Measuring and Modeling Dispersal Distances of Anemophilous Pollen

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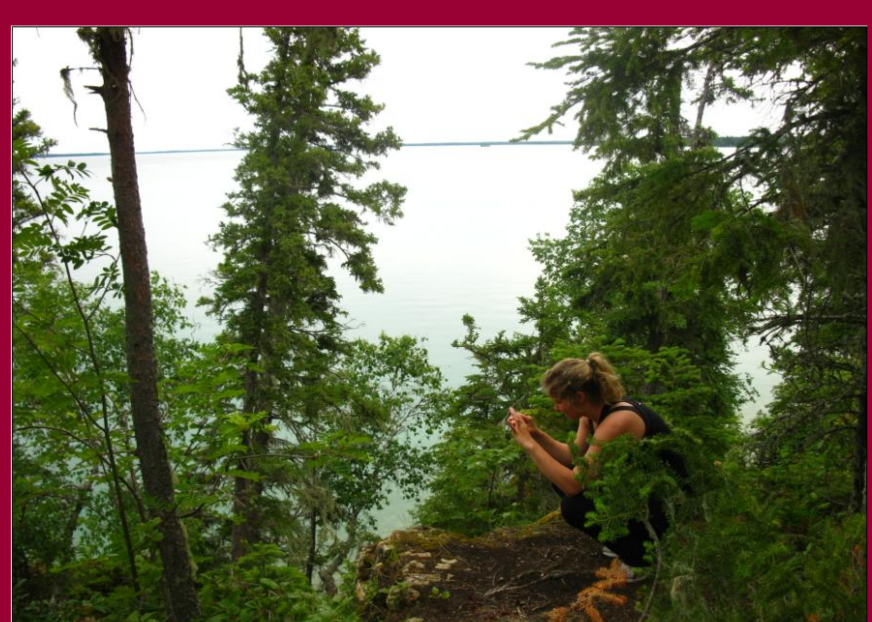
ABSTRACT

Our present understanding of pollen dispersal by wind (anemophily) is quite limited. Data sets of long distance dispersal are almost nonexistent, so previously developed models have remained untested for distances exceeding a few hundred meters. For this project, pollen concentrations were measured using rotorods on rafts anchored in two large lakes in Northern Manitoba during several weeks in the early summer of 2010. The pollen of black spruce, jack pine, balsam fir and alder can travel much further than previously expected. Generalizing across species, the pollen concentration at 2 km distance averaged 40.0% of the shore concentration. At 8 to 10 km we averaged 21.2 % of the shore concentration. These measured concentrations are significantly greater than expected from existent micrometeorological models of particle dispersal. These results have implications for required isolation distances with GMO crops and forest seed orchards.



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INTRODUCTION

Anemophily is the process by which wind is used as a vector to transport the male reproductive cells (pollen) to female cells (ovules). It is the primary means of sexual reproduction in all conifers, many hardwood species, almost all grasses and sedges.

The majority of the point source models are simply empirical fits such as the power law or negative exponential.[1] Mechanical models, including factors such as terminal velocity and wind speed, predict a peak in concentration being reached some distance away from the source, due mostly to release height effects[2]. Another conclusion of these latter models is that updrafts will play a crucial role in determining the magnitude of the far tail, as they carry pollen into zones of higher horizontal wind speeds[3]. However, the lack of both short and (especially) long-distance dispersal data has limited the ability to test the majority of existent dispersal models

Research Goals:

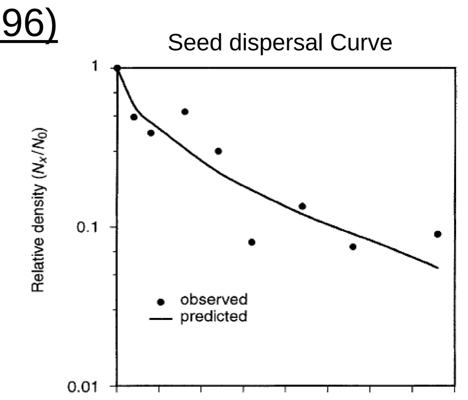
1. To develop useful data sets of pollen dispersal from 1 to 10 kilometres for a number of conifer species in the boreal forest of northwest Manitoba.

2. To test the accuracy of existing dispersal models with the acquired field data, to near and far field deposition points.

