evaluation is warranted to determine whether differences in fish-assemblage composition exist between these three stream types.

In this study, I compare fish assemblages from streams that drain active-cranberry bogs, abandoned-cranberry bogs, and forest land. All sites were located in central-Pinelands streams with minimal upland agriculture or developed land. I address two questions. First, are there differences in fish-assemblage composition based on the presence-absence or relative abundance of fish species between the three stream types? Secondly, does fish abundance and biomass differ between stream types?

Methods

Land Use and Study Site Selection

I selected three active-cranberry (cranberry) streams, four abandoned-cranberry bog (abandoned-bog) streams, and four forest streams (Figure 1, Table 1). All eleven streams were included in earlier fish studies and drainage basin boundaries were delineated and land-use profiles were completed as part of those studies (Zampella et al. 2001, 2003). The data set used to create the land-use profiles used a modified Anderson et al. (1976) system. In this paper, I refer to the Anderson-type land-use classes of urban land, agriculture, and agricultural wetlands as developed land, upland agriculture, and wetland agriculture, respectively. Collectively, I refer to developed land and upland agriculture as altered land. Wetland agriculture includes cranberry and blueberry farming. Most wetland agriculture in the study basins is cranberry agriculture.

The percentage of altered land (developed land and upland agriculture) was below ten percent in all study basins (Table 1). The four forest sites were located in streams with no apparent agricultural history. Abandoned-bog sites were located in streams that drained abandoned bogs and forest. The three cranberry sites were located immediately downstream from active-cranberry farms and were within abandoned bogs. All abandoned bogs succeeded to emergent, shrub, or forested wetlands types. In the cranberry basins, the percentage of wetland agriculture ranged from 8.4 to 34.3%.

Fish Surveys

Species-composition Surveys. To determine species composition, I sampled fish within 100-m stream reaches at the eleven study streams using a 4-mm mesh nylon seine. Surveys were completed from July through September 2001 and August through September 2002. Three stream reaches were less than 100-m (two reaches at Shane Branch were each 50 m and one reach at Little Hauken Run was 75 m). The number of sampling reaches per stream ranged from one to six. I identified, counted, and measured the total length of all fish collected. Some juvenile *Esox* and *Enneacanthus* could not be identified to species and were not included in the analysis. I determined fish presence-absence and relative abundance for each stream reach. Relative abundance was calculated as: [number of individuals of a species/total number of individuals] x 100. The data from individual stream reaches were used to calculate presence/absence, mean relative abundance, and the number of fish collected per 100 m of stream for each study stream.

Biomass Surveys. To develop species-specific relationships between total length and weight, I completed separate surveys to collect six target species at three streams (Batsto River, Hospitality Brook, and North Branch Mount Misery Brook) from July through September 2001 and August through September 2002. Four species, banded sunfish (*Enneacanthus obesus*), eastern mudminnow (*Umbra pygmaea*), swamp darter (*Etheostoma fusiforme*), and mud sunfish (*Acantharchus pomotis*), were among the most frequently occurring and abundant species collected during the species-composition surveys. The other two species, redfin pickerel (*Esox americanus*) and chain pickerel (*Esox niger*), are major piscivores. I weighed and measured the total length of all individuals collected for use in determining fish biomass.

Environmental Factors

From May through November 2001 and April through November 2002, pH, specific conductance, dissolved oxygen, and water temperature were measured monthly near each fish-sampling site. All water-quality measurements were completed under baseflow conditions. Temperature and dissolved oxygen were measured with a YSI 52 dissolved-oxygen meter, pH was measured using an Orion model-250A meter, and specific conductance was measured with an Orion model-122 meter. All available data were used to calculate median values for each sampling site.

From October 2000 through October 2003, stream discharge was measured on 63 to 64 dates at or near seven fish-sampling sites. Two additional sites were monitored for a shorter period (Batsto River - March 2002 to October 2003, n = 22, and Skit Branch - October 2000 to October 2001, n = 34). Discharge was not measured at Buck Run and Deep Run. To allow a comparison of all sites where discharge was measured, including the Batsto River and Skit Branch sites, available discharge values for each date were ranked and a median discharge rank was calculated for each site (Table 1).

Stream habitat was characterized along transects established at 25-m intervals within each fish-sampling reach. At each transect, bankfull-channel width and depth were measured, canopy cover was measured using a spherical densitometer, and stream-vegetation cover was estimated in 0.5 x 0.5-m quadrats located at the right and left side of the channel and the thalweg (deepest point in the channel). Stream-bed substrate texture was subjectively classified as sand or muck in each quadrat. For each transect, I determined bankful-channel width, mean bankful-channel depth, mean channel-vegetation cover, mean canopy cover, and the frequency of occurrence of muck and sand expressed as a percentage.

Data Analysis

Species Composition. I used detrended correspondence analysis (DCA, Hill 1979a, Hill and Gauch 1980) and TWINSPAN (Hill 1979b) to ordinate and classify fish assemblages and the eleven stream sites based on presence-absence and relative-abundance data. Relative-abundance data were log transformed prior to the DCA analysis. Default settings were used for the ordination and classification analyses. I used Spearman rank correlation to assess the relationship between the first two DCA axes of the presence-absence and relative-abundance ordinations and species richness and between these axes and the eleven environmental variables (basin area, discharge rank, pH, specific conductance, dissolved-oxygen concentration, temperature, channel-vegetation cover, canopy cover, muck frequency, channel depth, and channel width). I also used correlation to evaluate the relationship between the first and second DCA axes from both ordinations.

Nonparametric multi-response permutation procedures (MRPP, McCune and Mefford 1999) were used to compare the presence-absence and relative abundance of fish species between the three stream types. The MRPP analyses were based on Euclidean distance. I report the p and A values for each analysis. The p value describes the likelihood that an observed difference is due to chance. The A statistic (chance-corrected within-group agreement) describes agreement within groups (i.e., stream type). $A = 1$ when all attributes within a group are identical, $A = 0$ when within group heterogeneity equals that expected by chance, and $A < 0$ when within-group heterogeneity is greater than expected by chance.

Biomass and Abundance. I used simple linear regression to develop species-specific relationships between total length and weight for the six target species collected during the biomass surveys. Total length and weight values were log transformed prior to the regression analyses. I then used these relationships and data from the species-compositon surveys to predict the total weight of each target species, summed the predicted weights by stream, and expressed the sum as total weight per 100 m of stream (biomass). Total fish abundance for each stream was calculated as the total number of individuals of all species expressed per 100 meters of stream.

I used separate Mann-Whitney U Tests to evaluate differences in biomass (total weight of the six target species per 100 m of stream), fish abundance (total number of fish per 100 m of stream), and species richness between the three stream types. I used Spearman rank correlation to assess the relationship between fish biomass and abundance and between biomass, abundance, and species richness and the eleven environmental variables.

I used an alpha level of 0.05 to assess significance for all tests. Within groups of related correlations and Mann-Whitney tests, the alpha level was corrected for multiple comparisons using the sequential Bonferroni significance-level adjustment (Rice 1989, 1991). Ordinations, TWINSPAN classifications, and MRPP analyses were performed using PC-ORD for Windows 4.27 (MjM Software, Gleneden Beach, OR). Mann-Whitney tests, correlations, and regression analyses were performed using Statistica 7.1 (StatSoft, Inc., Tulsa, OK).

