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

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

Capstone Seminar

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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 nationwide¹
- Over \$300 million annually in New York State²
 - Frequent “spot-treatments” to control blowing snow problems, often in remote areas

LSF are potentially more cost effective..

- Than structural snow fences³
- Other forms of passive snow control ⁴ (berms)
- Mechanical & chemical controls⁴

Economic performance of LSF depends on...

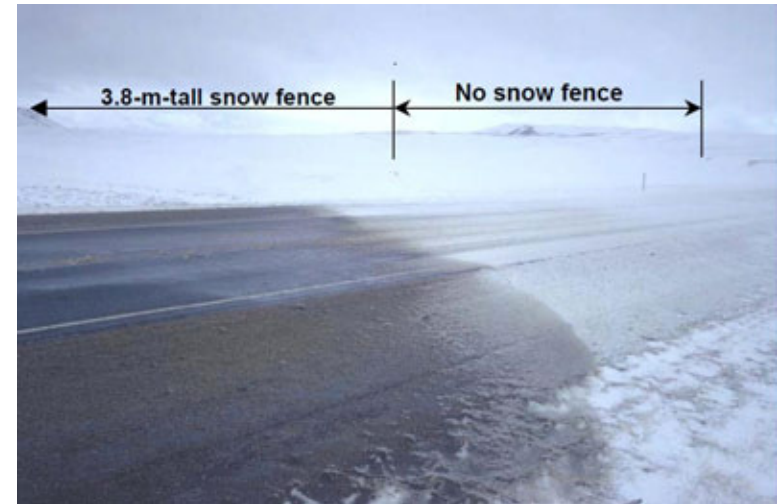
- Cost of installation and maintenance
- Survival of plants short and long term
- Time lag until fences become functional
- Level of snow control and other benefits



Public Benefits

Improved Highway Safety

- Road conditions and visibility
- 75% reduction in accident rates⁵
- Average cost of car accidents⁶
 - \$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 travel⁷
 - \$15/hr car travel
 - \$25/hr truck travel



Environmental Benefits

“Green” approach to snow and ice control

- Recognized as transportation best management practice^{1,8}
- Highest certification in the NYSDOT “GreenLITES” program⁹
 - Ranks environmental sustainability of transportation projects

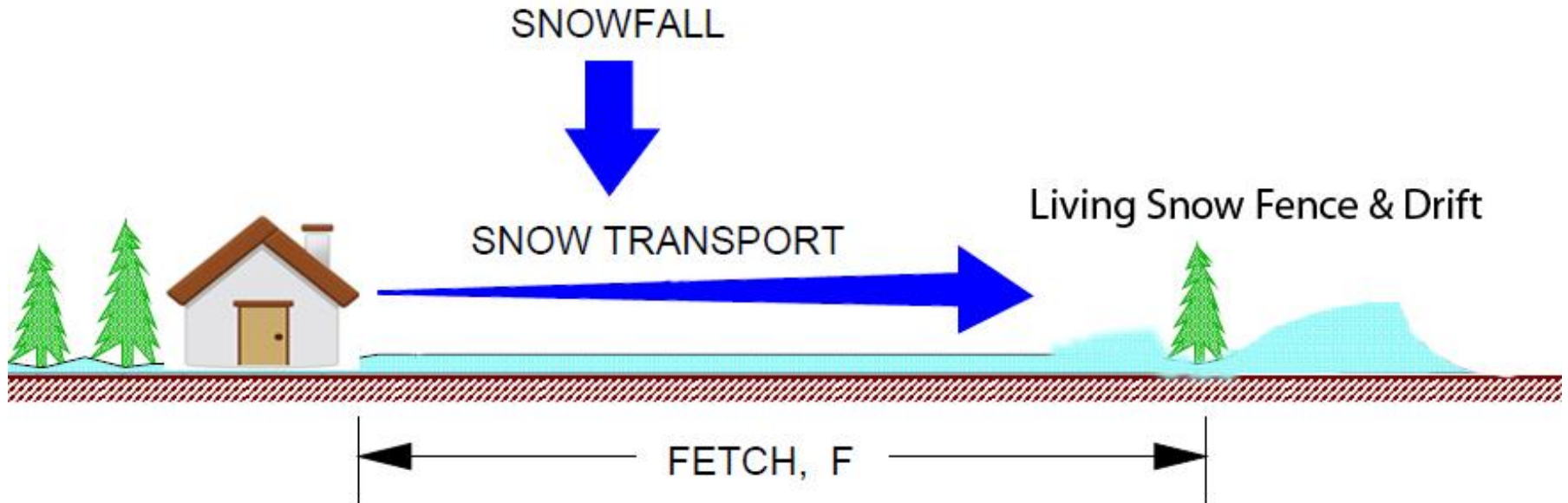


Potential for numerous auxiliary benefits^{10,11,12}

- Wildlife habitat
- Carbon sequestration and offsets
- Air and water quality
- Agroforestry products
- Aesthetic value
- Phytoremediation
- Crop improvements
- And other environmental benefits



