# Effects of Agricultural Runoff on Vegetation Composition of a Priority Conservation Wetland, Vermont, USA

Shelley Gustafson and Deane Wang*

## ABSTRACT

**This study examined the effects of agricultural runoff on the vegetation structure of Franklin Bog, a priority conservation area located in a rapidly developing region of northwestern Vermont. Forested and agricultural runoff from the mixed land use watershed created differential vegetation patterns in the wetland, including weedy species introductions. Concentrations of nitrogen and phosphorus were measured in the stream runoff from four forested subwatersheds and two agricultural subwatersheds. Nutrient concentrations were significantly higher for agricultural vs. forested runoff for all measured parameters. Nitrate and total phosphorus concentrations in agricultural runoff ranged from 0.62 to 1.35 mg $L^{-1}$ and 0.07 to 0.37 mg $L^{-1}$, respectively. Forested runoff values were less than 0.37 mg $L^{-1}$ nitrate and 0.09 mg $L^{-1}$ total phosphorus. Significantly higher proportions of weedy species occurred at impacted vs. reference sites (46 $\pm$ 5% vs. 23 $\pm$ 4%). Furthermore, significantly higher total percent vegetated cover occurred at impacted vs. reference sites (116 $\pm$ 11% vs. 77 $\pm$ 9%) suggesting nutrient induced plant growth. Of the nine frequently occurring species categorized as bog species, only one was found within impacted sites while all nine were found at the reference sites. This suggests that the wetland's distinctive native flora is being replaced by widespread, vigorous species enhanced by agricultural nonpoint pollution in the watershed of Franklin Bog. Protection of wetlands requires attention to conservation measures throughout the entire watershed.**

Very few studies have been conducted to demonstrate the impacts of agricultural nonpoint pollution on priority conservation wetlands. In our literature survey, threats to vegetation composition were only documented in studies of the Florida Everglades and New Jersey Pine Barrens. Studies in the Everglades, a wetland complex of unique ecological value, have demonstrated a shift in floral community composition due to agricultural runoff high in phosphorus. The result of this anthropogenically-induced nutrient enrichment has been a replacement of native flora by widespread, nonindigenous species (Davis, 1991; Davis, 1994; Doren et al., 1996; Craft and Richardson, 1997). This same threat to vegetation composition has been observed in wetlands in the New Jersey Pine Barrens (Ehrenfeld, 1983). Although these studies have demonstrated an effect of nutrient enrichment on two ecologically important wetland systems, our understanding of this problem and the extent of its impact on wetlands in general is still incomplete.

In the present study, we examined the effects of agricultural runoff on vegetation patterns of the peripheral forested wetland of Franklin Bog, a Nature Conservancy designated priority conservation area. The study evaluates the following hypotheses: first, stream nutrient concentrations are higher within streams draining agricultural land than streams draining forested land within the Franklin Bog watershed; second, stream water quality has an effect on the soil chemistry of the wetland; and third, within the wetland, these water quality and soil chemistry alterations affect plant community composition, including the relative abundances of species and the presence or absence of weedy species.

School of Natural Resources, Univ. of Vermont, Burlington, VT 05405. Received 22 Mar. 2001. *Corresponding author (Deane.Wang@uvm.edu).

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## METHODS

### Study Area

Franklin Bog is a wetland complex located in the small town of Franklin, VT, approximately 3 km south of the Canadian border and within the Lake Champlain watershed. Three distinct ecological communities comprise the bog: the open mat, the peripheral forested wetland, and patches of emergent marsh.

The open mat of *Sphagnum* covers approximately 40 hectares and is located in the central portion of the basin. In addition to *Sphagnum*, many shrubs and herbs typical of ombrotrophic bogs inhabit this area.

The peripheral forested wetland begins at the edge of the open mat and extends toward the upland until elevation permits adequate drainage. This ecological community is a mix of species associated with both poor and intermediate nutrient regimes. *Thuja occidentalis* L. (northern white cedar), *Larix laricina* (Duroi) K. Koch (tamarack), *Acer rubrum* L. (red maple), and *Betula alleghaniensis* Britton (yellow birch) are the dominant trees (nomenclature follows Gleason and Cronquist 1991). Shrubs inhabiting this area include *Alnus incana* (L.) Moench (speckled alder), *Kalmia angustifolia* L. (sheep-laurel), *Chamaedaphne calyculata* (L.) Moench (leatherleaf), and several species of *Salix* sp. (willow). As the canopy is only partially complete, many herbs and ferns also inhabit the flooded floor of the forest. Common ferns include *Onoclea sensibilis* L. (sensitive fern), *Thelypteris palustris* Schott (marsh fern), and *Osmunda regalis* L. (royal fern). *Typha latifolia* L. (common cattail), *Iris versicolor* L. (blue-flag iris), *Polygonum arifolium* L. (halberd-leaved tearthumb), and *Lemna* sp. (duckweed) can be found in more deeply flooded sections of the forest.