Results

Environmental Factors

All eleven streams were acidic, with low specific conductance values and dissolved oxygen (Table 1). Except for Tulpehocken Creek, where the streambed was primarily sand, the dominant stream-bed substrate at all sites was muck. Streams were generally shallow with mean depth ranging from 18.0 to 70.0 cm. Basin area ranged from 4.0 to 56.6 km^2. Although the number of discharge measurements varied by stream and streamflow was not measured at two sites, median discharge for the period of record was below 17.0 cfs.

Canopy cover at the study streams was dominated by Atlantic white cedar (*Chamaecyparis thyoides*), red maple (*Acer rubrum*) and other hardwoods, and mixed cedar/hardwood forests (Laidig 2006). Canopy cover ranged from 90% at Papoose Branch, one of the forest streams, to no canopy cover at Deep Run, an abandoned-bog stream (Table 1). Cranberry and abandoned-bog streams were generally characterized as having reduced canopy cover, lower pH and dissolved-oxygen concentrations, and higher water temperatures. Median specific conductance was lowest at forest sites and highest at cranberry sites.

The Spearman rank correlation matrix revealed strong relationships between some environmental variables (Table 2). Generally, lower pH streams displayed lower dissolved oxygen and higher specific conductance values, sites with less canopy cover exhibited higher water temperatures, deeper streams were associated with higher discharge ranks, and streams with wider channels were in larger basins and displayed lower specific conductance values and higher dissolved-oxygen concentrations. Due to the large number of comparisons, conclusions regarding the statistical significance of these associations cannot be made.

Fish Inventory

A total of 2,998 individuals, representing twelve species of native Pinelands fish, were collected from the eleven streams during the species-composition surveys (Table 3). Species richness ranged from 2.0 to 10.0 with an overall mean (±1 SD) and median of 6.4 (± 2.5) and 6.0, respectively. Mann-Whitney test results indicated there was no significant difference in species richness between the three stream types. There was a significant positive correlation between species richness and basin area ($r = 0.77$, $p = 0.0054$), channel width ($r = 0.71$, $p = 0.0136$), channel depth ($r = 0.67$, $p = 0.0251$), discharge rank ($r = 0.74$, $p = 0.0228$), and dissolved-oxygen concentration ($r = 0.66$, $p = 0.0279$). However, due to the large number of comparisions, these relationships were not significant after Bonferroni correction. Species richness was not related to any of the other environmental variables.

The most-frequently occurring species were the eastern mudminnow and banded sunfish (Table 3). All twelve species were present in the cranberry streams and eleven species were found in both the abandoned-bog and forest streams. The bluespotted sunfish (*Enneacanthus gloriosus*) was absent from abandoned-bog streams and the creek chubsucker (*Erimyzon oblongus*) was absent from forest streams.

The most abundant species were the banded sunfish, eastern mudminnow, and swamp darter. Mean (±1 SD) abundance was highest for banded sunfish (56.4 ± 79.1), intermediate for the eastern mudminnow (30.1 ± 34.4), and lowest for the swamp darter (10.7 ±12.4). Mean abundance of each of the remaining nine species was < 6.7 individuals per site. Banded sunfish were most abundant in cranberry streams and least abundant in forest streams (Table 4). Eastern mudminnows were most abundant in abandoned-bog streams and least abundant in forest streams. Cranberry and forest streams supported similar numbers of swamp darters, but abundance for this species was lowest at abandoned-bog streams.

Relative abundance of species also varied between stream types (Figure 2). The mean relative abundance of the swamp darter was higher at forest streams (28%) compared to cranberry (8%) or abandoned-bog (7%) streams. Although less abundant overall, the American eel (*Anguilla rostrata*), pirate perch (*Aphredoderus sayanus*), yellow bullhead (*Ameiurus natalis*), and chain pickerel were also more abundant at forest sites compared to the other two stream types. The redfin pickerel showed the opposite trend. The mud sunfish was more abundant at abandoned-bog and forest streams compared to cranberry streams. The mean relative abundance of banded sunfish was considerably higher at cranberry (56%) and abandoned-bog (45%) streams compared to forest streams (10%). Eastern mudminnows and banded sunfish together represented about 70% of the fish collected from cranberry and abandoned-bog streams compared to about 40% for forest streams. In general, relative abundance was spread across more of the species present at forest sites compared to the other two stream types.

Species Composition

The DCA ordination based on presence-absence data contrasted Batsto River, Shane Branch, Deep Run, and Papoose Branch, shown on the left side of the site diagram, with Hospitality Brook, Tulpehocken Creek, and Bass River, shown on the right side of the site diagram (Figure 3). Both groups included representatives of each stream type. Like the ordination, the TWINSPAN classification did not distinquish between stream types. The first division of the TWINSPAN classification separated Buck Run along with the Batsto River, Shane Branch, Deep Run, and Papoose Branch sites from all other sites.

The Batsto River, Shane Branch, Deep Run, and Papoose Branch sites were characterized by low species richness and the absence of the blackbanded sunfish (*Enneacanthus chaetodon*), creek chubsucker, American eel, bluespotted sunfish, and yellow bullhead (Figure 3). Three of these four sites were shallow, narrow cranberry or abandoned-bog streams. In contrast, Hospitality Brook, Tulpehocken Creek, and Bass River displayed the highest species-richness values. These three sites were deep and wide with some of the highest discharge ranks.

The results of the MRPP based on presence-absence data indicated there was no significant difference between stream types (A = -0.049, $p = 0.8665$). Spearman rank correlation results revealed a significant positive relationship between the presence-absence community gradient, represented by the first DCA axis, and basin area, discharge rank, and channel depth (Table 5). Because of the large number of comparisons, only the relationship with channel depth remained significant after Bonferroni adjustment. There was also a significant positive relationship between the presence-absence community gradient and species richness (r = 0.86, *p* = 0.0006). The increase in species richness was primarily due to the addition of new species along the community gradient. The second axis of the presence-absence community gradient was not related to any of the environmental variables or species richness.

Results from the ordination based on relative-abundance data were similar to those obtained using presence-absence data (Figure 4). There was a significant correlation between the first DCA axes from both site ordinations (r = 0.87, *p* = 0.0005), but the second axes were not related. Likewise, the first DCA axes from both species ordinations were correlated (r = 0.89, p = 0.0001), but there was no relationship between the second axes.

The first division of the TWINSPAN classification based on relative-abundance data separated Bass River, Skit Branch, Hospitality Brook, and Tulpehocken Creek, shown on the right side of the first axis, from the other seven sites. The relative abundance of the creek chubsucker, American eel, bluespotted sunfish, blackbanded sunfish, and yellow bullhead was generally greater at these four sites, whereas the redfin pickerel was absent.

The results of the MRPP based on relative-abundance data indicated there was no significant difference between stream types (A = 0.021, *p* = 0.2758). Spearman rank correlation results revealed a significant positive relationship between the relative-abundance community gradient, represented by the first axis of the relative-abundance ordination, and dissolved oxygen, channel width, channel depth, and discharge rank (Table 5). Because of the large number of tests, none of these relationships was significant after Bonferroni adjustment. There was a significant positive correlation between the second axis of the relative-abundance ordination and channel width, and a significant negative correlation between the second axis and temperature and specific conductance (Table 5). Only the relationship with channel width remained significant after Bonferroni correction. As with the presence-absence ordination, there was a significant positive correlation between the relative-abundance community gradient and species richness (r = 0.82, *p* = 0.0021), and species were added along this community gradient rather than replaced.

