Relative Contribution of Hemlock Pollen to the Phosphorus Loading of the Clear Lake Ecosystem Near Minden, Ontario

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Abstract

The forest stand composition within the terrestrial watershed of a small lake on the southern Precambrian Shield was assessed. Total phosphorus inputs from the terrestrial watersheds were obtained for two sub inflows by measuring flow rates and phosphorus concentrations. Direct aerial phosphorus fallout was estimated from nearby sites sampled by the Ontario Ministry of the Environment. Pollen fallout on the 88 ha lake surface was measured during the growing season with a series of floating pollen traps. Detailed microscopic examination was made of the slides prepared from the trapped pollen samples. Pollen grain volumes, species identification, frequency and percentage composition were obtained. Phosphorus contents of several species of pollen grains were calculated for pollen collected directly from broad leaf tree flowers and coniferous strobili. In the old growth watershed, hemlock (*Tsuga canadensis* (L.) Carr.) contributed the largest component of pollen-source phosphorus to the ecosystem.

Introduction

Phosphorus is one of the most important components of lake ecosystems because, along with nitrogen, it is the nutrient that often limits algal productivity (Vallentyne 1970, Edmonson 1972 and Schindler 1977) and can influence species composition (Levine and Schindler, 1999). Most of the phosphorus input to lakes on the Canadian Shield enters the lakes with runoff or is deposited on the lakes from the atmosphere (Dillon 1974, Schindler *et al*. 1976). Richerson *et al*. (1970), Gomolka (1975), Nichols and Cox (1978) and Scheider et al. (1979) noted that part of the atmospheric influx of phosphorus was due to pollen grains. Richerson *et al*. (1970) estimated that the input of phosphorus in pollen was insignificant when compared with the total phosphorus loading of Lake Tahoe (surface area of approximately 50,000 ha), a lake surrounded by extensive stands of pine and fir. However, the study indicated that under parallel conditions pollen would contribute as much as 5.8% of the total phosphorus budget of Castle Lake, California (surface area = 14.9 ha).

The purpose of this study was to determine the importance of pollen as a source of phosphorus input for Clear Lake, a small lake on the southern Precambrian Shield. Since the amount of phosphorus lost to the terrestrial watershed by the component of pollen influx entering the lake with runoff would be very difficult to estimate, only pollen grains deposited directly onto the lake were considered in this study.

Table 1.—Estimates of Tree Population Percentages for Clear Lake and two Neighbouring Watersheds (trees > 4 in. in diameter)

	Lake		
Tree	Clear	Blackcat	Black Kitten
Hemlock	43	57	62
White Pine	13	5.0	7.1
Red Pine	0.6	0.2	0.4
White Cedar	4.5	11	20
Balsam Poplar	1.2	1.3	0.4
Big - Toothed Aspen	1.0	0.2	-
Trembling Aspen	0.1	-	-
White Spruce	0.1	-	-
Black Spruce	-	0.3	-
Sugar Maple	11.3	5.3	0.7
Red Maple	6.3	6.7	5.3
Striped Maple	0.1	0.5	0.4
White Birch	6.6	3.5	1.1
Yellow Birch	2.6	1.0	0.4
Red Oak	7.3	5.3	1.5
Beech	1.1	1.9	-
Ironwood	1.2	1.1	0.4
Black Ash	0.7	-	-

Clear Lake is in Sherbourne township of Haliburton County, Ontario at 45E 11' N and 78E 43' W. It is completely underlain by very insoluble Precambrian Shield bedrock that lies exposed on steeper slopes. The remainder of the watershed is covered by shallow soils containing scattered pockets of deeper soil with a well defined B horizon (Schindler and Nighswander, 1970).

Clear Lake is a headwater lake with a mean depth of 12.3 m. Its terrestrial watershed is only 146 ha. Two nearby lakes, (Blackcat and Black Kitten) have mean depths of 16.9 m and 6.5 m, respectively, and corresponding watersheds of 44 ha and 3.6 ha. Tree population percentages given in Table 1 were estimated by counting and measuring trees greater than 10 cm in diameter in eight 10 m wide cruise lines extending along the major compass points from a point in the centre of the lake to the perimeter of its watershed.