Patches of emergent marsh occur within the peripheral forested wetland. Common plants of these flooded areas include *T. latifolia*, *Myrica gale* L. (sweetgale), *Carex lasiocarpa* Ehrh., *Utricularia* sp. (bladderwort), *Lemna* sp., and *Wolffia* sp. (watermeal).

### Study Sites

Study sites were selected at locations along the wetland's perimeter that are situated at the base of inflowing streams. Because the major outflow of the wetland complex originates from a central pond within the bog mat and flows west, many of the approximately 20 intermittent and first order streams flowing into the wetland enter at locations that are downgradient of the bog mat. Given that the bog mat comprises the

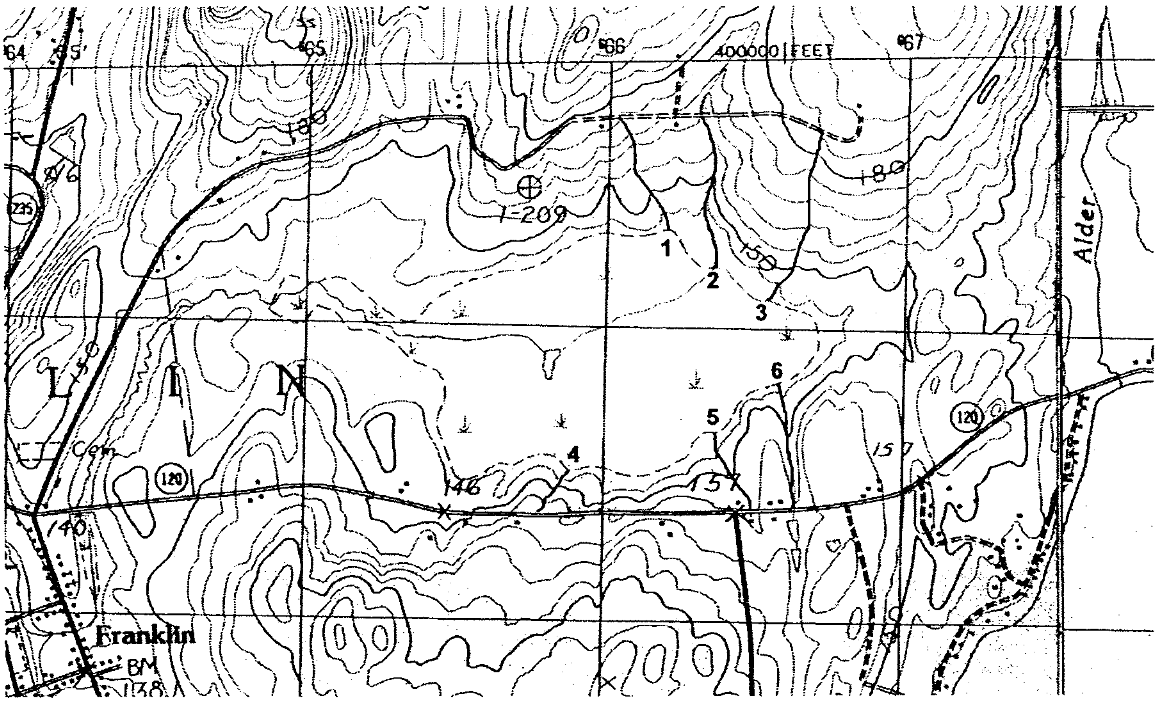


**Fig. 1. Map of Franklin Bog. Numbers 1 through 6 mark the location of the base of each study stream. Forested streams influence sites 1 through 4; agricultural streams influence sites 5 and 6.**

most fragile portion of the wetland complex, study sites were selected upgradient of the mat, within the eastern half of the wetland complex. Additional criteria required for site selection included channelization of the inflowing stream up to the edge of the wetland and the presence of peripheral forested wetland as the dominant community type at the base of the stream. Only seven streams met all of these criteria. One of the seven, however, was not selected because of the presence of a spring at its base. The remaining six streams were included in the study. Sites 1 through 4 constitute wetland areas fed by forested streams whereas sites 5 and 6 consist of wetland areas influenced by agricultural streams (Fig. 1).

## Watershed Analysis

Subwatershed boundaries were delineated and digitized from 7.5 min. USGS topographic maps. The U.S. Soil Conservation Service (1972) method was used to approximate yearly runoff. Specifically, overall runoff curve factors for each subwatershed were obtained from the Franklin County Soil Survey (USDA, 1979). The dominant land use for each subwatershed was determined from 1995, 1:5000 aerial orthophotos. Based on the runoff curve factor and dominant land use of each subwatershed as well as the 30-year normal precipitation for Enosburg Falls, VT, an approximate yearly rate of runoff was estimated for the subwatersheds of each of the six sampled streams (U.S. Soil Conservation Service, 1972). This is an admittedly rough calculation, but the results provide useful context for comparing possible impacts on the wetland.