Biomass and Abundance

Overall mean (±1 SD) and median fish abundance (number of fish collected per 100 m of stream) was 123.4 (±116.9) and 87.0, respectively. Fish abundance ranged from 24 individuals at East Branch Bass River, a forest stream, to 437 individuals at Hospitality Brook, a cranberry stream. Initial Mann-Whitney test results showed a significant difference in fish abundance only between abandoned-bog and forest streams (*p* = 0.0286), but this difference was not significant after Bonferroni correction. Although not significant, mean (±1 SD) fish abundance was highest for cranberry streams (226.0 ± 183.7), intermediate for abandoned-bog streams (123.4 ± 65.8), and lowest for forest streams (46.5 ± 18.0)(Figure 5).

Based on the regression analysis, there was a significant relationship between fish total length and weight for the six target species, with R-square values that ranged from 0.70 for swamp darter to 0.99 for mud sunfish (Figure 6). Biomass (total predicted weight of the six target species per 100 m of stream) ranged from 50.5g at Skit Branch, a forest stream, to 631.6g at Hospitality Brook, a cranberry stream. Mean (±1 SD) biomass was considerably higher for cranberry (396.0 ± 218.2) and abandoned-bog (343.3 ± 184.5) streams compared to forest streams (109.6 ± 45.0) (Figure 5). However, Bonferroni corrected Mann-Whitney tests results indicated no significant difference in biomass between stream types.

The relative contribution of the six target species to the total weight varied by stream type (Figure 7). Swamp darters represented a greater percentage of the total weight at forest streams compared to the other two stream types. Redfin pickerel showed the opposite trend. Chain pickerel represented a greater proportion of the total weight at abandoned-bog and forest sites compared to cranberry streams. Banded sunfish represented 60% of the total weight at cranberry streams compared to 28% at abandoned-bog streams and 22% at forest streams. The eastern mudminnow accounted for slightly more of the total weight at abandoned-bog streams compared to the other two stream types. Together, banded sunfish and eastern mudminnows comprised 71% of the total weight at cranberry streams, 46% of the total weight at abandoned-bog streams, and 34% of the total weight at forest streams.

There was a significant positive relationship between fish abundance and biomass ($r = 0.80$, $p = 0.0034$). Relationships between fish abundance and biomass and the environmental variables were not significant after Bonferroni correction due to the large number of comparisons. However, initial p values indicated a positive correlation between both fish abundance and biomass and specific conductance, and a negative relationship between fish abundance and dissolved oxygen and canopy cover (Table 6).

Discussion

The strong relationship between the first-axis site and species scores of both ordinations indicated that the primary fish-community gradient based on presence-absence data paralleled that using relative-abundance data. The ordinations and associated MRPP analyses did not reveal differences in the presence-absence or relative-abundance of fish species between cranberry, abandoned-bog, and forest streams.

The low species richness found for all study streams is typical of the depauperate fish fauna that characterizes Pinelands streams (Hastings 1979, Zampella and Bunnell 1998) and small, acid-water streams elsewhere (Mendonca et al. 2005). Although species richness did not differ between stream types, variations in species richness were related to several measures of stream size (basin area, channel width, channel depth, and discharge). Similarly, the presence-absence and relative-abundance fish-community gradients were related to species richness and the same measures of stream size. The increase in species richness with stream size was primarily due to the addition of new species, rather than species replacement.

Increasing species richness with stream size is a pattern consistent with basic theory of stream ecology (Matthews 1998). In many river systems of the central United States, species richness increases with both watershed area and stream order (Fausch et al. 1984), and can rise rapidly from upstream to downstream sections, mainly due to the addition of new species (Horowitz 1978). Although a similar trend has been observed in New England streams (Sheldon 1968), increasing species richness with stream order in South Carolina coastal plain streams is primarily due to species replacement, rather than addition (Paller 1994, 1995). In contrast to trends in the United States, in France, sharp increases in species richness can occur further downstream between fifth and sixth order streams (Grenouillet et al. 2004). Exceptionally high species turnover can occur when species loss equals addition, leading to fairly constant richness along stream systems (Mendonca et al. 2005). The lack of a relationship between species richness and basin area or stream discharge in a previous Pinelands fish study was attributed to the relative stability of the permanently flowing streams sampled (Zampella and Bunnell 1998).

Although not significant after Bonferroni correction, fish abundance and biomass were generally higher at cranberry and abandoned-bog streams compared to forest streams. The correlation of increasing fish abundance with higher specific conductance values and lower canopy cover is consistent with this observation because cranberry and abandoned streams generally displayed higher specific conductance and lower canopy-cover values. Higher fish abundance and biomass for cranberry and abandoned-bog streams was primarily due to the greater abundance of banded sunfish and eastern mudninnows at these stream types. A similar pattern was observed by Zampella et al. (2001), who found that the same two species were associated with acidic, narrow, ditched streams located in abandoned-cranberry bogs in the Mullica River basin.

While no single environmental variable can account for the greater abundance of banded sunfish and eastern mudninnows at cranberry and abandoned-bog streams, pH, dissolved oxygen, and temperature most likely play a role. Six of the seven sites with the lowest pH and dissolved-oxygen levels and highest temperature values were cranberry and abandoned-bog sites. Of all the Pinelands fish species, the eastern mudminnow is perhaps the most tolerant of low dissolved oxygen due to its ability to breathe atmospheric oxygen through the connection of its esophagus and swim bladder (Werner 2004). The banded sunfish, which has been reported from waters with pH as low as 3.7 (Graham and Hastings 1984), is one of the most acid-tolerant fish species known (Gonzalez and Dunson 1987, 1989, 1991). These physiological adaptations may allow both species to tolerate harsh environmental conditions such as those found at most of the cranberry and abandoned-bog sites. Both species may also be more tolerant of higher stream temperatures than some of the other species collected. Dominance of tolerant species often characterizes stream sites impacted by altered hydrologic regime, riparian-destruction, and channelization related to urbanization or agriculture (Scott and Hall 1997, Waite and Carpenter 2000, Kennen and Ayres 2002).

Another factor that may contribute to the higher abundance of banded sunfish at cranberry and abandoned-bog streams is the landscape modification associated with past and present cranberry agriculture. Cranberry farming involves clearing land to construct bogs, impounding streams to establish reservoirs, and channelizing stream segments and creating extensive ditch networks to control the flow of water (Eck 1990). Although banded sunfish are common in both streams and impoundments throughout the Pinelands, this species is much more abundant in impoundments (Zampella et al. 2001, 2003, 2005), such as the reservoirs and flooded abandoned bogs associated with past and present cranberry agriculture.

Removal of riparian vegetation that shades coastal plain streams can result in high water temperatures and severe dissolved-oxygen depletion (Maxted et al. 1995). Compared to forest streams, cranberry and abandoned-bog streams generally displayed higher water temperature and specific conductance values and lower pH, dissolved-oxygen, and canopy-cover values. Higher stream temperatures and reduced dissolved-oxygen and canopy-cover values for cranberry and abandoned-bog streams are likely due to deforestation and the greater amount of open water associated with active and historic cranberry agriculture (Procopio and Bunnell 2006). The similarity in some of the habitat, water-quality, and fish-assemblage attributes between cranberry and abandoned-bog streams suggests that these stream types are more similar to each other than to forest streams.

