Structure and Function of Eighteen Living Snow Fences in New York State across an Eleven Year Chronosequence

Justin P. Heavey
SUNY College of Environmental Science and Forestry

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Structure and Function of Eighteen Living Snow Fences in New York State across an Eleven Year Chronosequence

Capstone Seminar
Justin P. Heavey
M.S. Candidate
Department of Forest and Natural Resource Management
Major Professor: Dr. Timothy Volk

State University of New York
College of Environmental Science and Forestry
Syracuse, NY
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Project Overview

Observational study of living snow fences of various ages, species, and locations

Literature Review

Methods

Results

Discussion

Conclusion
Literature Review
Background Information

Living Snow Fences

- Rows of trees, shrubs, or combinations of multiple species
- Planted along roadways to mitigate blowing snow problems
- Same purpose and function as structural snow fences (wooden or plastic)
- Disrupt wind and cause controlled snow deposition around the fence
- Formation of snow drifts in designated areas away from the road
Economic Benefits

Reduction of snow and ice control costs

- Over $2 billion annually nationwide\(^1\)
- Over $300 million annually in New York State\(^2\)
  - Frequent “spot-treatments” to control blowing snow problems, often in remote areas

LSF are potentially more cost effective...

- Than structural snow fences\(^3\)
- Other forms of passive snow control\(^4\) (berms)
- Mechanical & chemical controls\(^4\)

Economic performance of LSF depends on...

- Cost of installation and maintenance
- Survival of plants short and long term
- Time lag until fences become functional
- Level of snow control and other benefits
Public Benefits

Improved Highway Safety

- Road conditions and visibility
- 75% reduction in accident rates\(^5\)
- Average cost of car accidents\(^6\)
  - $3.5 million for each fatal accident
  - $100,000 for injury inducing crashes
  - Protecting human life and wellbeing

Value of Travel Time Savings (VTTS)

- Time is money
- Prevented road closures & reduced speeds
- Value of public and commercial travel\(^7\)
  - $15/hr car travel
  - $25/hr truck travel
Environmental Benefits

“Green” approach to snow and ice control
- Recognized as transportation best management practice\textsuperscript{1,8}
- Highest certification in the NYSDOT “GreenLITES” program\textsuperscript{9}
  - Ranks environmental sustainability of transportation projects

Potential for numerous auxiliary benefits\textsuperscript{10,11,12}
- Wildlife habitat
- Carbon sequestration and offsets
- Air and water quality
- Agroforestry products
- Aesthetic value
- Phytoremediation
- Crop improvements
- And other environmental benefits
How Snow Fences Work

- Snow is picked up by the wind and transported across an open area
- Wind and blowing snow encounters a snow fence
- Snow fence disrupts wind flow and causes turbulence around fence
- Turbulence deposits snow in drifts around the fence
How Snow Fences Work

Fence causes wind turbulence & eddies

Turbulence causes snow deposition
Structural Variables that Influence Snow Trapping

(Tabler 2000\textsuperscript{13}, 2003\textsuperscript{5})

Height
- Distance from the base of the fence vegetation to the top (m)

Optical Porosity
- Percentage of open area not occupied by vegetation (\%)

Setback Distance
- Distance from the edge of road to the fence (m)

Site Characteristics
- Snowfall over the drift accumulation season
- Percentage of snow transported by the wind
- Fetch distance (open area upwind of the fence contributing to snow transport)

Vegetation Type and Planting Pattern
Models of Snow Trapping Function

(Tabler 2000\textsuperscript{13}, 2003\textsuperscript{5})

**Snow Transport Quantity**
- Quantity of blowing snow at a site in an average year (t/m)
- t/m = metric tons of snow water equivalent per linear meter of fence

**Snow Storage Capacity**
- Quantity of snow that a fence can capture and hold in a drift (t/m)

**Capacity/Transport Ratio**
- Ratio of fence capacity to snow transport quantity
- Influences the shape and length of the snow drift

**Predicted Drift Length**
- Model of drift length that indicates the required setback distance
- Based on Height, Porosity, and the C/T Ratio
Drift Length and Setback Distance