## Water Quality

Each stream was sampled during three separate runoff events in the period extending through the spring and summer of 1998. Streams were sampled once during each event without regard to the flow dynamics of the stream. Grab samples were taken where the streams entered the peripheral forested wetland, with acid-washed, polyethylene bottles. The samples were analyzed for concentrations of total phosphorus (TP), ammonium, and nitrate. Total phosphorus was analyzed colorimetrically following the persulfate digestion method (APHA, 1989). Ammonium and nitrate were analyzed by flow-injection colorimetric analysis on the Lachat autoanalyzer (Zellweger Analytics). The salicylate-hypochlorite method was used for ammonium analysis (Prokopy, 1992) and the cadmium reduction method was used for nitrate analysis (APHA, 1989).

Approximate annual stream loading rates also were estimated for total phosphorus, nitrate and ammonium by multiplying each subwatershed's estimated yearly runoff rate by its stream's average concentration for each nutrient parameter.

## Vegetation

One transect was established at each site. Transects began where the sampled stream entered the poorly drained, peripheral forested wetland and were oriented toward the center of the bog mat, proceeding along the natural transition that occurs across the peripheral forested wetland to the mat. Starting at the mouth of the stream, $4 \times 2$ m plots were placed at 25 m intervals along each transect until either the bog mat was reached or a total of six plots had been established. Site 1 contained 5 plots; sites 2 and 3 contained 6 plots; site 4 contained 2 plots; and sites 5 and 6 contained 4 plots.

In July of 1998, the percent cover of shrub species (woody stem between 1 and 4 meters high) in each plot was determined by an ocular estimate. At the same time, percent cover of the herbaceous layer (non-woody or 0 to 1 m high) was estimated for 4, alternating, $1 \times 1$ m quadrats placed within the larger $4 \times 2$ m plot.

## Soil

After sampling vegetation, one soil sample was collected from each plot with a random number table to locate sample positions. With a 4 cm-diameter soil auger, the top 25 cm of soil was collected. Two-gram sub-samples were analyzed in the laboratory for available phosphate, total phosphorus, ammonium, and nitrate. Available phosphate was extracted with ammonium acetate (McIntosh, 1969). Total phosphorus samples were digested with nitric and perchloric acid (APHA, 1989). Ammonium and nitrate were extracted with KCl (Keeney and Nelson, 1982). Chemical analyses followed procedures used for water quality analyses.

### Data Analysis

All data were analyzed with JMP 3.1 (SAS Institute, Inc.). Stream water chemistry from agricultural subwatersheds was compared with forested subwatersheds by ANOVA. Linear regressions were used to compare average TP, nitrate, and ammonium stream water concentrations (three sample dates) with available phosphate, TP, nitrate, and ammonium soil concentrations.

In addition, phosphorus (P) and nitrogen (N) loading estimates also were compared to P and N soil concentrations by linear regression. Each plot location was used in a separate analysis. For example, TP in stream water was compared against TP soil concentration in the closest plot location to the stream mouth. An additional regression was conducted for the next closest plot location, etc. Sample size, therefore, varied depending on the number of transects that were still within the peripheral forested wetland at a particular location (e.g., at the 50-m sampling location, site 4's transect had already reached the open mat, beyond the peripheral forested wetland, resulting in a sample size of 5 instead of 6).

Two-way analysis of variance was used to evaluate the effect of site type (i.e., sites affected by forested streams or "reference sites" vs. sites affected by agricultural streams or "impacted sites") and distance from stream mouth as well as their interaction on the concentration in the soil of each of the measured nutrient parameters: TP, available phosphate, nitrate, and ammonium. Because both of the impacted sites' transects contained 4 sample locations, only data from the first 4 sample locations for all sites were included in the analysis. The one exception was site 4 which contained only 2 sample locations along its transect. This resulted in a sample size of 22 for this analysis.

For the shrub layer, relative abundance of each species was calculated as a fraction of the sum of % cover estimates for all species within the layer. Relative abundance for the herbaceous layer was calculated similarly from the average % cover estimate of the four quadrats within each plot. A species was classified as frequent in a given plot if its relative abundance in that plot was at least 0.1 (i.e., 10%). Community structure was contrasted among sites by calculating Sorenson's coefficient of community similarity (Sorenson, 1948) by the following equation:

$$CCs = 2c/(s1 + s2)$$

where $s1$ and $s2$ represent the number of species in communities 1 and 2 respectively (i.e., two given sites) and $c$ is the number of species common to both communities. Two coefficients were calculated per site comparison and evaluated separately. The first calculation considered all species present within a given site while the second considered frequent species only. For each calculation, an average coefficient of community was determined for reference sites and compared with the coefficient determined for impacted sites. Sample location data were pooled for this analysis.