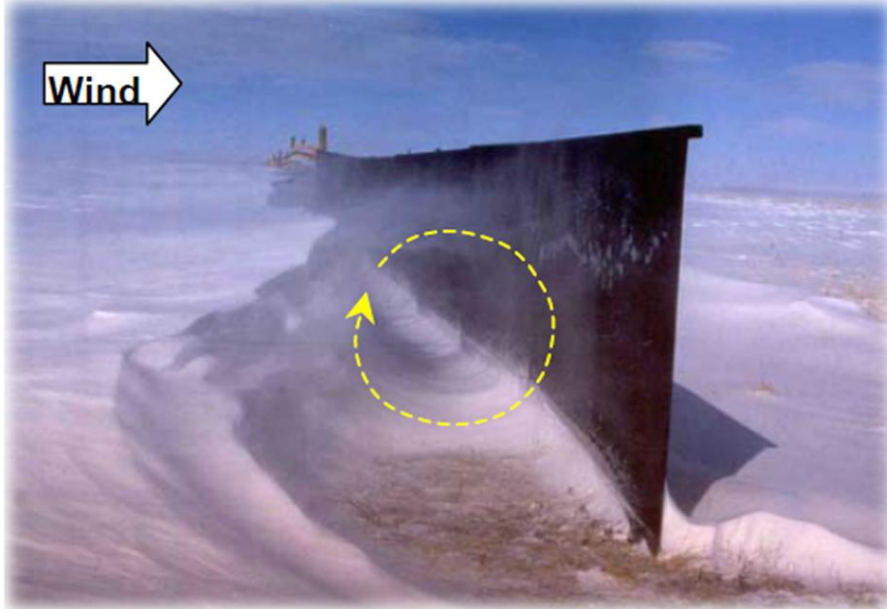
How Snow Fences Work



- 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 2000¹³, 2003⁵)

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 2000¹³, 2003⁵)