The small Clear Lake watershed is situated on the Precambrian Shield and, therefore, expected to exhibit relatively low phosphorus loading values. Dillon and Kirchner (1975) found that similar areas export the least phosphorus per unit area. The impermeability of the shield bedrock also limits the influx of phosphorus in groundwater to the extent

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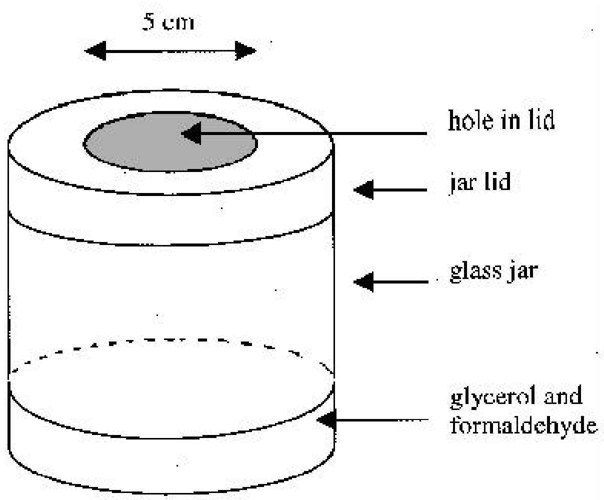

Figure 1.—Pollen trap for airborne pollen.

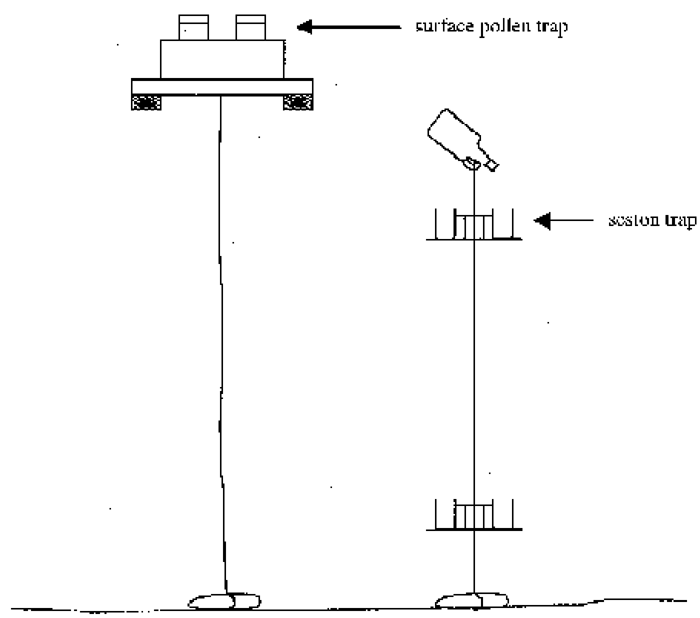

Figure 2.—Deep water sampling site.

that this source of phosphorus loading is often assumed to be negligible (*e.g.* Dillon 1974, Schindler et al. 1976).

There are no permanent dwellings and only a few cottages on the Clear Lake basin. The study area is also a considerable distance from any large urban or industrial centre. Anthropogenic sources of phosphorus loading are, therefore, likely to be comparatively low. More information on Clear Lake and its terrestrial watershed is given in Schindler and Nighswander (1970).

Materials and Methods

The importance of hemlock pollen to the phosphorus budgets of Clear Lake was determined by estimating the phosphorus content of the pollen, the amount of pollen falling on the lake and the phosphorus loading values for the lakes.

Pollen was collected for phosphorus analysis by picking ripe male strobili from the trees and holding them in loosely covered paper boxes for a period of two days to a week until the pollen was released. Strobili were shaken over a 1 mm mesh screen to separate the large flower parts from the pollen. The pollen was separated from small flower pieces by placing the screenings on a slightly tilted piece of paper and gently flicking the underside of the paper with a finger. This process was repeated until all the visible flower parts had been separated from the pollen. Microscopic analysis indicated that essentially pure pollen samples could be collected by this technique.

The pollen samples were oven dried for 48 hr at 90EC. Approximately 0.2 g was subjected to mixed acid digestion (Allen et al. 1974), followed by the molybdic technique of Jackson (1958) for colorimetric analysis to determine the weight of phosphorus in pollen to weight of pollen ratio.