Frequent species for all sites were sorted into three groups: those species found only at reference sites, those found only at impacted sites, and those found at both. Each frequent species was labeled as weedy or non-weedy following Muenscher (1955). Within this reference, weeds are defined as "those plants, with harmful or objectionable habits or characteristics, which grow where they are not wanted, usually in places where it is desired that something else should grow." This reference was chosen because it is the most comprehensive list available (571 species) that documents species within the study region that are able to spread aggressively through various competitive strategies. Common characteristics of species documented in this reference include the ability to regenerate lost parts, vegetative spreading, and the production of enormous numbers of seeds each growing season. Species were also classified as bog or non-bog species following Seymour (1969). A Fisher's Exact test was used to determine if significant association existed between species type (i.e. weedy or non-weedy, bog or non-bog) and site type (i.e. reference or impacted). Sample location data were, again, pooled for this analysis.

The proportion of all species classified as weedy, regardless of their relative abundance, was tabulated at each successive sampling location for each site. A two-way ANOVA was used to evaluate the effect of site type and distance from stream mouth as well as their interaction on the proportion of weedy species. This procedure was repeated for species classified as bog species.

Total % cover of all species was also calculated at each successive sampling distance for each site. A two-way ANOVA was again used to evaluate the effect of site type and distance from stream mouth as well as their interaction on the total % cover of all species.

## RESULTS AND DISCUSSION

### Water Quality

Higher concentrations of TP occurred in the agricultural streams (sites 5 and 6) than the forested streams (sites 1 through 4) for all three sampling events (Fig. 2). Nitrate concentrations were also higher for the two agricultural streams than the forested streams across all three sampling events. Ammonium concentrations were generally higher for the agricultural streams than the forested streams, the one exception being the July sampling event when stream 6 had a lower ammonium concentration than streams 3 and 4. When evaluated by ANOVA, these stream type differences are significant at $P < 0.001$.

The levels of phosphorus in sampled stream water are comparable with reported values for forested and agricultural streams. Budd and Meals (1994) reported 0.20 mg $L^{-1}$ as the concentration of TP most representative of agricultural streams within the Lake Champlain Basin. Likewise, an older, more general reference (Dunne and Leopold, 1978) reported that polluted, agricultural streams typically contain greater than 0.20 mg $L^{-1}$ TP. In the agricultural streams of the present study, the mean TP concentration was 0.20 mg $L^{-1}$. The mean concentration of TP in the forested streams of this study was 0.036 mg $L^{-1}$. By comparison, Budd and Meals (1994) reported a representative concentration of 0.015 mg $L^{-1}$ TP for forested streams within the Lake Champlain Basin.

Reported nitrogen values are similar to those measured in the present study. Dunne and Leopold (1978) reported that while forested catchments generally have nitrate concentrations of about 0.1 mg $L^{-1}$, the nitrate concentrations of agricultural runoff can exceed 1.0 mg $L^{-1}$. The mean concentration of nitrate in forested streams in our study was 0.18 mg $L^{-1}$ and the mean concentration of nitrate in agricultural streams was 1.01 mg $L^{-1}$. Likens and Bormann (1995) reported a mean ammonium concentration of 0.04 mg $L^{-1}$ in stream water of undisturbed, forested subwatersheds in New Hampshire. In the present study, the mean concentration of ammonium in the forested streams was 0.09 mg $L^{-1}$ whereas the agricultural streams had a mean concentration of 0.38 mg $L^{-1}$.

Stream loading estimates for P and N are presented in Table 1. Because of the relatively large size of stream 2's subwatershed, its annual flow and resulting loading estimate is consistently higher for all nutrient parameters than the other 3 forested streams and is sometimes higher than the agricultural streams. Thus, if the impact of the nutrient additions is due to total loading, then this "reference" site should be more comparable to the two impacted sites in terms of soil chemistry as well as species composition. However, if the impact is related to concentration and qualitative aspects of the stream water, then this site should be more comparable to other reference sites.

## Soil Analysis

The results of a two-way ANOVA examining the effect of site type and distance from stream mouth, as well as their interaction on soil concentration of the measured nutrient parameters, indicate that site type has a significant effect on soil available phosphate and soil nitrate ($P = 0.08$ and 0.01 respectively), with higher concentrations occurring within the impacted than reference sites (7.0 ± 1.0 mg $kg^{-1}$ vs. 4.3 ± 0.7 mg $kg^{-1}$ and 3.0 ± 0.5 mg $kg^{-1}$ vs. 1.3 ± 0.4 mg $kg^{-1}$, respectively). However, the results suggest no significant effect of site type on soil TP or soil ammonium. The results also indicate that distance from stream mouth has a significant negative effect on soil TP and soil ammonium ($P = 0.001$ and 0.07, respectively). Mean soil TP values for the first four sampling locations beginning at the stream mouth are as follows: 1.6 ± 0.1 g $kg^{-1}$, 1.0 ± 0.1 g $kg^{-1}$, 0.9 ± 0.1 g $kg^{-1}$ and 0.7 ± 0.1 g $kg^{-1}$. Mean soil ammonium values for the first four sampling locations are as follows: 94 ± 6 mg $kg^{-1}$, 82 ± 6 mg $kg^{-1}$, 83 ± 6 mg $kg^{-1}$ and 68 ± 6 mg $kg^{-1}$. There is no significant distance effect on soil available phosphate and soil nitrate. Furthermore, the interaction between site type and distance from stream mouth has no significant effects on any of the four measured nutrient parameters.