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

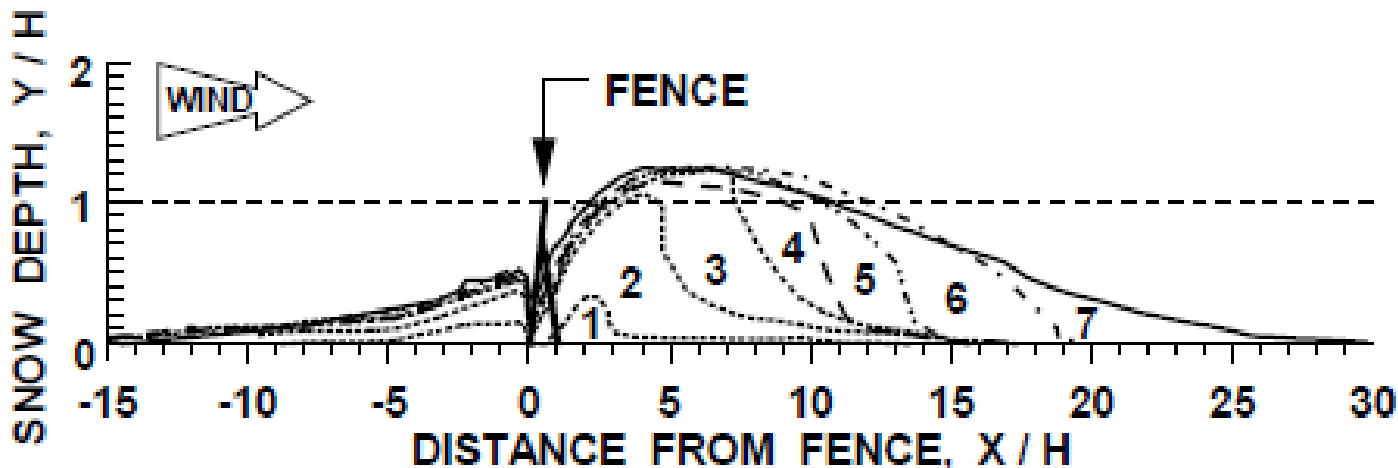
Drift Length and Setback Distance

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

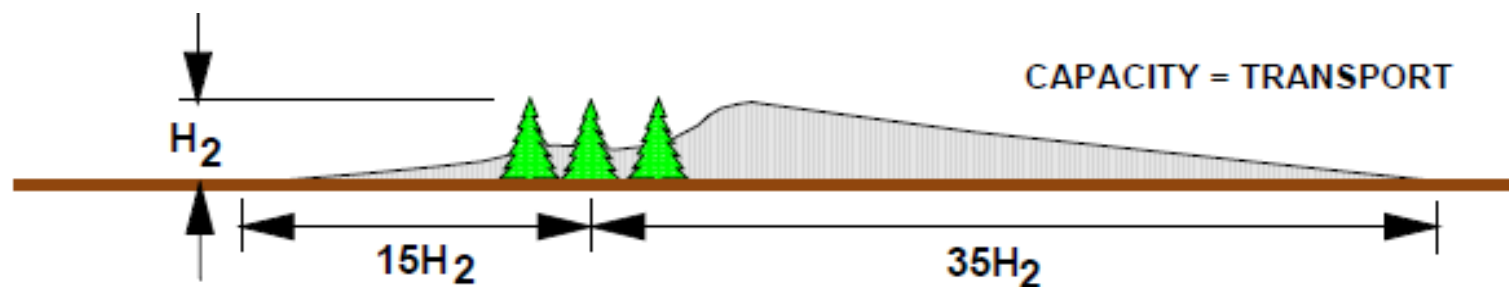
- Maximum drift length is 35 times fence height, when fence is at full capacity
- Prior to $35H$, drifts form in incremental stages as snow transport increases
- Drift stage and length depends on the fence capacity, relative to snow quantity



Drift Length and Setback Distance

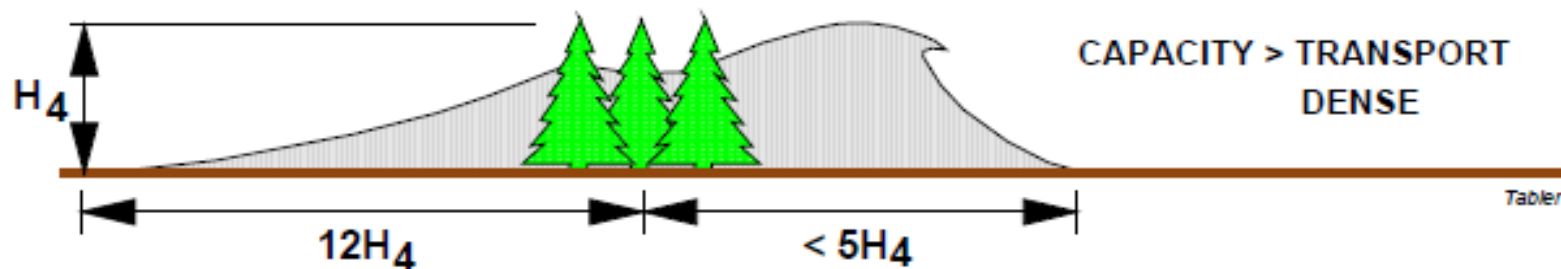
When fence capacity is less than or equal to snow transport...

- 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



Identifying a subset of living snow fences for study

Sources of information

- List of statewide LSF provided by NYSDOT²²
- 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