Acknowledgements

Robert Zampella, Kim Laidig, Nick Procopio, Christina Burns, and Jason Shvanda assisted with various aspects of this study. The New Jersey Division of Parks and Forestry authorized the state-lands research permits. The Division of Fish and Wildlife provided the necessary fish-collection permits. Funding for this study was provided by the U. S. Environmental Protection Agency (State Wetlands Grant Program, Grant No. CD-99298001-1), the Pinelands Commission, and the National Park Service.

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Table 1. Environmental attributes for cranberry, abandoned-bog, and forest streams in the New Jersey Pinelands. Altered land includes developed land and upland agriculture. Land-use values are expressed as a percentage of a basin area.

Site Type and Stream Name	pH	Specific conductance (uS cm^{-1})	Dissolved oxygen (mg L^{-1})	Dissolved oxygen (%)	Temperature (^{o}C)	Discharge rank	Bankful-channel depth (m)	Bankful-channel width (m)	Basin area (km^{2})	Altered land (%)	Wetland agriculture (%)	Upland forest (%)	Water (%)	Wetland (%)	Barren land (%)	Canopy cover (%)	Channel-vegetation vover (%)	Channel sand (%)	Channel muck (%)
Cranberry Streams																			
Batsto River	4.5	45.1	2.6	29.6	22.0	1	0.38	3.5	4.0	0.5	8.4	47.6	1.7	41.6	0.2	68.7	25.0	11.1	88.9
Hospitality Brook	4.7	46.2	6.5	63.5	22.9	6	0.70	4.6	4.9	8.4	34.3	24.7	6.9	23.0	2.7	9.6	50.5	23.3	76.7
Little Hauken Run	4.6	49.1	4.4	40.6	21.3	8	0.65	4.5	15.6	2.3	25.1	32.9	7.5	31.8	0.3	41.5	7.0	35.6	64.4
Mean	**4.6**	**46.8**	**4.5**	**44.6**	**22.1**	**5**	**0.58**	**4.2**	**8.2**	**3.7**	**22.6**	**35.1**	**5.4**	**32.1**	**1.1**	**39.9**	**27.5**	**23.3**	**76.7**
SD	**0.1**	**2.1**	**2.0**	**17.3**	**0.8**	**4**	**0.17**	**0.6**	**6.4**	**4.1**	**13.1**	**11.6**	**3.2**	**9.3**	**1.4**	**29.6**	**21.8**	**12.2**	**12.2**
Median	**4.6**	**46.2**	**4.4**	**40.6**	**22.0**	**6**	**0.65**	**4.5**	**4.9**	**2.3**	**25.1**	**32.9**	**6.9**	**31.8**	**0.3**	**41.5**	**25.0**	**23.3**	**76.7**
Abandoned-bog Streams																			
Deep Run	4.0	89.6	2.9	36.8	27.0	-	0.41	2.5	4.6	0.2	0.0	15.9	4.2	79.7	0.0	0.0	16.8	0.0	100.0
N. Br. Mt. Misery Brook	4.6	31.3	4.8	44.5	16.0	3	0.35	4.8	29.4	3.3	0.1	86.1	1.4	9.2	0.0	38.9	34.6	16.7	83.3
Shane Branch	4.2	39.4	4.7	57.6	27.2	1	0.18	2.6	4.6	0.4	0.0	50.8	0.0	48.8	0.0	34.9	15.6	45.0	55.0
Tulpehocken Creek	4.9	23.9	7.6	71.7	21.4	7	0.49	5.3	56.6	0.2	0.1	61.3	1.0	37.4	0.0	17.4	15.2	80.0	20.0
Mean	**4.4**	**46.0**	**5.0**	**52.6**	**22.9**	**4**	**0.36**	**3.8**	**23.8**	**1.0**	**0.0**	**53.5**	**1.7**	**43.8**	**0.0**	**22.8**	**20.6**	**35.4**	**64.6**
SD	**0.4**	**29.7**	**1.9**	**15.3**	**5.3**	**3**	**0.13**	**1.4**	**24.8**	**1.5**	**0.0**	**29.1**	**1.8**	**29.2**	**0.0**	**17.8**	**9.4**	**35.0**	**35.0**
Median	**4.4**	**35.4**	**4.7**	**51.1**	**24.2**	**3**	**0.38**	**3.7**	**17.0**	**0.3**	**0.0**	**56.0**	**1.2**	**43.1**	**0.0**	**26.2**	**16.2**	**30.8**	**69.2**
Forest Streams																			
E. Br. Bass River	4.4	37.4	6.8	67.7	18.9	9	0.59	4.9	21.1	2.0	0.0	82.7	1.0	14.0	0.2	53.5	8.7	46.7	53.3
Buck Run	4.8	26.5	6.0	63.5	18.9	-	0.43	4.0	7.8	0.0	0.0	86.5	0.2	13.3	0.0	73.5	26.8	26.7	73.3
Papoose Branch	4.7	29.9	7.1	68.6	17.6	5	0.44	4.8	11.4	0.0	0.0	87.5	0.0	12.4	0.1	91.7	7.5	40.0	60.0
Skit Branch	4.7	24.2	5.9	69.4	23.3	4	0.48	6.0	13.0	0.3	0.0	80.3	0.0	19.4	0.0	35.7	29.1	6.7	93.3
Mean	**4.6**	**29.5**	**6.5**	**67.3**	**19.7**	**6**	**0.48**	**4.9**	**13.3**	**0.6**	**0.0**	**84.3**	**0.3**	**14.8**	**0.1**	**63.6**	**18.0**	**30.0**	**70.0**
SD	**0.2**	**5.8**	**0.6**	**2.6**	**2.5**	**3**	**0.07**	**0.8**	**5.6**	**1.0**	**0.0**	**3.3**	**0.5**	**3.1**	**0.1**	**24.3**	**11.5**	**17.6**	**17.6**
Median	**4.7**	**28.2**	**6.4**	**68.2**	**18.9**	**5**	**0.46**	**4.8**	**12.2**	**0.2**	**0.0**	**84.6**	**0.1**	**13.7**	**0.0**	**63.5**	**17.7**	**33.3**	**66.7**

Table 2. Spearman rank correlation matrix of environmental variables. Correlations significant at 0.05 are in bold face type.

Environmental Attribute	pH	Specific cond.	Diss. oxygen concentration	Temperature	Discharge rank	Basin area	Channel depth	Channel width	Canopy cover	Channel veg.
pH	-									
Specific conductance	**-0.77**	-								
Dissolved oxygen concentration	**0.68**	**-0.66**	-							
Temperature	-0.43	0.34	-0.41	-						
Discharge rank	0.22	0.03	0.52	-0.36	-					
Basin area	0.46	-0.52	0.58	-0.59	0.59	-				
Channel depth	0.33	0.03	0.48	-0.11	**0.84**	0.40	-			
Channel width	0.60	**-0.71**	**0.71**	-0.39	0.45	**0.78**	0.48	-		
Canopy cover	0.27	-0.29	0.11	**-0.67**	-0.03	0.04	-0.09	0.10	-	
Channel cegetation	0.12	-0.07	-0.14	0.17	-0.49	-0.21	-0.19	0.00	-0.32	-
Channel muck	-0.25	0.35	**-0.65**	0.28	-0.51	-0.43	-0.26	-0.30	-0.20	0.60

Table 3. Frequency of occurrence values for 12 fish species from cranberry, abandoned-bog, and forest streams. Nomenclature follows Page and Burr 1991.