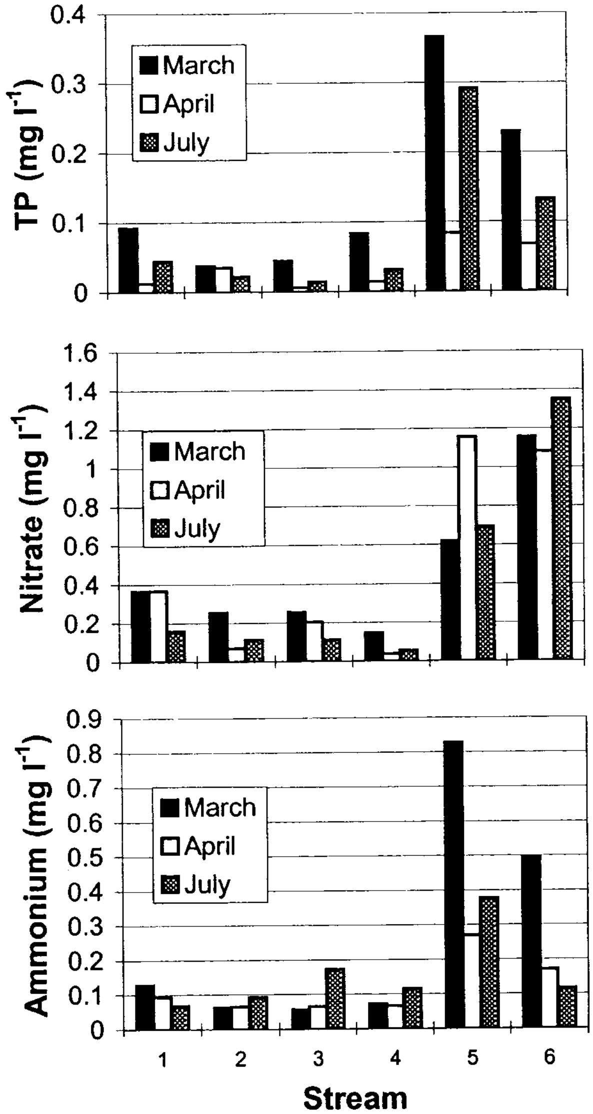


**Fig. 2. Nutrient concentrations in stream samples for three sampling events. Streams 1 through 4 are agricultural streams, 5 and 6 are forested streams. For TP, nitrate, and ammonium, stream type is significant at the $P < 0.001$ level.**

Regression analyses showed no significant relationships between nutrient concentrations in stream water and nutrient concentrations in soil. In addition, there were no significant relationships between loading rates of nutrients and soil nutrient concentrations.

On the basis of the results from the regression analyses, we cannot conclude that the stream water nutrient concentrations or the nutrient loading rates are signifi-

**Table 1. Area, predominant land use, and rough runoff and loading estimates for each study site's watershed. Predominant land use comprises at least 95% of the total area for each watershed.**

| | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 |
|---|---|---|---|---|---|---|
| Area, ha | 14.4 | 60.7 | 6.9 | 19.1 | 11.6 | 8.0 |
| Predominant land use | forested | forested | forested | forested | agricultural† | agricultural† |
| Annual runoff, L × $10^6$ $yr^{-1}$ | 100 | 500 | 60 | 200 | 100 | 80 |
| Annual loading, kg $yr^{-1}$ | | | | | | |
| Total phosphorus | 6 | 20 | 1 | 7 | 30 | 10 |
| Nitrate | 40 | 80 | 10 | 10 | 90 | 90 |
| Ammonium | 10 | 40 | 6 | 10 | 50 | 20 |

† Dairy farming is the specific agricultural land use within Watersheds 5 and 6.

**Table 2. Sorenson's coefficient of community similarity, within and between site types. CC*s* = 2*c*(*s*1 + *s*2), *s*1 = number of species in community 1, *s*2 = number of species in community 2, *c* = number of species common to both communities.**