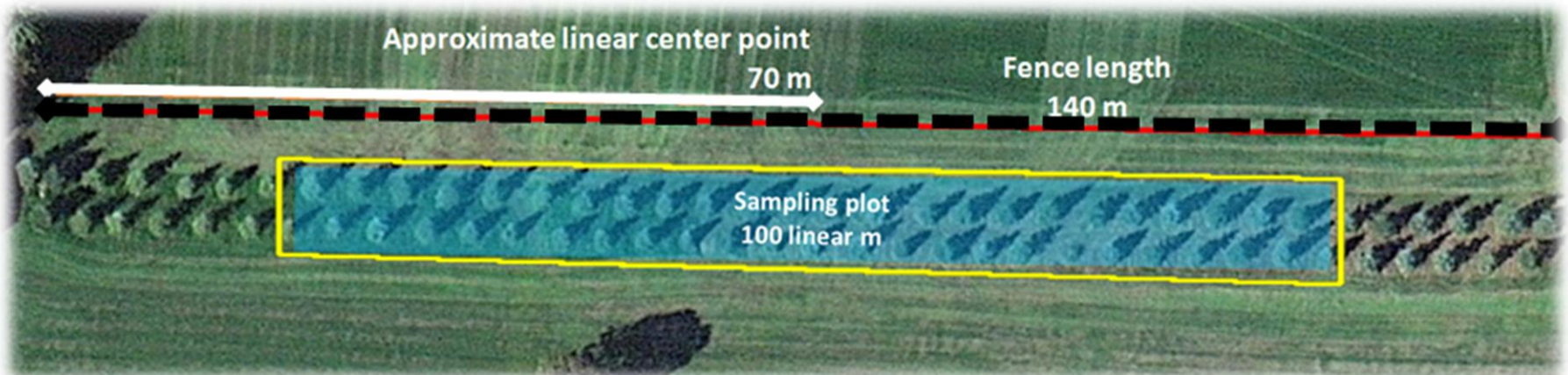
Stratified sample of state-wide fences based on...

- 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



(Not To Scale)