Approximately 50 mg of the sample analysed for phosphorus content was weighed and transferred to a drop of glycerol on a microscope slide. A coverslip was immediately applied and the number of pollen grains counted. This was repeated three times for each species of pollen grain analysed.

Sufficient quantities of *Betula alleghaniensis* Britt., *Betulat papyrifera* Marsh, *Populus tremuloides* Michx., *Pinus strobus* L. and *Pinus resinosa* Ait. pollen were collected to run the minimum three phosphorus analyses necessary to establish 95% confidence limits for phosphorus content. Sufficient *Populus balsamifera* L., *Quercus rubra* L., *Ostrya virgiana* (Mill.) K. Koch, *Tsuga canadensis, Picea glauca* (Moench) Voss and Betula glandulosa Michx. var. *glandulifera* (Regel) Gleason pollen was collected to allow for one phosphorus content analysis. Phosphorus content of pollen grains not available for analysis were established by correlating known pollen phosphorus values to pollen volume values estimated from averages of pollen diameters given by Kapp (1969), Richard (1970) and McAndrews et al. (1973) (see Table 2).

Pollen influx was estimated from pollen counts of samples collected from pairs of surface traps that had been placed on styrofoam floats on the lake. The surface traps were 0.5 litre, wide-mouth specimen jars with a 5 cm hole cut out of the plastic lids. Glycerol, containing a few drops of formalin, was added to the jars to capture the pollen (see Figure 1). Seston traps were placed adjacent to the surface traps to verify the results from the surface traps. For a sketch of a deep water sampling site see Figure 2.

Table 2.—Several Pollen Grain Parameters

				Phosphorus Content per Grain (in g P / grain x 10^{-10})			
				from chemical analysis		from relationship to pollen volume	
Pollen Type	V (µm3)	DW (µg)	95%CI (µg)	PC	95%CI	PC	95%
Tsuga canadensis	113,000	.054	.017	3.73	2.66	.71	
Pinus strobus	66,300	.024	.013	1.37	.88	1.84	.36
P. resinosa	48,800	.022	.004	.957	.33	1.54	.27
Picea glauca	136,000	.037	.031	3.06	.90		
P. mariana	82,900	.053	.015	2.78	2.13	.47	
Abies balsamea	371,000					7.15	2.9
Thuja occidentalis	13,800					.928	.32
Juniperus communis	10,300					.867	.34
Larix larcina	187,000					3.95	1.3
Betula lutea	12,000	.012	.004	1.42	.89	.896	.34
B. papyrifiera	10,500	.012	.005	1.07	.55	.870	.34
B. glandulosa	3,760	.011	.003	.34	.753	.38	
Ostrya virgiana	9,590	.0078	.002	.698	.854	.35	
Populus tremuloides	20,200	.0089	.011	.706	.94	1.04	.29
P. grandidentata	15,600	.0093	.0056	.959	.31		
P. balsamifera	18,100	.0103	.008	1.52		1.00	.33
Quercus rubra	9,140	.014	.006	1.83		.847	.35
Fagus grandifolia	47,100					1.51	.26
Acer rubrum	13,100					.916	.32
A. saccharum	12,800					.910	.33
Alnus rugosa	7,370					.816	.36
Ambrosia(spp.)	3,420					.74	.38
Artemisia(spp.)	8,830					.841	.35
Lycopodiales(spp.)	33,500					1.27	.25
Chenopodinaceae(spp.)	8,180					.830	.35
Gramineae(spp.)	65,400					1.83	.35
Vaccinium(spp.)	33,500					1.27	.25

V = voulme, DW = dried weight, 95%CI = 95% confidence interval and PC = phosphorus content. Confidence intervals for phosphorus content of the pollen grains determined from the relationship between pollen volume and phosphorus content assume that the volume measurements are accurate.