| | Within reference sites | | Within impacted sites | | Between ref. and impact. sites | |
|---|---|---|---|---|---|---|
| | *s*1, *s*2 | Coefficient | *s*1, *s*2 | Coefficient | *s*1, *s*2 | Coefficient |
| All species | 1, 2 | 0.65 | 5, 6 | 0.67 | 1, 5 | 0.60 |
| | 1, 3 | 0.71 | | | 1, 6 | 0.64 |
| | 1, 4 | 0.42 | | | 2, 5 | 0.41 |
| | 2, 3 | 0.60 | | | 2, 6 | 0.56 |
| | 2, 4 | 0.34 | | | 3, 5 | 0.58 |
| | 3, 4 | 0.43 | | | 3, 6 | 0.63 |
| | | | | | 4, 5 | 0.42 |
| | | | | | 4, 6 | 0.29 |
| | Average | 0.53 | | 0.67 | | 0.53 |
| Frequent species† only | 1, 2 | 0.30 | 5, 6 | 0.55 | 1, 5 | 0.43 |
| | 1, 3 | 0.40 | | | 1, 6 | 0.30 |
| | 1, 4 | 0.22 | | | 2, 5 | 0.38 |
| | 2, 3 | 0.21 | | | 2, 6 | 0.09 |
| | 2, 4 | 0.24 | | | 3, 5 | 0.32 |
| | 3, 4 | 0.20 | | | 3, 6 | 0.34 |
| | | | | | 4, 5 | 0.00 |
| | | | | | 4, 6 | 0.12 |
| | Average | 0.26 | | 0.55 | | 0.25 |

† A species was classified as frequent if its relative abundance was at least 10% within at least one plot for a given site.

cantly affecting soil nutrient concentrations. However, the results of the analysis of variance do suggest that the impacted sites have higher soil concentrations of available phosphate and nitrate than the reference sites. One explanation for this apparent contradiction in results is that the variability associated with the small sample size of the regression analyses ($n \leq 6$) obscured the relationship between water nutrient concentrations and soil nutrient concentrations.

## Vegetation Analysis

Sorenson's coefficient, an index of community similarity, ranges from 0 to 1 with higher values indicating a higher degree of similarity; a coefficient of 1 means complete overlap of species between two communities. In this study, similarity was determined within site types (i.e., reference and impacted) and between site types (Table 2). Considering all species present, the average similarity coefficient within reference sites was 0.53, while the similarity coefficient within the two impacted sites was 0.67. Due to limitations in sample size, statistical analysis was not used to compare values. This value of 0.67, however, falls within the range of coefficients calculated within reference sites (0.34 to 0.71). Consequently, we cannot conclude that the overlap of species within impacted sites is greater than within reference sites. The average similarity coefficient between the reference and impacted sites was 0.52, essentially identical to that found within the reference sites. This indicates that the reference sites are not any more distinct from the impacted sites in terms of overall species composition than the reference sites are from each other.

When only frequent species (relative abundance ≥ 10% within at least one plot of a given site) were considered, the average similarity coefficient within the reference sites was 0.26, while the similarity coefficient within the two impacted sites was 0.55. This value of 0.55 was well outside the range of values determined within reference sites (0.20 to 0.40). This indicates that the impacted sites exhibit greater similarity to each other in terms of frequent species composition than the reference sites. The similarity coefficient between the reference and impacted sites was 0.25, again virtually identical to the average value determined within reference sites. These results are important because they suggest that differences in vegetation structure between the impacted vs. reference sites are observed through consideration of species occurring frequently within the communities rather than through examination of all species present, regardless of their relative abundance.

The results of this analysis, as displayed in Table 2, also suggest that Site 4 differs the most dramatically from other sites regarding species composition. One explanation for this observation is that Site 4 also contained the fewest number of plots along the transect due to the relatively short distance between the upland edge of the peripheral forested wetland and the bog mat at this location. Therefore, sampling of species within this site was more limited and may have affected the results of the analysis.

Table 3 lists all species classified as frequent and the site in which they occur as such. All frequent species were identified as weedy or non-weedy according to Muenscher (1955). Four of the six frequent species found only in the impacted sites were weedy. However, only one of the 23 frequent species found only in the reference sites was weedy. Four of the 10 frequent species found in both site types were weedy. Using a Fisher's Exact test, the association between species type (W in Table 3) and site type was significant ($P = 0.002$). Figure 3 displays this distribution graphically.

Because all study sites were located within the peripheral forested wetland, a community encountered along the perimeter of the bog mat, it is usual to find species associated with both poor and intermediate nutrient regimes intermixed within this system. To estimate the presence of species that are more typical of nutrient poor systems, frequent species were also categorized as bog or non-bog species according to Seymour (1969).

**Table 3. Frequent species by site within the peripheral forested wetland of Franklin Bog. Species listed at a given site have a relative abundance of at least 10% within at least one plot for that site. Weedy species (W) classified by Muenshcer (1955) and bog species (B) classified by Seymour (1969) are labeled.**