Wind & Snow Transport



Fetch Area

Snow Fence



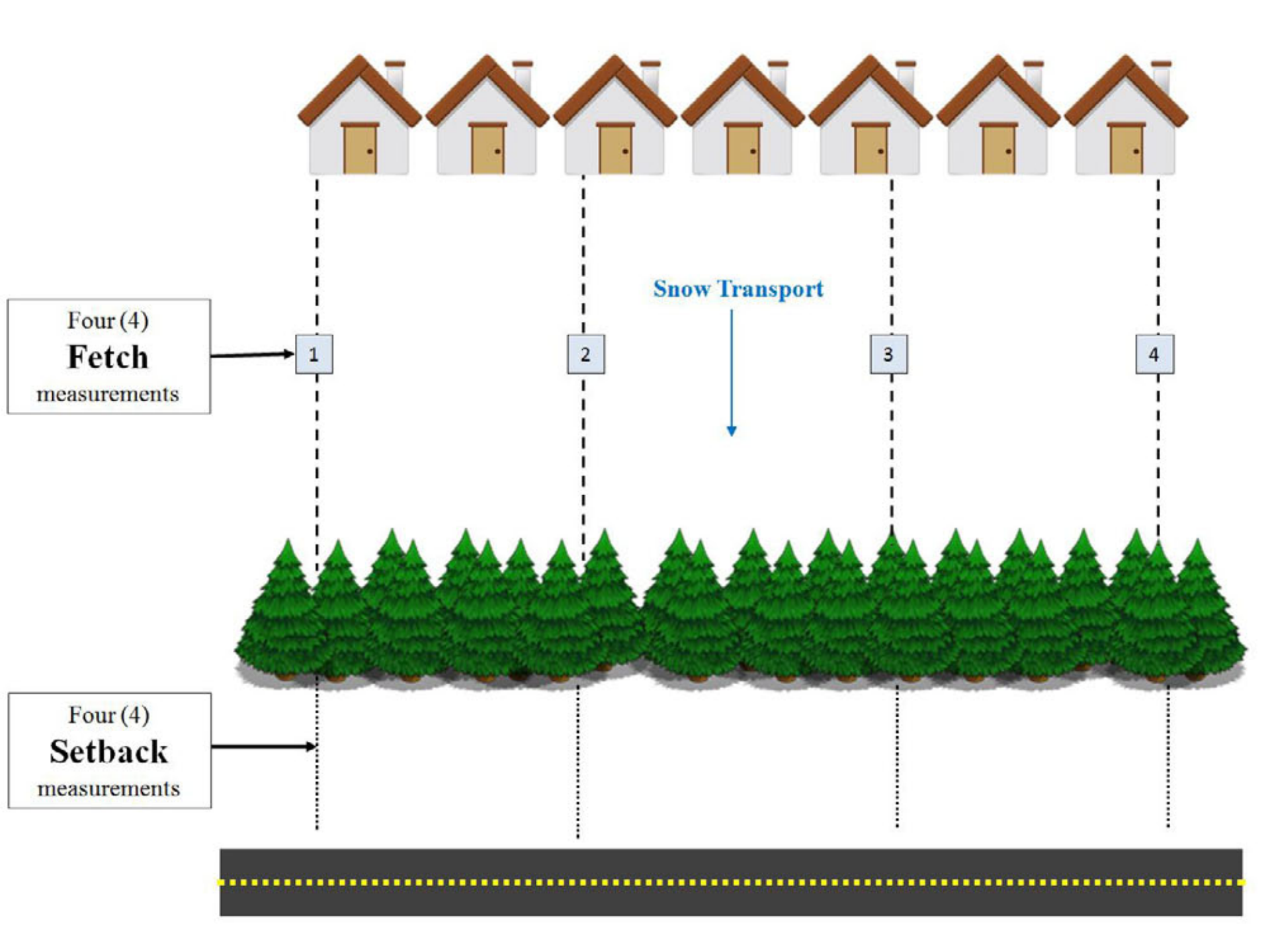
100 m sampling plot

Min. 7.5 m
buffer

Setback

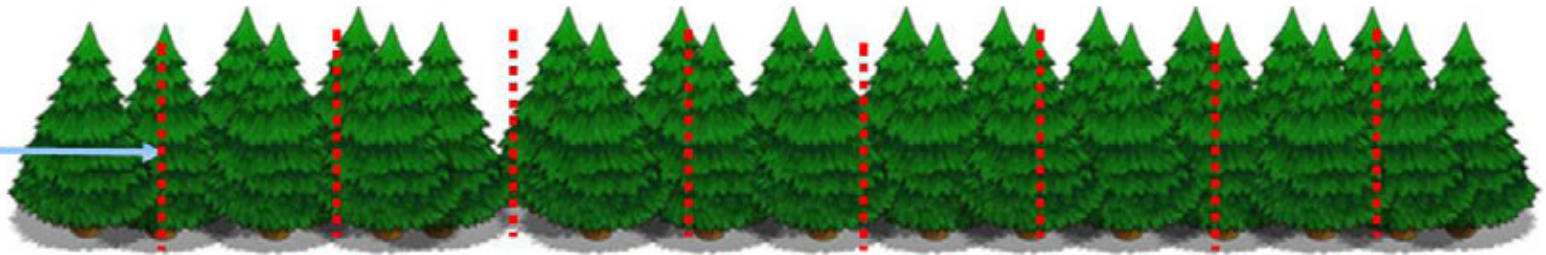
Protected
Roadway







Snow Transport

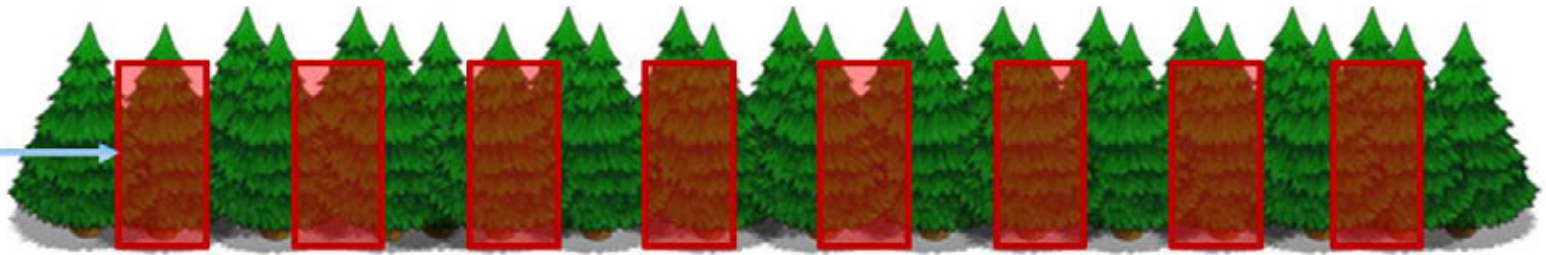


Eight (8)
Height
measurements





Snow Transport

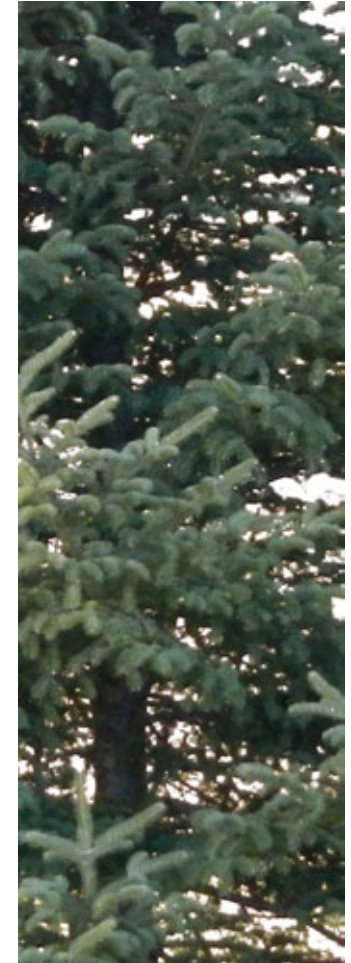


Eight (8)