The traps were positioned on two transects roughly traversing the length and width of each lake. Pollen traps were placed on the lakes in May, before locally produced pollen was being released, and emptied four times: at the end of June, the beginning of August, and in the middle of September and November. The traps were removed from the lakes in the winter when it was assumed that a negligible amount of pollen would be released from the frozen, snow - covered watersheds. Traps were placed closer together near the lake shore because most studies on pollen dispersion indicate that pollen rain rapidly decreases as distance from the source increases (Wolfenbarger, 1959, Tauber 1965),

Similarities in size, morphological characteristics and estimated phosphorus content led to the grouping of the following pollen types for counting: *Pinus strobus* with *P. resinosa*; *Betula papyrifera* with *B. alleghaniensis* and *Ostrya virgiana*; *Populus grandidentata* with *P. tremuloides* and *P. balsamifera*; *Picea glauca* with *P. mariana*; *Thuja occidentalis* L.with *Juniperus communis* L.; all *Ambrosia* (spp.); all *Gramineae* (spp.); all periporates - most of which were *Chenopodonaceae* (spp.); all pollen with trilete scars - most of which were *Lycopodiales* (spp.); and all pollen of the general size and shape of *Artemisia* (spp.).

Hemlock pollen fallout at each trap site was calculated by dividing the estimated number of hemlock pollen in the trap by the open area of the trap mouth (0.00196 m^2) to give an estimation of the aerial pollen input per square metre. Pollen fallout was then regressed against the distance from shore (linear, log/normal, normal/log and log/log relationships were regressed) to establish the relationship between the two variables. The relationship giving the best correlation coefficient was then used in the "Planimetry and Integration Method" (Banks and Nighswander, 1982) to estimate the total amount of hemlock pollen falling onto the lake.

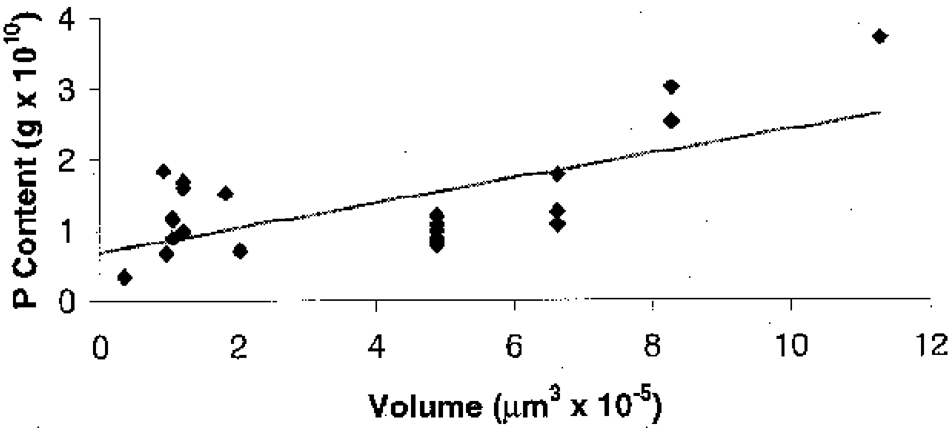

Figure 3.—Relationship between pollen grain volume and phosphorus content.

Phosphorus in hemlock pollen falling onto the lake can then be calculated by multiplying the amount of pollen falling on the lake by the phosphorus content of pollen. A similar method was used to find the total phosphorus in all pollen falling onto the lake.

Phosphorus loading with runoff for the three lakes was determined by monitoring the flow rates and phosphorus concentrations of the two Clear Lake inflows and then extrapolating the average phosphorus export value to the entire watershed. Estimates of atmospheric phosphorus inputs were made from the averages of several Ontario Ministry of the Environment 0.25 m^2 bulk precipitation collectors placed on nearby lakes and non-forested areas within a 25 km radius of Clear Lake. Jeffries et al. (1977) shows that accurate chemical precipitation values can be obtained in this manner. All phosphorus analyses of precipitation and stream samples were performed by the Water Quality Branch of the Ontario Ministry of the Environment. As in Dillon (1974) and Schindler *et al*. (1976), phosphorus inputs from groundwater and from resuspension from the sediments were assumed to be negligible.