3. To develop a Lagrangian model of pollen dispersal.

MODELING

The Greene & Johnson dispersal model (1996)
Determines the concentration at each distance (x) from the edge of a forest. The lognormal dispersal curve of individual trees (point sources) are summed over all the trees in the area source. The source strength (BQ=pollen produced per m^2) deep in the forest will be reduced by one half at the forest edge. Release height, vertically averaged wind speed, turbulence in the vertical and horizontal axes, and terminal velocity of the particle are coupled into a dispersal parameter T which increases with x (distance from edge):



Greene & Johnson (1996)

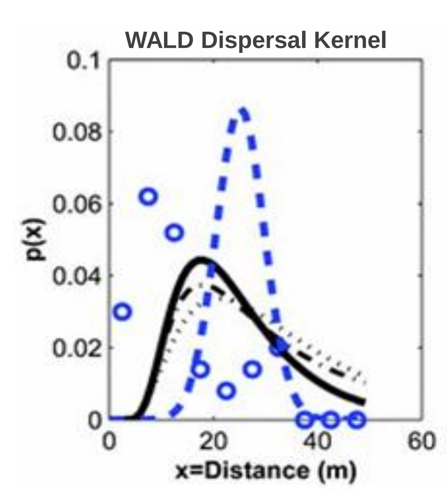
$$N_x = 0.5BQ\exp(-\tau T^{\Phi})$$

Greene & Johnson Dispersal Equation

The Katul WALD point source model (2005)
is a simplified three-dimensional stochastic dispersion model that includes the same parameters as Greene and Johsnon but makes more formal assumptions about the relationship between the horizontal speed and the turbulence structure.

$$p(x_1) = \frac{x_{3,r}}{\sigma\sqrt{2\pi x_1^3}}\exp\left[-\frac{(x_{3,r}-\gamma x_1)^2}{2\sigma^2 x_1}\right]$$

WALD Dispersal Kernel Equation (Katul, 2005)



Comparison between modeled (lines) and measured (circles) dispersal kernels for seeds. Vt = 1.5m/s , Zr = 30m, u=0.23m/s