Porosity
measurements



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

$$L = \{[10.5 + 6.6(Q/Q_c) + 17.2(Q/Q_c)^2]/34.3\}(12 + 49P + 7P^2 - 37P^3)(H_{req})$$

Results



Summary of Fences

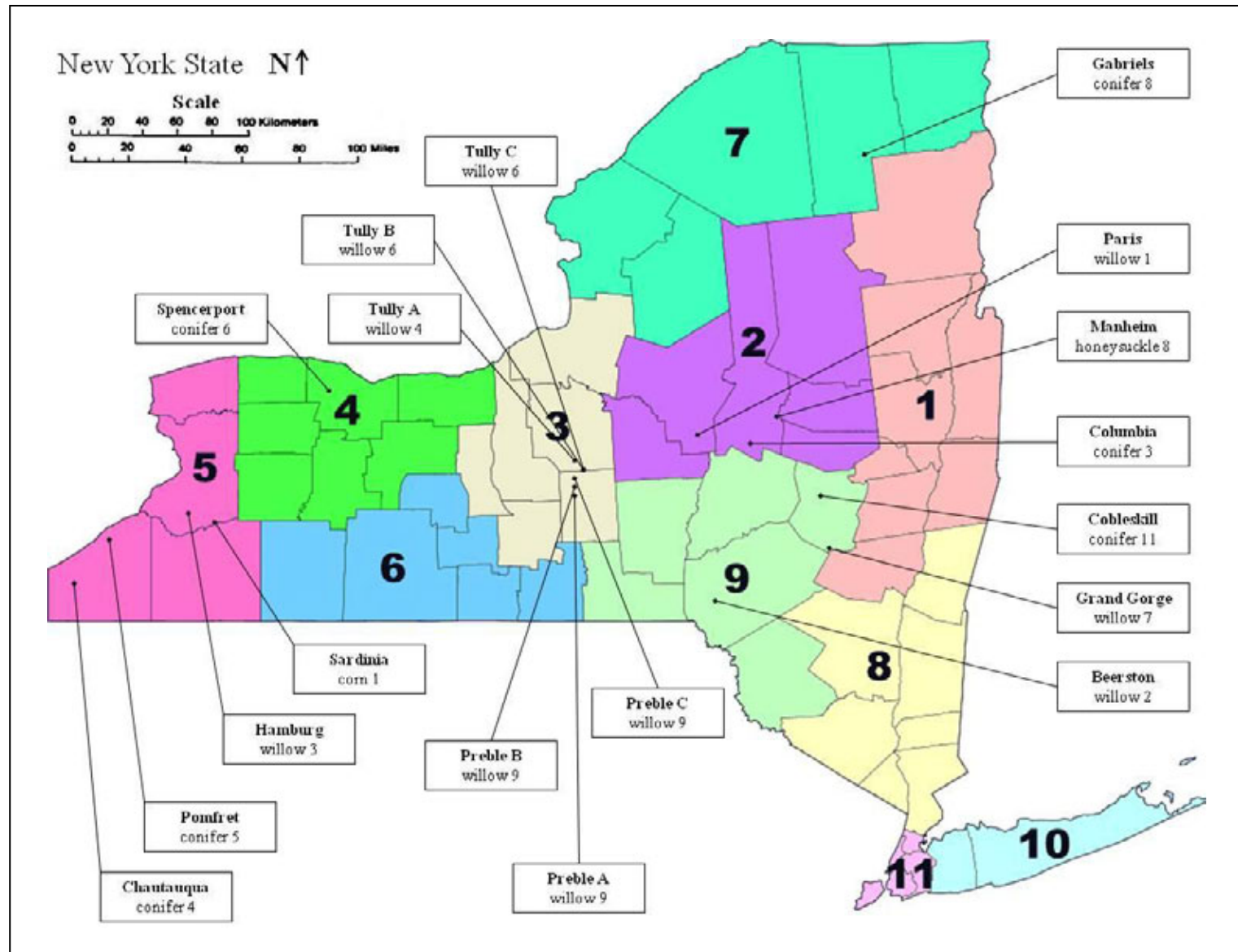
- 18 fences identified and studied
- 10 counties & 6 NYSDOT regions
- Fence age ranged from 1 – 11 years

Four General Vegetation Types...