Table 3.—Components of phosphorus loading (in kg). Values in parentheses give the percentage of the phosphorus loading due to each particular source

Phosphorus Source	Lake		
	Clear	Blackcat	Black Kitten
Loading with Runoff	12.4 (34.8)	3.49 (46.2)	0.31 (48.8)
Direct Deposition (excluding pollen)	20.0 (56.0)	3.33 (44.0)	0.21 (33.1)
Hemlock Pollen	0.55 (1.5)	0.31 (4.1)	0.054 (8.5)
Other Pollen Types	2.74 (7.7)	0.43 (5.7)	0.061 (9.6)

Results

Table 2 lists the pollen volumes estimated from parameters given in the literature, along with the experimentally determined values for phosphorus content of the several types of pollen grains analysed. The volumes of the pollen grains were regressed against their phosphorus content to generate the relationship given in Figure 3. This relationship was then used to estimate the phosphorus content of the pollen grains not available for phosphorus analysis.

Surface pollen traps caught an average of 3,480 pollen grains / cm^2 / yr. Values ranged from 1,180 to 7,600 grains / cm^2 / yr. Relationships between hemlock pollen deposition and distance from shore are given in Figure 4. Pollen-source phosphorus loading values are presented in Table III. The seston traps analysed for this study held from 1.1 to 6.5 (mean = 3.4) times as many sinking pollen grains per unit area as the surface traps.

Flow rate and phosphorus concentration determinations on the two Clear Lake inflows resulted in export estimates of 8.4 mg / m^2 / yr. and 8.6 mg / m^2 / yr. The mean of these two values was multiplied by the watershed areas to estimate the phosphorus entering the lake with runoff (see Table 3).

Analysis of phosphorus concentrations of samples from Ministry of the Environment bulk precipitation collectors gave an atmospheric phosphorus loading value of 26.3 mg / m^2 for the entire year and 11.2 mg / m^2 in the May-June sampling period. These values were used to determine the atmospheric phosphorus loading values given in Table III.

Percentages of phosphorus deposition attributable to hemlock pollen are listed in Table 3. Hemlock pollen was even more significant in relationship to the phosphorus budgets of the lakes when only the May/June collection

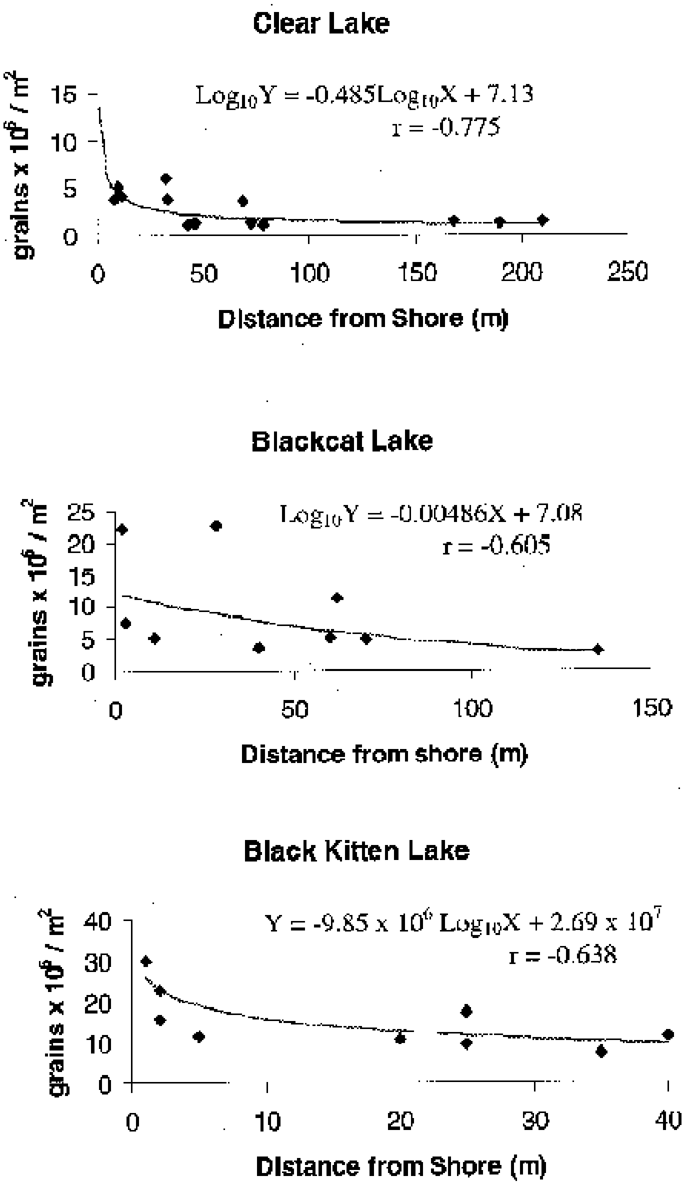

Figure 4.—Relationships between distance from shore and hemlock pollen deposition.