		Frequency of Occurrence (%)			
Common Name	Scientific Name	Cranberry Streams	Abandoned-bog Streams	Forest Streams	All Streams
Eastern mudminnow	*Umbra pygmaea*	100	100	100	100.0
Banded sunfish	*Enneacanthus obesus*	100	100	75	90.9
Chain pickerel	*Esox niger*	67	75	100	81.8
Swamp darter	*Etheostoma fusiforme*	100	50	100	81.8
Mud sunfish	*Acantharchus pomotis*	67	75	50	63.6
Blackbanded sunfish	*Enneacanthus chaetodon*	67	50	75	63.6
Yellow bullhead	*Ameiurus natalis*	67	50	50	54.5
Redfin pickerel	*Esox americanus*	67	50	25	45.5
Pirate perch	*Aphredoderus sayanus*	67	50	25	45.5
Bluespotted sunfish	*Enneacanthus gloriosus*	67	-	25	27.3
American eel	*Anguilla rostrata*	33	25	25	27.3
Creek chubsucker	*Erimyzon oblongus*	33	25	-	18.2

Table 4. Mean abundance values for the three most abundant species collected from cranberry, abandoned-bog, and forest streams.

	Banded sunfish		Eastern mudminnow		Swamp darter	
Stream Type	Mean	SD	Mean	SD	Mean	SD
Cranberry streams	130.4	120.8	26.7	16.4	13.2	6.7
Abandoned-bog streams	53.0	44.3	47.8	52.6	3.9	5.0
Forest streams	4.3	3.3	15.0	16.2	15.8	18.9

Table 5. Spearman rank correlation results between environmental variables and the first and second DCA axes from ordinations based on the presence-absence and relative-abundance of fish species. Correlations significant at an alpha of 0.05 are in bold face type and those significant following the Bonferroni correction are noted with an asterisk.

		Presence-absence Ordination				Relative-abundance Ordination			
		DCA Axis 1		DCA Axis 2		DCA Axis 1		DCA Axis 2	
Environmental Attribute	N	r	*p*	r	*p*	r	*p*	r	*p*
pH	11	0.39	0.2345	0.29	0.3855	0.43	0.1899	0.60	0.0510
Specific conductance	11	-0.16	0.6307	0.03	0.9366	-0.37	0.2589	**-0.75**	**0.0073**
Dissolved oxygen conc.	11	0.57	0.0655	0.38	0.2466	**0.65**	**0.0320**	0.60	0.0510
Temperature	11	-0.11	0.7388	-0.53	0.0947	-0.27	0.4160	**-0.64**	**0.0347**
Basin area	11	**0.61**	**0.0467**	0.40	0.2229	0.60	0.0510	0.55	0.0767
Discharge rank	9	**0.79**	**0.0104**	0.44	0.2318	**0.68**	**0.0448**	0.06	0.8810
Channel width	11	0.57	0.0648	0.36	0.2769	**0.74**	**0.0095**	**0.81**	**0.0025***
Channel depth	11	**0.85**	**0.0008***	0.45	0.1697	**0.73**	**0.0112**	0.10	0.7699
Canopy cover	11	-0.34	0.3118	0.25	0.4669	-0.08	0.8110	0.52	0.1025
Channel vegetation	11	0.07	0.8317	-0.32	0.3403	0.24	0.4841	0.04	0.9155
Channel muck	11	-0.31	0.3550	-0.42	0.2006	-0.19	0.5739	-0.15	0.6696

Table 6. Spearman rank correlation results between environmental variables and two measures of biomass (fish abundance and weight of six target species per 100 m stream). Correlations significant at an alpha of 0.05 are in bold face type. None of the relationships were significant following the Bonferroni correction.

		Number of Fish		Weight of Six Target Species	
Environmental Attribute	N	r	*p*	r	*p*
pH	11	-0.38	0.2515	-0.41	0.2115
Specific conductance	11	0.72	**0.0133**	0.66	**0.0260**
Dissolved oxygen concentration	11	-0.59	0.0573	-0.35	0.2981
Temperature	11	0.42	0.1956	0.12	0.7287
Basin area	11	-0.32	0.3319	-0.10	0.7699
Discharge rank	9	-0.23	0.5588	-0.09	0.8138
Channel width	11	-0.45	0.1651	-0.38	0.2515
Channel depth	11	0.01	0.9682	0.00	1.0000
Canopy cover	11	-0.62	**0.0401**	-0.48	0.1334
Channel vegetation	11	0.38	0.2454	0.19	0.5739
Channel muck	11	0.56	0.0702	0.07	0.8317