Important topic in the analysis and design of living snow fences

- Living snow fence structure and function changes over time as plants grow
- The appropriate setback distance is based on the length of the downwind drift

Drift length depends on the stage of drift formation

- Maximum drift length is 35 times fence height, when fence is at full capacity
- Prior to 35H, drifts form in incremental stages as snow transport increases
- Drift stage and length depends on the fence capacity, relative to snow quantity
When fence capacity is less than or equal to snow transport…

- Fence fills to capacity and drift length is 35H

When fence capacity is greater than snow transport…

- Fence does not fill to capacity and drift length is less than 35H
- Setback distance can be reduced
Setback Distance in the Literature

Tabler (2003)

- Provides the most comprehensive treatment of setback for living snow fences
- Includes a drift model for LSF that accounts for the key variable of C/T ratio

Other literature on setback of living snow fences…

- Offers vague guidelines and conservative estimates of setback
- Some peer reviewed journals\(^{14,15}\) – mostly fact sheets, brochures, and bulletins from...
  - Transportation, Agriculture, Forestry, and Extension Agencies\(^{10,17,18,19,20,21}\)
  - Important sources of information for resource managers when designing LSF

Summary of Literature (Outside of Tabler, 2003)

- Setback recommendation anywhere from 30 m - 180 m or more
- No mention Tabler’s drift model or C/T ratio
- Complexities of setback for living snow fences have not been well understood, further researched, or incorporated into design standards
Research Objectives

1) Identify a subset of living snow fences for study

2) Collect data on key structural variables at each fence
   - Height
   - Optical porosity
   - Vegetation Type
   - Site characteristics

3) Model structural data to determine snow trapping function
   - Snow transport
   - Snow storage capacity
   - Capacity/transport ratio
   - Drift length and required setback

4) Interpret and discuss results in the context of current literature on living snow fences
Methods
Indentifying a subset of living snow fences for study

Sources of information

- List of statewide LSF provided by NYSDOT
- Willow Project data archive

Initial remote sensing of Snow Fence Sites

- ArcMAP GIS with NYSDOT mile markers layer
- Most recent aerial photos from Google Earth

Followed by site investigations

- Fall 2011 through Fall 2012

Stratified sample of state-wide fences based on...

- Ability to identify fence remotely and in the field
- Site accessibility and safety considerations
- Select a range of ages and vegetation types for study
- Age defined as years since installation
Sampling Plots and Measurements

- Sampling unit reported on = one living snow fence
- 100 m sampling plot established across linear center of each fence
- Remote measurements of setback and fetch distance
- Field measurements of fence height and porosity
Four (4) Fetch measurements

Four (4) Setback measurements

Snow Transport
Snow Transport

Eight (8) Height measurements
Optical Porosity Sampling

- Chroma-key backdrop (willow)
- High-contrast photos (conifers)
- Functionally equivalent result
- Photos analyzed in Adobe Photoshop
- Quantify open space vs. vegetation
Models of Snow Trapping Function

Tabler (2003)
- Synthesis of 40 year career in snow fence engineering

Tabler (2000)
- Climate variables specific to the function of snow fences in NY

Snow Transport
\[ Q = 1500(C_r)(S_{we})(1 - 0.14^{F/3000}) \]

Fence Capacity
\[ Q_c = (3 + 4P + 44P^2 - 60P^3)H^{2.2} \]

Capacity/Transport Ratio
\[ (Q_c/Q) \]

Drift Length
\[ L = \left\{ \frac{[10.5 + 6.6(Q/Q_c) + 17.2(Q/Q_c)^2]}{34.3}(12 + 49P + 7P^2 - 37P^3)} \right\}(H_{req}) \]
Results
Summary of Fences

- 18 fences identified and studied
- 10 counties & 6 NYSDOT regions
- Fence age ranged from 1 – 11 years

Four General Vegetation Types…
- Shrub-willow (10 fences)
- Conifer (6 fences)
- Honeysuckle (1 fence)
- Standing corn (1 fence)