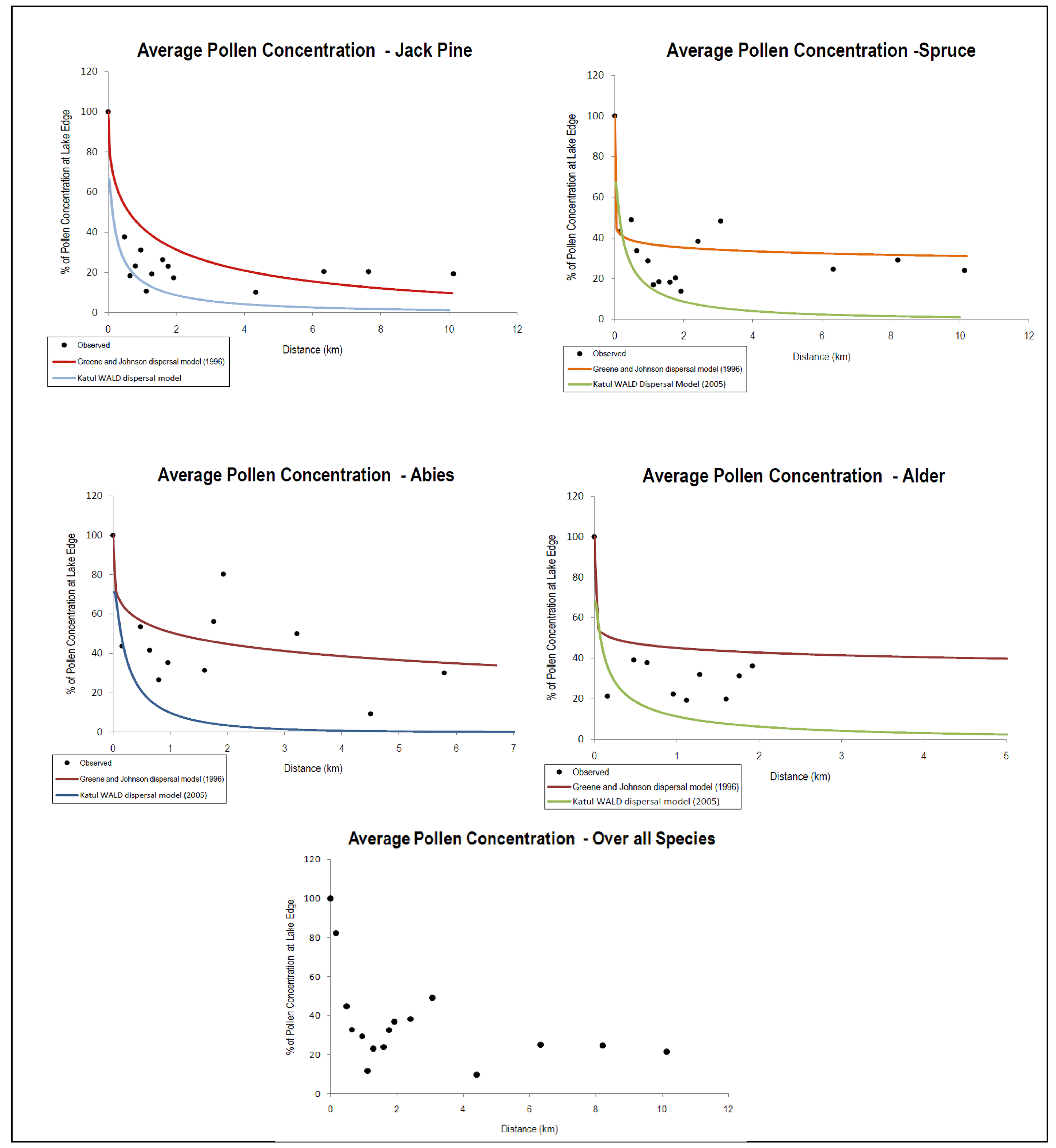
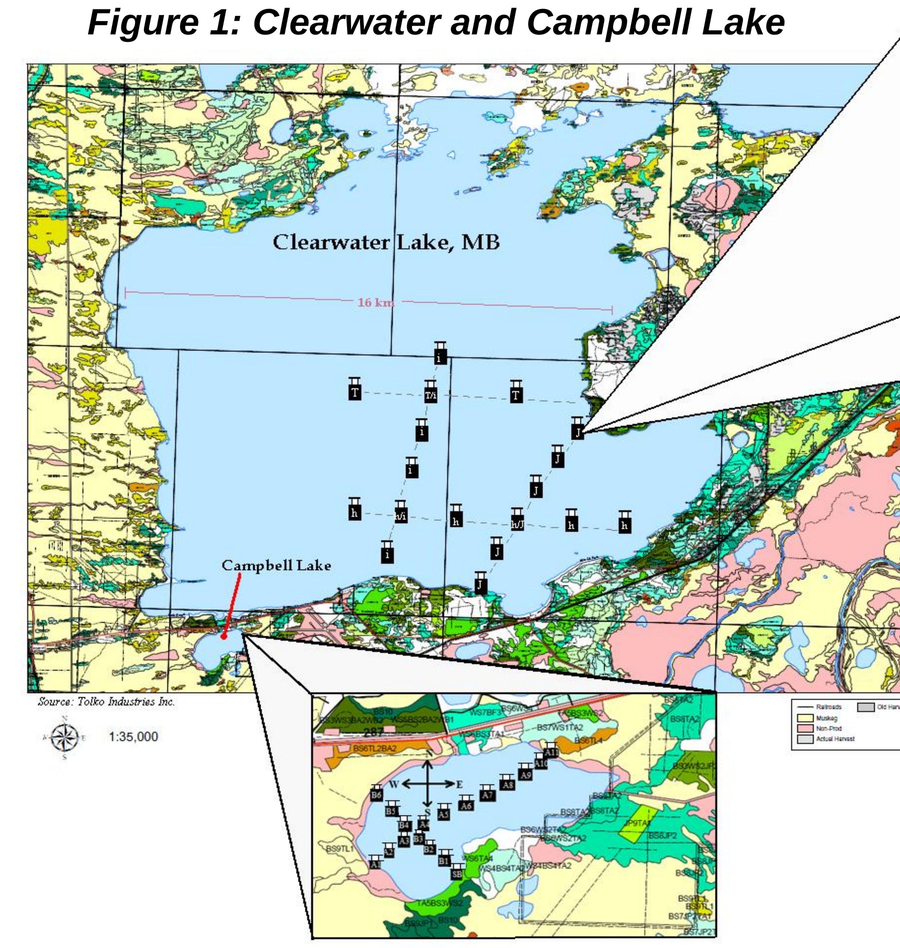


Figure 3: Measured & Modeled Pollen Concentrations for Each Study Species
The bottom graph shows the average over all trials and species - 40.0% of the shore pollen concentration remains at 2 km and 21.7% of the shore concentration remains at 10 km.