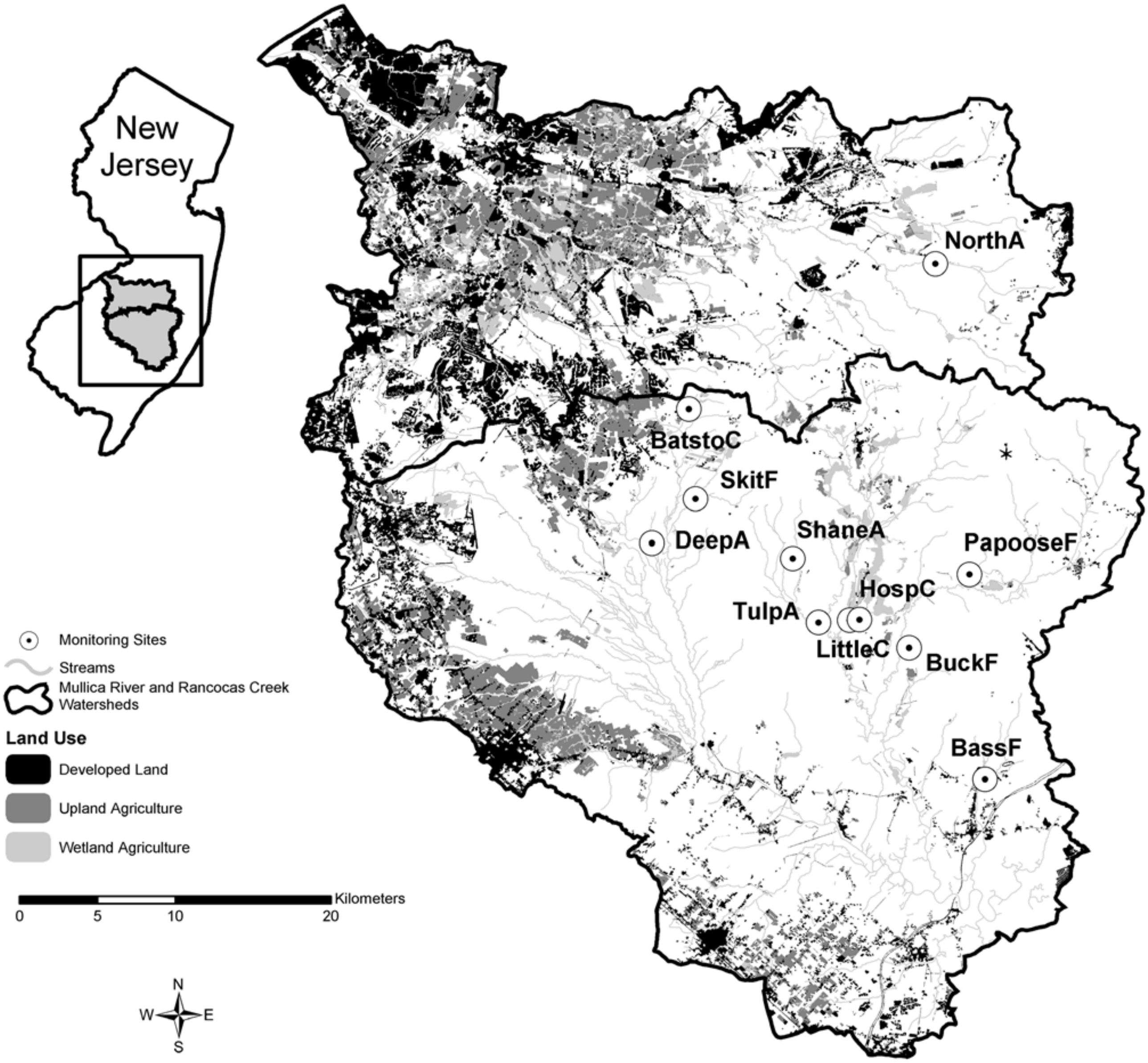


Figure 1. Location of eleven fish-sampling sites in the Rancocas Creek (top) and Mullica River (bottom) watersheds. The last capital letter in each site name refers to the stream type. Site types include cranberry (C), abandoned-bog (A) and forest (F) streams. Refer to Table 1 for complete site names.

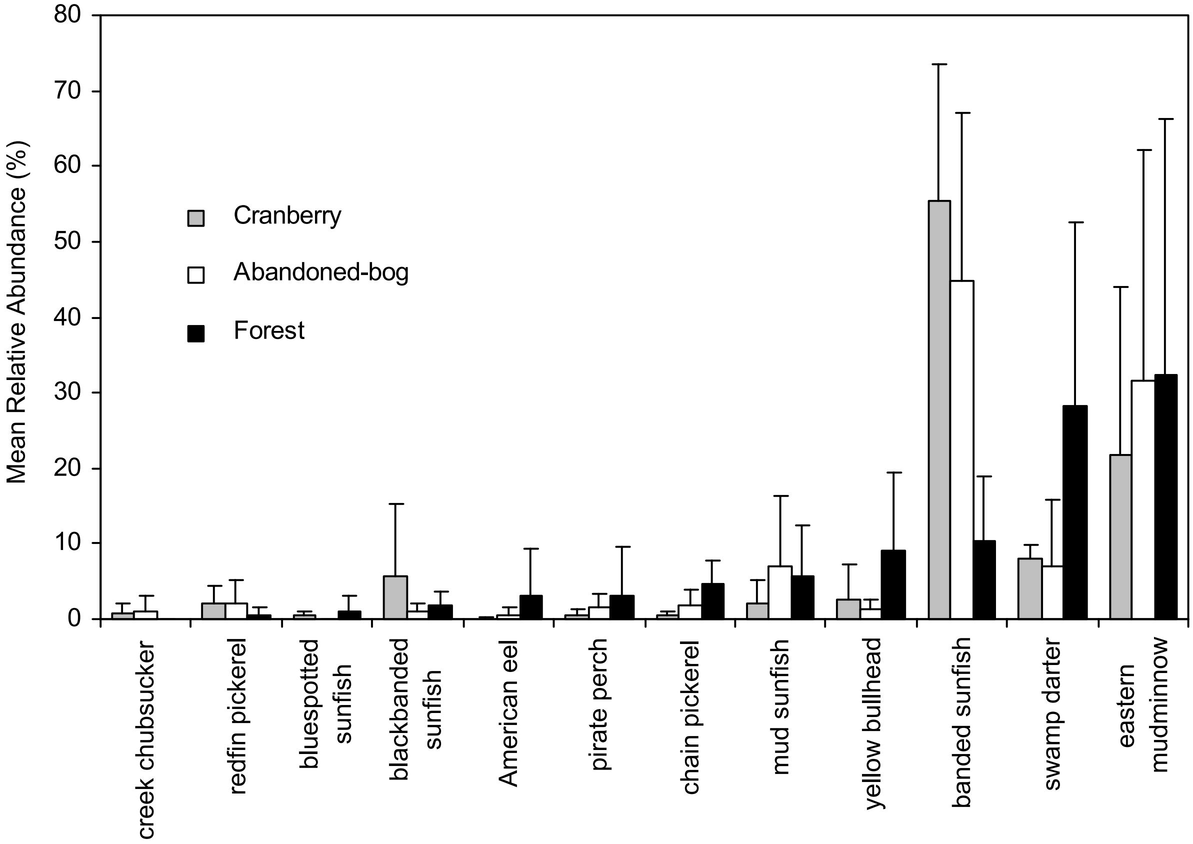


Figure 2. Mean (±1 SD) relative abundance of twelve fish species from cranberry, abandoned-bog, and forest streams.