| Location of species | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 |
|---|---|---|---|---|---|---|
| **Reference sites only** | | | | | | |
| *Abies balsamea* (L.) Miller | | x | | | | |
| *Alnus incana* (L.) Moench | | | x | | | |
| *Aralia nudicaulis* L. | | x | | | | |
| *Calamagrostis canadensis* (Michx.) P. Beauv. (B) | | | x | | | |
| *Carex comosa* F. Boott. (B) | | | x | | | |
| *Carex lasiocarpa* Ehrh. (B) | | | x | | | |
| *Carex* sp. (114) | | | x | | | |
| *Carex* sp. (209) | | | | x | | |
| *Carex* sp. (211) | x | | | | | |
| *Carex* sp. (Stellulatae) | x | x | | x | | |
| *Chamaedaphne calyculata* (L.) Moench (B) | | x | | | | |
| *Coptis trifolia* (L.) Salisb. | | x | | | | |
| *Fraxinus pennsylvanica* Marshall | x | | | | | |
| *Ilex verticillata* (L.) A. Gray | x | | | | | |
| *Lycopus* sp. (W) | | | x | | | |
| *Myrica gale* L. (B) | | x | | | | |
| *Nemopanthus mucronatus* (L.) Loes (B) | x | | | | | |
| *Potentilla palustris* (L.) Scop. (B) | | | x | | | |
| *Sparganium* sp. | x | | x | x | | |
| *Thelypteris palustris* Schott | x | x | x | | | |
| *Thuja occidentalis* L. | x | | | | | |
| *Triadenum virginicum* (L.) Raf. (B) | | | x | | | |
| *Tsuga canadensis* (L.) Carriere | | x | | | | |
| **Impacted sites only** | | | | | | |
| *Bidens* sp. (W) | | | | | x | |
| *Carex stricta* Lam. | | | | | | x |
| *Cicuta maculata* L. (W) | | | | | x | x |
| *Leersia oryzoides* (L.) Swartz (W) | | | | | x | x |
| *Spiraea tomentosa* L. (W) | | | | | x | x |
| *Ulmus* sp. | | | | | | x |
| **Both reference and impacted sites** | | | | | | |
| *Acer rubrum* L. | x | x | x | | x | x |
| *Calla palustris* L. (B) | x | x | | | | x |
| *Impatiens* sp. | | x | | | | x |
| Moss | | x | x | x | | x |
| *Onoclea sensibilis* L. (W) | x | | x | | x | x |
| *Osmunda cinnamomea* L. (W) | x | | x | | x | x |
| *Osmunda regalis* L. | | x | | | | x |
| *Polygonum arifolium* L. | x | | x | | x | |
| *Spiraea alba* Var. *latifolia* (Aiton) Dippel (W) | | | x | | | x |
| *Typha* sp. (W) | x | | | | x | |

While none of the frequent species found only in the impacted sites was a bog species, eight of the 23 frequent species found only in the reference sites were classified as such. One of the 10 frequent species found in both site types was a bog species. Using a Fisher's Exact test, association between species type (B in Table 3) and site type was not significant ($P = 0.14$). There is nevertheless an apparent fidelity of bog species to reference sites, as shown in Fig. 4.

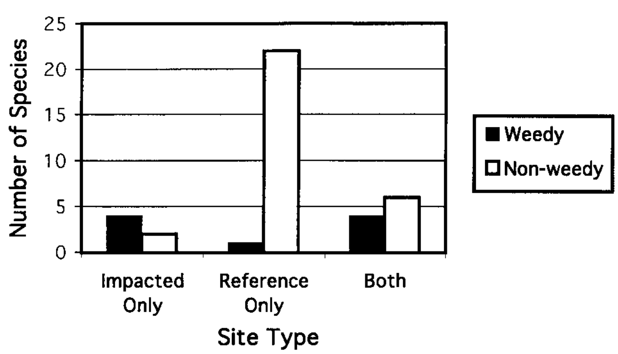


**Fig. 3. Number of weedy and non-weedy species found only at impacted sites, only at reference sites, and at both site types. All plots in each site type were pooled for this analysis. Only frequent species were considered (see text for explanation).**

A two-way ANOVA was used to examine the effect of site type and distance from stream mouth as well as their interaction on proportion of weedy species. Unlike the Fisher's Exact test, the two-way ANOVA was based on all species, regardless of their relative abundance. The results of this test indicate that site type has a significant effect ($P = 0.002$) on the proportion of all species which are weedy, whereas neither distance from stream mouth nor the interaction between site type and

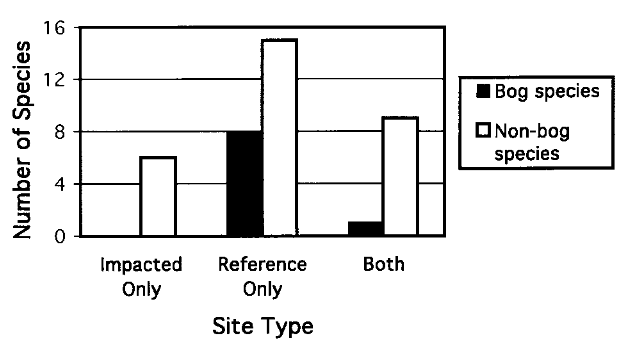


**Fig. 4. Number of bog and non-bog species found only at impacted sites, only at reference sites, and at both site types. All plots in each site type were pooled for this analysis. Only frequent species were considered (see text for explanation).**

distance are significant factors. The mean proportion of weedy species in the impacted sites was 0.46 which was significantly higher than 0.23, the mean in the reference sites.