- One, two, or three rows. Corn = 8
- Various plant and row spacings
Map of Fence Locations

New York State

Scale

0 20 40 60 80 100 Kilometers
0 20 40 60 80 100 Miles

Gabriels
conifer 8

Paris
willow 1

Manheim
honeysuckle 8

Columbia
conifer 3

Caledon
conifer 11

Grand Gorge
willow 7

Benton
willow 2

Spencerport
conifer 6

Tully B
willow 6

Tully A
willow 4

Sardina
corn 1

Hamburg
willow 3

Pomfret
conifer 5

Chautauqua
conifer 4

Preble C
willow 9

Preble B
willow 9

Preble A
willow 9
- Fence height ranged from ~1 – 7 m
- Height increased linearly over time (P < 0.001)
- Shrub-willow increased at slightly faster rate than all fences
- Porosity was between ~90% and 25%  
  corn was 0% (non-porous)
- Porosity decreased linearly time (P = 0.005)
- Shrub-willow decreased at a faster rate than all fences
Snow Transport Model

- Snow transport ranged from 4 – 19 t/m
- Mean snow transport was 9 t/m
- Severity of blowing snow conditions
  - Classified as “Very light” to “Light” across all sites

Snow Severity Classifications

<table>
<thead>
<tr>
<th>Class</th>
<th>Snow Transport (t/m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;10</td>
<td>Very light</td>
</tr>
<tr>
<td>2</td>
<td>10 – 20</td>
<td>Light</td>
</tr>
<tr>
<td>3</td>
<td>20 – 40</td>
<td>Light-to-moderate</td>
</tr>
<tr>
<td>4</td>
<td>40 – 80</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>80 – 160</td>
<td>Moderately severe</td>
</tr>
<tr>
<td>6</td>
<td>160 – 320</td>
<td>Severe</td>
</tr>
<tr>
<td>7</td>
<td>&gt;320</td>
<td>Extreme</td>
</tr>
</tbody>
</table>
- Snow storage capacity ranged from 0 - 430 t/m, mean 185 t/m
- Capacity increased linearly over time (P < 0.001)
- Shrub-willow again increased at a slightly faster rate than all fences
- Mean C/T ratio amongst all fences was 27:1
- All fences were fully functional (capacity > transport) by age 3
- C/T ratio between ~10:1 and 100:1 for all fences age 5 and older
Observed Setback Distance

- Observed setback distance ranged from ~ 10 – 100 m  mean 35 ±25 m
  - High maximum, large range, and large standard deviation in setback distances

- No significant relationship between setback and C/T ratio, nor any other predictor variables that would influence the choice of setback (P > 0.417)

- Likely influenced by site limitations, but also reflects literature which provides no standard or precise guidelines for selecting setback distance for LSF

Blue spruce setback 60 m

Blue spruce setback 30 m
Drift Model

- Significant negative relationship (P = 0.006) between C/T ratio and drift length
- Best fit to an asymptomatic curve (S = 4.037)
- Drift length rapidly decreases from 35 m - 8 m, when C/T ratio is between 0 and 15:1
- When C/T ratio exceeds 15:1, drift length is consistently less than 10 m
Discussion
Results of this study showed *fully functional* snow fences by age three (3) (capacity was greater than the average annual transport)

Literature states 5 - 20 years or longer for full functionality of LSF$^{16,24}$

Some studies indicate shrub-willows can be functional earlier$^{22,23}$ but…

Factors contributing to the observed early functionality in current study…

- Light transport conditions across all sites
- **Shrub-willows**: fast growth rate and porosity exclusion
- **Conifers**: use of large planting stock (not seedlings), multiple rows, high planting densities
Implications of early functionality

- Less lag time for benefits, better life cycle economic performance
- Dependent on the use of best management practices for LSF\textsuperscript{4,10,25}
  - Site preparation, plant selection, planting techniques, and weed control

Three year old Norway spruce living snow fence fully functional
Capacity/Transport Ratio