METHODS

- ❑ Ambient pollen concentrations were measured at a range of source distances across two lakes in Northern Manitoba: Clearwater and Campbell Lake. (Figure 1)
- ❑These lakes were chosen because they (1) contained no *islands* (and therefore we could be sure that all pollen must be arriving from the mainland forest) and (2) were relatively shallow. We focused on the four most common woody species (*Picea mariana*, *Pinus banksiana*, *Abies balsamea*, and *Alnus rugosa*
- ❑ Rotorod samplers were placed on rafts which were aligned along transects corresponding to the direction of the prevailing wind during the sampling period (Figure 2).
- ❑ Mean terminal velocity for each species was based on published data[2]. Pollen source strength (BQ) was assumed to be exactly twice as great as the mean amount (grains/m^2) found at the forest edge. The other parameters required for the testing of the two micrometeorological models were measured:
  - Pollen release height and forest height
  - Wind velocity and direction
  - Distance of each raft from the forest edge

Figure 1: Clearwater and Campbell Lake



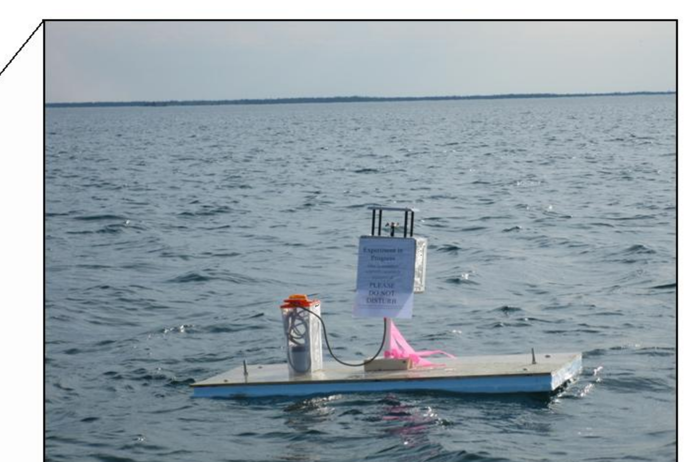


Figure 2: Rotorod In Action

RESULTS AND DISCUSSION

The Greene and Johnson model performed well at large distances (Figure 3). However, for all species there is a tendency for the Greene and Johnson model to over-predict at distances of about 0.5 to 2 km from the shore. By contrast, the WALD model under-predicted at all distances. While neither model explicitly considers the well-known tendency for a standing eddy near the edge to produce a downdraft, this cannot be the explanation for the over-prediction at that distance interval as that effect should be confined to a zone only a few tree heights out onto the lake.

This is the first study to empirically describe dispersal curves to such large distances. The most dramatic result is the virtual flattening of the curve at such great distances. This implies that our isolation distances for anemophilous GM crops or seed orchards are seriously inadequate.

Another result is to cast doubt on the WALD model as a useful expression of the dispersal of pollen or seeds at long distances. WALD has become, despite the lack of empirical confirmation, the model of choice for examining long distance dispersal issues such as plant migration in response to rapid climate change—but it is clearly underestimating the movement of pollen (or seeds).

The next step in the analysis of the Manitoba data is to re-examine the data using a Lagrangian (following the movement of an individual grain in small time steps) so that we can more realistically treat issues such as the standing eddy at the lea of a forest and the filtration (due to e.g. spider webs) that must occur as pollen moves through the forest toward the lake. In addition, this spring we will directly test point source models using Lycopodium in a large farm field.

RFERENCES/ACKNOWLEDGEMENTS

1. Okubo, A., & Levin, S. A. (1989). A theoretical framework for data analysis of wind dispersal of seeds and pollen. *Ecology, 70*(2), 329-338.
2. Jackson, S. T., & Lyford, M. E. (1999). Pollen dispersal models in quaternary plant ecology: Assumptions, parameters, and prescriptions. *Botanical Review, 65*(1), 39-75.
3. Katul,G.G., Porporato, A., Nathan, R., Siqueira, M., Soons, M.B., Poggi, D., Horn, H.S., Levin, S.A. (2005). Mechanistic Models for Long-Distance Seed Dispersal by Wind. *The American Naturalist*, 166(3), 368-381.
4. Greene, D. F., & Johnson, E. A. (1996). Wind dispersal of seeds from a forest into a clearing. *Ecology, 77*(2), pp. 595-609.

We would especially like to thank the NSERC Canadian Pollination Initiative, the University College of the North, and Nick Quenneville and Kristina Millett for their field assistance.