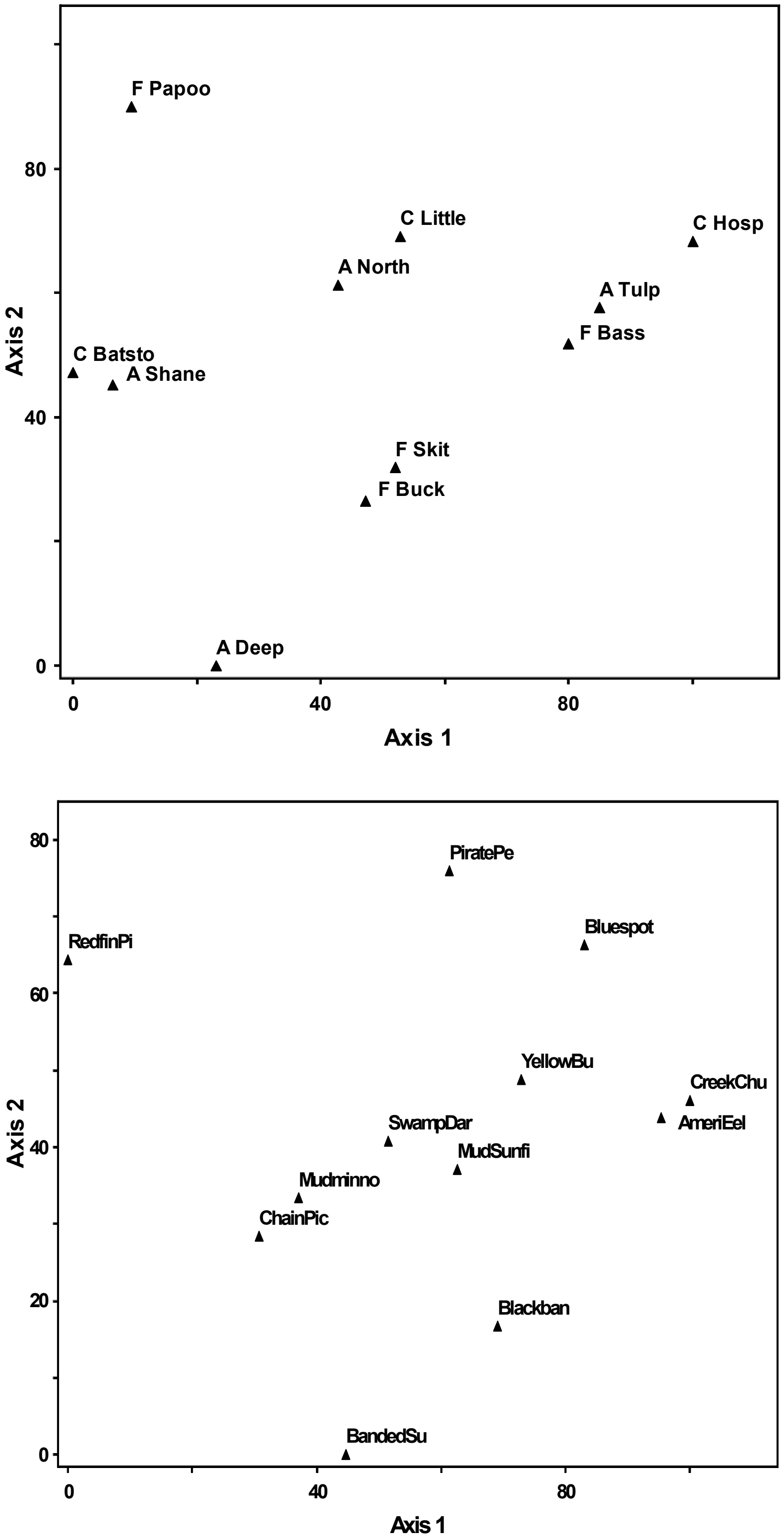
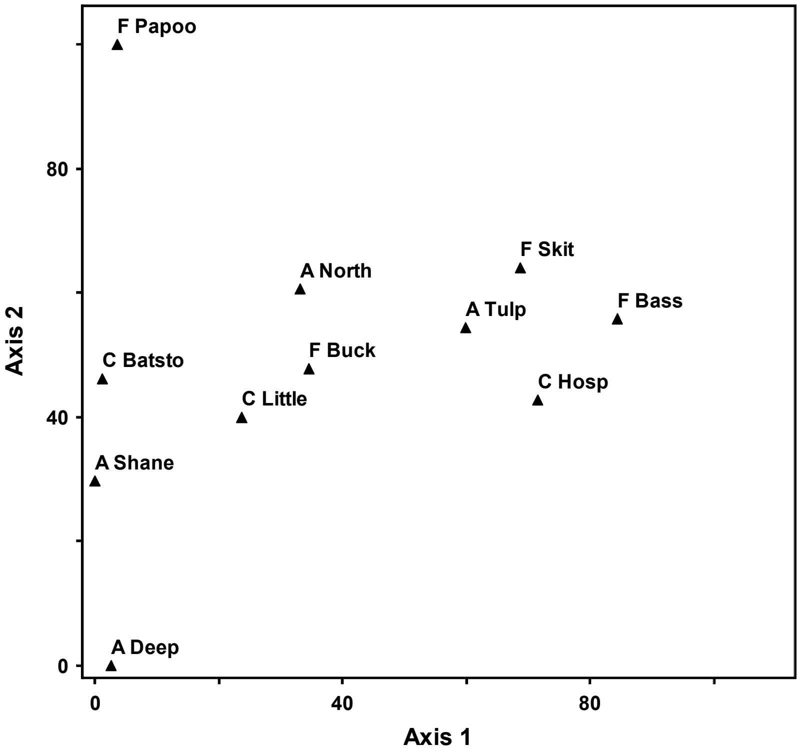


Figure 3. Site (top) and species (bottom) diagrams from the presence-absence ordination of twelve fish species from cranberry (C), abandoned-bog (A), and forest (F) sites. The first few letters of sites and species are shown. Refer to Table 1 and Table 3 for complete names of sites and species, respectively.



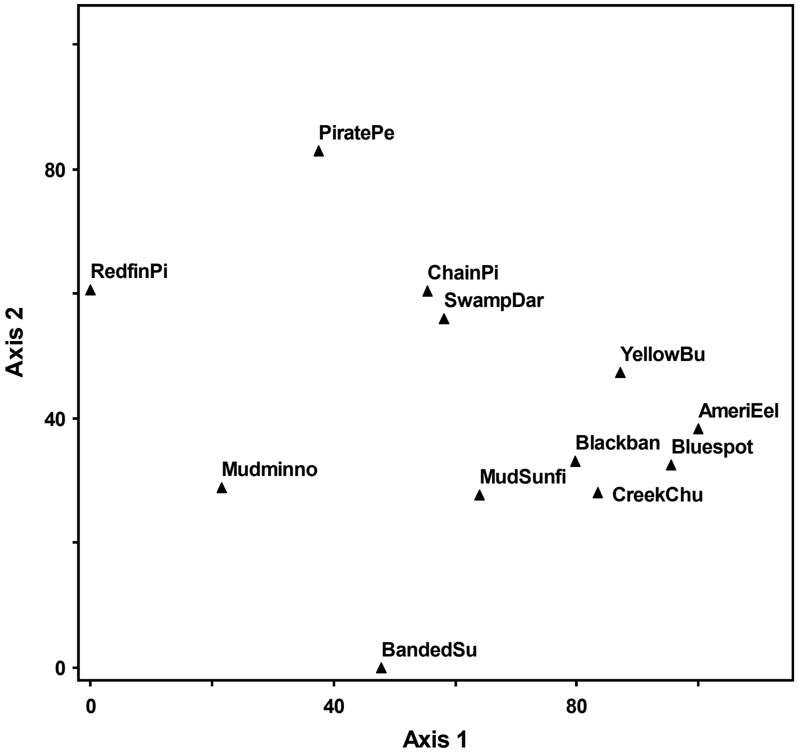


Figure 4. Site (top) and species (bottom) diagrams from the relative-abundance ordination of twelve fish species from cranberry (C), abandoned-bog (A), and forest (F) sites. The first few letters of sites and species are shown. Refer to Table 1 and Table 3 for complete names of sites and species, respectively.

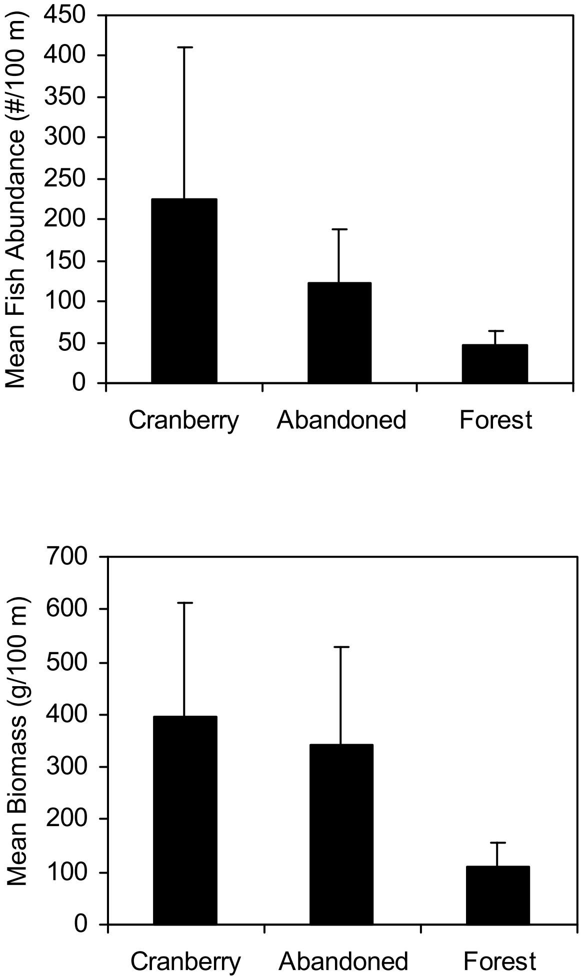


Figure 5. Mean (±1 SD) fish abundance and biomass (weight of six target species) per 100-m of stream length for cranberry, abandoned-bog, and forest streams.