Results showed large amounts of excess capacity at early ages
- C/T ratio between 10:1 and 100:1 for all fences age 5 and older
- Fences to add even more capacity in future years based on the observed linear growth trends, further increasing C/T ratios

Implication
- High C/T ratios will reduce drift lengths from the maximum of 35H, and reduce the required setback distance
Drift Model Results

- Showed the expected negative response of drift length to C/T ratio
- As C/T ratio increases, drift length decreases
- Drift length is less than 10 m when C/T ratio is >15:1
- Predicted drift length was also less than the observed setback distance for 16 of the 18 fences in this study
Drift Length and Setback

Implications of shorter drift lengths
- For the conditions and fences investigated, setback distance can be much less than the 30 - 180 m or 35H commonly prescribed in the literature

Reduced setback distances have the potential to...
- Reduce the cost of living snow fences
- Eliminate “near snow” problems
- Allow LSF installations where ROW space is limited

If validated in future research, this finding...
- Provides a clear methodology for calculating the most appropriate setback distance for living snow fences
- Clarifies the hodgepodge of vague recommendations found in the current literature
Snow Fences by Vegetation Type

Standing Corn Fences
- Limited height growth limits functionality
- Snow load & herbaceous form also reduce height
- Annual recurring costs to purchase corn
- Likely less economically efficient than other vegetation types

Honeysuckle Fences
- Lacks some of the key plant traits for LSF
- Capacity was lower than the trend of all fences
- Bottom gap was observed in single row fence
- Likely less economically efficient than other vegetation types
**Shrub-willow Fences**

**Benefits**
- Fastest height growth and capacity increase
- Likely more cost effective than structural fences and other vegetation types\(^{24,26}\)

**Drawbacks**
- High intensity maintenance for several years
- Long term survival may be limited by…
  - Susceptibility to pests and diseases
  - Other traits associated with pioneer species
    - Coppice potential may be a means of regeneration that can extend the life cycle of fences
Conifer Fences

Benefits

- More widely researched and demonstrated as living fences (shelterbelts)
- More climax species traits with longer natural lifecycles
- Rapid functionality by installing large trees and multiple rows (landscape effect)

Drawbacks

- Higher costs associated with large planting stock
- Long term space requirements of large trees may limit feasibility
- Large stem diameters are not allowed in close proximity to some roadways
Failed Snow Fences

- Fences in this study were limited to a maximum age of 11 due to a lack of older fences identified in the landscape.

- Fences may have been...
  - Planted less frequently in previous years
  - Intentionally or accidentally removed over time
  - Grown together with natural vegetation
  - Poor growth and survival rates due to
    - Site conditions and/or management practices

- Some younger fences (or sections) also failed to thrive.

- At least 18 healthy living snow fences in NYS, but an equal or greater number that have struggled or failed.

- Biological systems in nature prone to natural and human disturbances and competition.

- Success is never guaranteed…but best management practices improve the chances.
Limitations and Future Research

Limitations of This Study

- Bias for fences that had best management practices and highest success
- Assumptions of snow transport quantity (relocation coefficient and fetch size)

Future Research

- Continued research and development of BMPs for living snow fences
- Repeat the methods of this study using…
  - More fences, more species, and fences older than age 11
  - Collect snow data to verify predicted values and drift lengths

Small snow drifts formed around honeysuckle living snow fence
Conclusion
Conclusion

- Identified and investigated 18 living snow fences in the landscape across New York State
- Collected data on key structural variables at each fence
- Modeled structural data to estimate snow trapping function
- Discussed results in the context of current literature on LSF
Conclusion

- Fence capacity (via height and porosity) increased faster than previously reported.

- Fences were fully functional by age three, much younger than generally reported.

- Large C/T ratios create shorter drifts lengths.

- Fences can likely be installed much closer to the roadway than the setback distances observed in the field, and what is commonly recommended in the literature.
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Willow Project at SUNY ESF: 4, 7b

New York State Department of Transportation 6b, 7a

Tabler (2003): 6a, 10, 11, 31, 40, 41, 42

Google Earth:15, 34a, 34b,
Questions