A two-way ANOVA was also used to examine the effect of site type and distance from stream mouth as well as their interaction on the total % cover of all species. The results of this test also indicate that site type has a significant effect ($P = 0.02$) on the total cover of all species, whereas neither distance from stream mouth nor the interaction between site type and distance are significant factors. The mean total % cover of all species in the impacted sites was 116% which was significantly higher than 77%, the mean in the reference sites.

The vegetation data indicate that a change in community structure has occurred due to the effects of diffuse agricultural pollution in the wetland watershed. Sites affected by nutrient-enriched, agricultural streams (i.e., impacted sites) contain higher proportions of weedy species than sites affected by forested streams. Furthermore, of the nine bog species frequently found within the peripheral forested wetland, only one was frequent within impacted sites. In comparison, all nine were frequent within reference sites. These results suggest that, within areas of the wetland affected by nutrient-enriched stream inputs, species adapted to nutrient-poor conditions are being replaced by more widespread and vigorous species.

While none of the frequent weedy species occurs within site 2, 1/3 of the frequent bog species occurs within this site (Table 3). As previously acknowledged, site 2 was unique in that it was influenced by a stream with low nutrient concentrations but with a relatively large subwatershed resulting in annual loading rates comparable to impacted sites (Table 1). The distribution of species within this site supports the idea that stream water quality in terms of nutrient concentration rather than total loading is responsible for the effect of nutrient additions on the peripheral forested wetland.

Total % cover of all species is also significantly higher in the impacted sites than the reference sites. These results suggest that increased plant growth within the peripheral forested wetland ecosystem is another response to nutrient additions.

Because bog species have slow growth rates and are generally poor competitors in nutrient-rich soils, one would expect the decline of these species in areas affected by nutrient enrichment as well as the increase of weedy species, which are typically fast-growing. Heil and Bruggink (1987) studied the effects of fertilization on the interactions between *Calluna vulgaris* (L.) Hull, a slow-growing species, and *Molinia caerulea* (L.) Moench, a comparatively fast-growing species, in a nutrient-poor heathland historically dominated by *C. vulgaris*. They found that while monocultures of both species increased in biomass with fertilization, the biomass of *M. caerulea* increased much more dramatically than that of *C. vulgaris*. They also found that fertilization of mixed cultures of the two species resulted in *M. caerulea* having a negative effect on *C. vulgaris* growth. Under the nutrient-poor conditions of the natural heathland, *C. vulgaris* coexists with *M. caerulea*. Because of its ability to capitalize on added nutrients, the faster growing *M. caerulea* competitively excludes *C. vulgaris* with nutrient enrichment.

Similar patterns of species replacement following nutrient enrichment have also been documented in the Everglades (Doren et al., 1996; Craft and Richardson, 1997), the New Jersey Pine Barrens (Ehrenfeld, 1983; Morgan and Philipp, 1986; Morgan, 1987) and the serpentine grasslands of California (Huenneke et al., 1990). For example, Doren et al. (1996) found that high soil phosphorus content caused by agricultural runoff in the Florida Everglades was linked to the replacement of native plant assemblages by *Typha* sp., a genus not historically dominant within Everglades plant communities. Similarly, Morgan and Philipp (1986) found that streams draining both urban and agricultural watersheds within the New Jersey Pine Barrens contained elevated pH and nitrate concentrations as compared to streams draining undeveloped watersheds; these polluted streams contained higher occurrences of non-typical Pine Barrens species and lower occurrences of indigenous species than the unpolluted streams.

## CONCLUSION

The results of this study demonstrate that adjacent land use has an impact on the vegetation of the peripheral forested wetland of Franklin Bog. Agricultural streams entering Franklin Bog have elevated concentrations of nutrients relative to adjacent forested streams. This enriched stream water may be linked to higher soil nutrient concentrations as both available phosphate and nitrate are significantly higher in impacted sites than in reference sites.

These impacted sites have a higher total percent cover of species, a greater proportion of weedy species and virtually no frequently found bog species. This suggests that, within the impacted sites, species that are more characteristic of nutrient-poor conditions are being replaced by widespread and vigorously growing species.

An additional hypothesis for the change in vegetation structure is that it is not caused by nutrient enrichment alone but that other disturbances related to agricultural land use may also contribute to the change. The species identified as weedy (Muenscher, 1955) grow vigorously in disturbed soil typical of agricultural fields. Thus, sites affected by agricultural streams would have increased exposure to weedy seeds than sites affected by forested streams.

Regardless of the specific mechanism, sites affected by agricultural land use at Franklin Bog evidence a shift in species composition. This result demonstrates the critical need to extend our understanding of wetland protection from the preserve itself to the watershed as a whole. The effects of urban development should be seriously considered as well. Budd and Meals (1994) reported that urban runoff contains even higher nutrient concentrations than agricultural runoff. As development pressure increases from both urban and agricultural sources, the integrity of natural wetlands will be increasingly compromised. In order to protect pristine wetlands of high conservation value, control of development within watershed boundaries is essential.

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