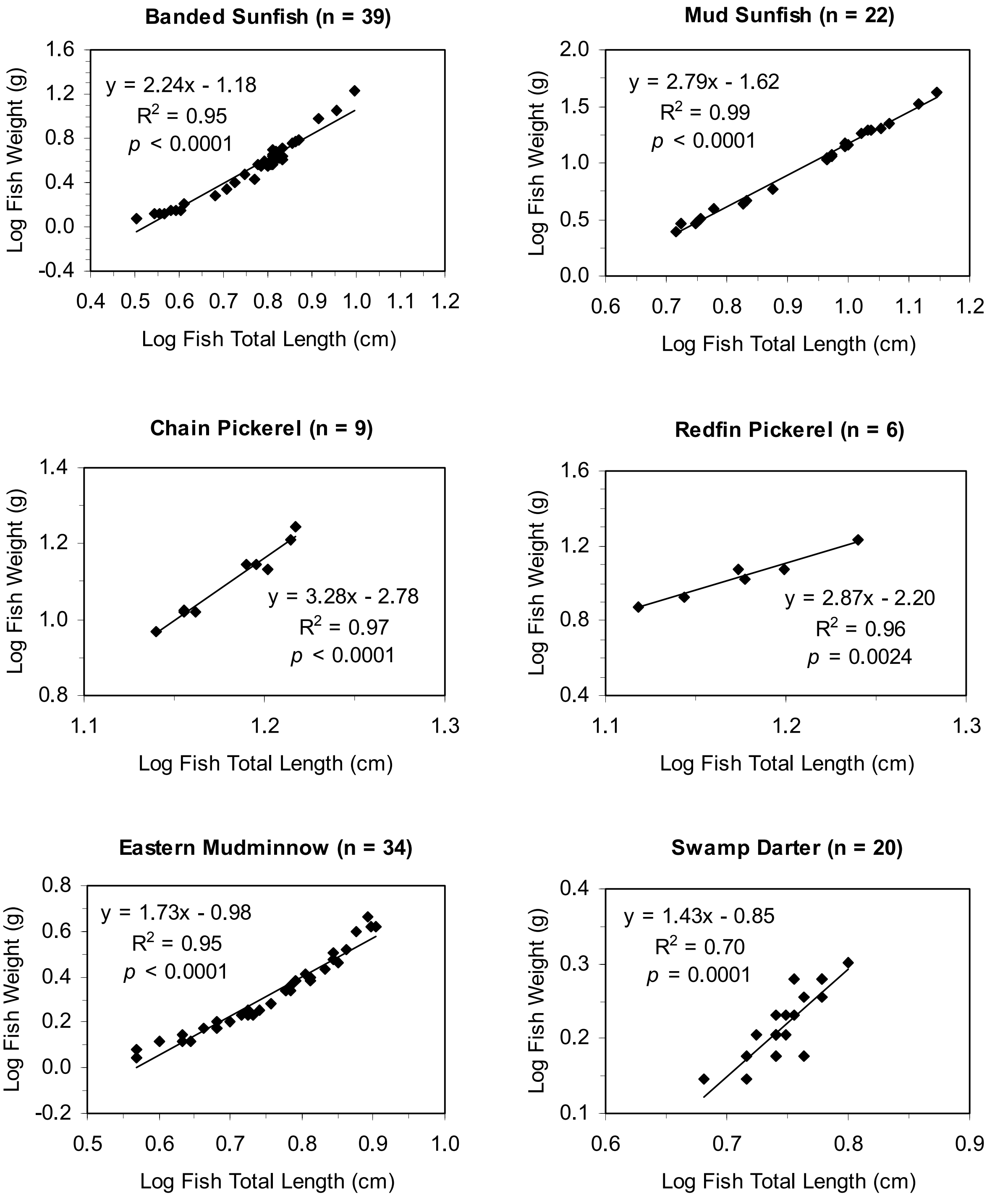


Figure 6. Fish length-weight relationships and regression equations based on log-transformed total-length and weight values. The sample size (n) represents the number of fish used to develop each model.

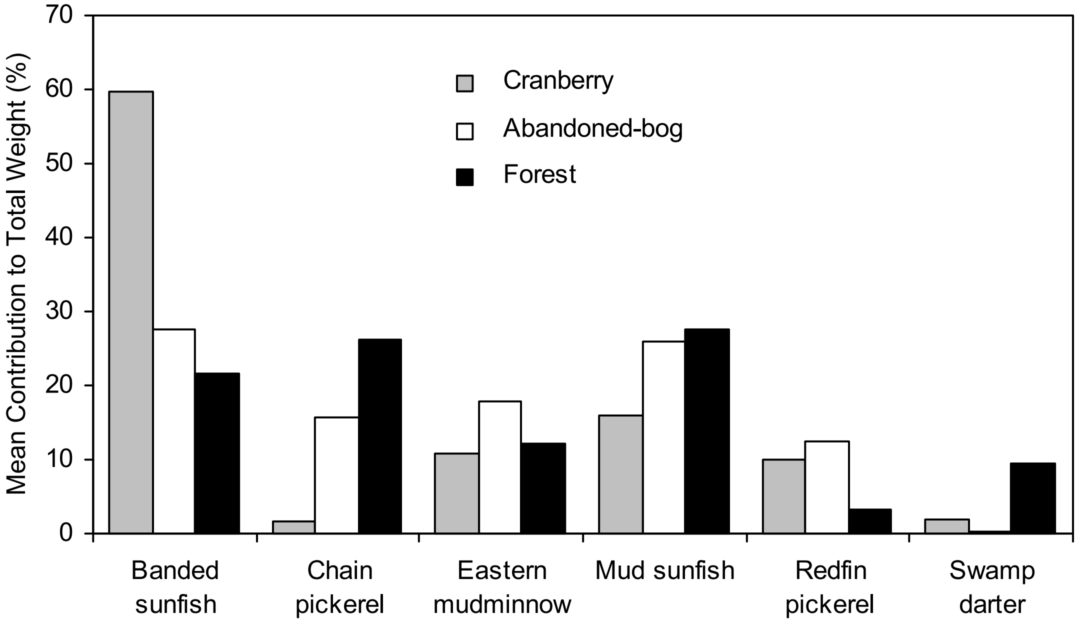


Figure 7. Relative contribution of each species to total weight of the six species used for determining biomass for cranberry, abandoned-bog, and forest streams.