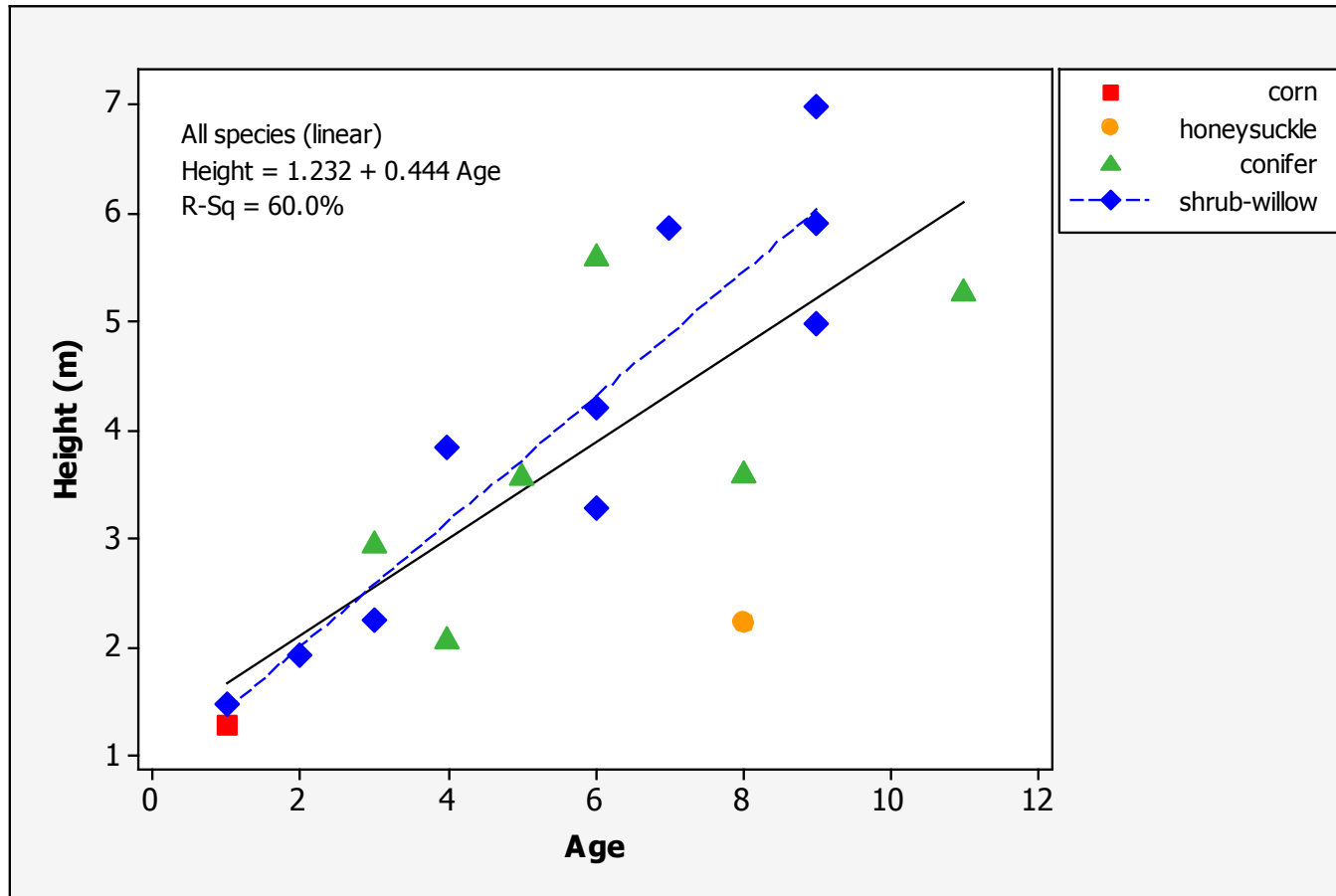
- **Shrub-willow** (10 fences)
 - **Conifer** (6 fences)
 - **Honeysuckle** (1 fence)
 - **Standing corn** (1 fence)
-
- One, two, or three rows. Corn = 8
 - Various plant and row spacings