period was considered. At this time of the year, when the hemlock pollen was being released, it accounted for 5.1% of the aerial phosphorus loading and 3.8% of the total phosphorus loading for Clear Lake. Corresponding values increase to 17% and 11% for Blackcat Lake and 35% and 22% for Black Kitten Lake

Discussion

The experimentally determined values listed in the results show reasonable agreement with values from other studies. Experimentally determined phosphorus export values agree well with the 8.8 mg / m^2 / yr. determined by Schindler and Nighswander (1970) for the Clear Lake watershed. The mean phosphorus export value of 8.5 mg / m^2 / yr. is close to the maximum phosphorus export values reported in the literature for forested igneous watersheds (see Dillon and Kirchner 1975); but this could be explained by the small, steeply - sloped watersheds that characteristically exhibit high P export values (see Dugdale and Dugdale 1961 and Mackenthun *et al.* 1964). The atmospheric phosphorus loading value of 26.3 mg / m^2 / yr. is also close to values from areas of similar geology and land use (see Dillon and Kirchner 1975).

Phosphorus concentrations established for pollen grains in this study (per cent phosphorus of the dried weight of pollen) are higher than those reported in the literature for foliage by Son and Gower (1991) and Chapin et al. (1983). Phosphorus concentrations of 0.3% for *B. glandulosa* to 1.5% for *P. balsamifera* pollen (mean value of 0.82% for the eleven types of pollen grains tested in this study) agree reasonably well with values of 0.35% for *Beta vulgaris*, 0.53% for *Alnus* (spp.) (Altman and Dittmer 1964) and 0.4% for a combined sample of *Abies* and *Pinus* pollen (Richerson et al. 1970). Similarly, ranges in pollen influx values of 1,200 grains / cm^2 / yr. to 7,600 grains / cm^2 / yr. from this study are comparable to values from surface traps from other studies (see Davis *et al.* 1973).

Values determined in this study should only be regarded as approximate. There are still problems involving the efficiency of the pollen traps and phosphorus precipitation collectors. Although the pollen loading values expressed here are similar with values from other studies involving surface traps (eg. Ritchie and Liche - Federovich, 1967 and Tauber, 1967), they are roughly an order of magnitude lower than values estimated from sediment studies (see Davis et. al., 1972). Bonny (1978) has shown that Tauber (1974) pollen traps caught approximately half as much pollen as sediment traps under experimental conditions where resuspension of pollen from the sediments and influx from pollen from the watershed could be considered unimportant. Under similar controlled conditions, Reynolds (1979) shows that it is sediment traps that most accurately measure pollen sedimentation rates.

The seston traps analysed for this study held from 1.1 to 6.5 (mean = 3.4) times as many sinking pollen grains as the surface traps per unit area. Some of the pollen caught in the seston traps, however, would probably have been carried into the lake with runoff or resuspended from sediments. Both phosphorus loading values and pollen production values can vary from year to year and this study only represents one year's results.

Atmospheric phosphorus input into the lakes is also likely to be underestimated. The bulk precipitation collectors used by the Ontario Ministry of Natural Resources probably catch less dry atmospheric phosphorus fallout than the water surface for the same reasons that surface pollen traps are less efficient than the water surface at catching pollen. Gomolka (1975) and Jeffries et al. (1977) have shown that atmospheric phosphorus deposition values are higher at on-land station than stations situated on a lake. This suggests an increase in atmospheric phosphorus loading values approaching lakeshores, a factor not considered in this phosphorus loading model.

In spite of methodological limitations, this study does illustrate that hemlock pollen does contribute a significant component of the phosphorus loading of the Clear Lake. Futhermore, pollen-source phosphorus makes up an even a larger proportion of the phosphorus loading during the time of year when the pollen is being released. Finally, the relative importance of pollen-source phosphorus appears to increase as lake area decreases.

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