Map of Fence Locations

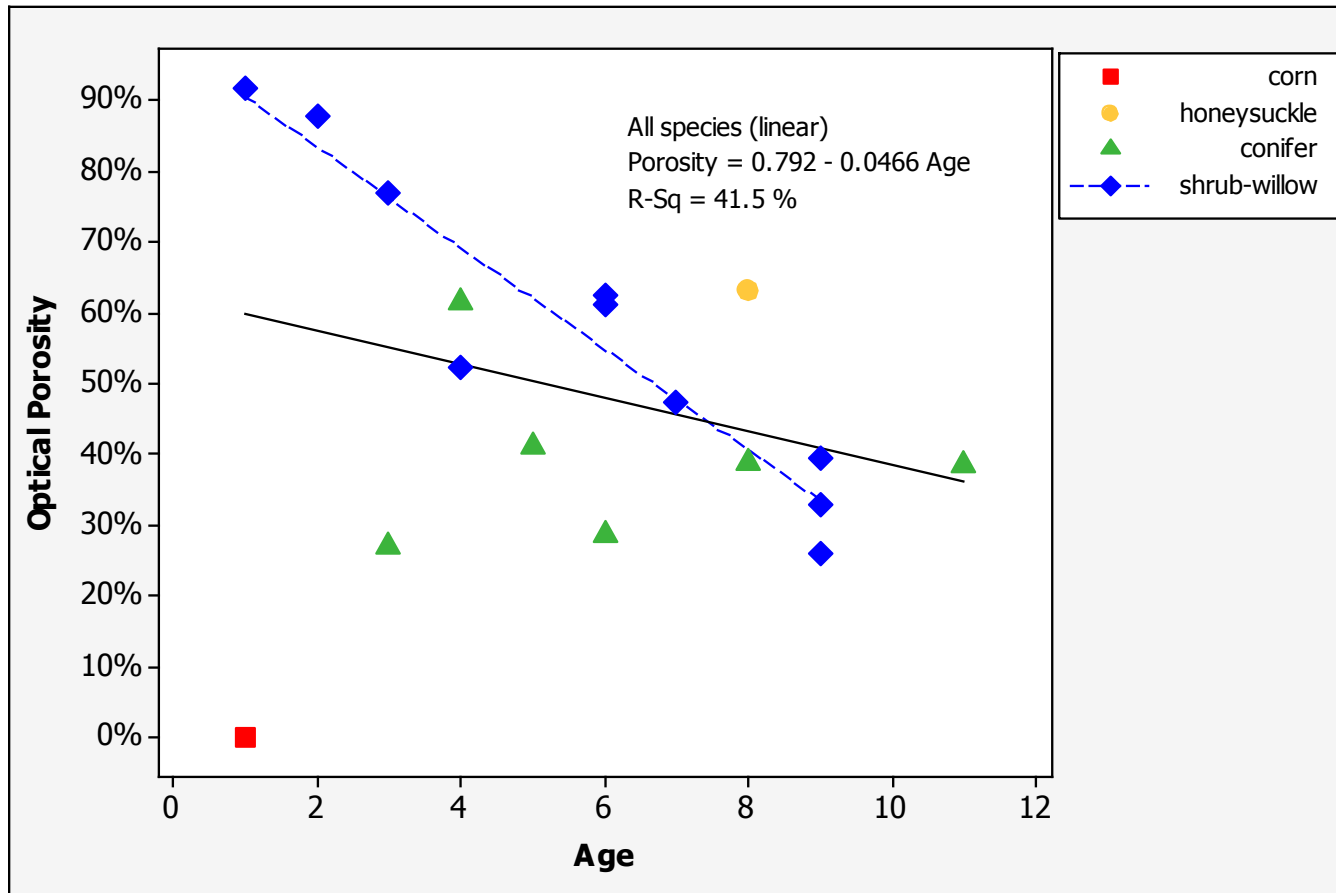


Age versus Height



- Fence height ranged from $\sim 1 - 7$ m
- Height increased linearly over time ($P < 0.001$)
- Shrub-willow increased at slightly faster rate than all fences

Age versus Porosity



- 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

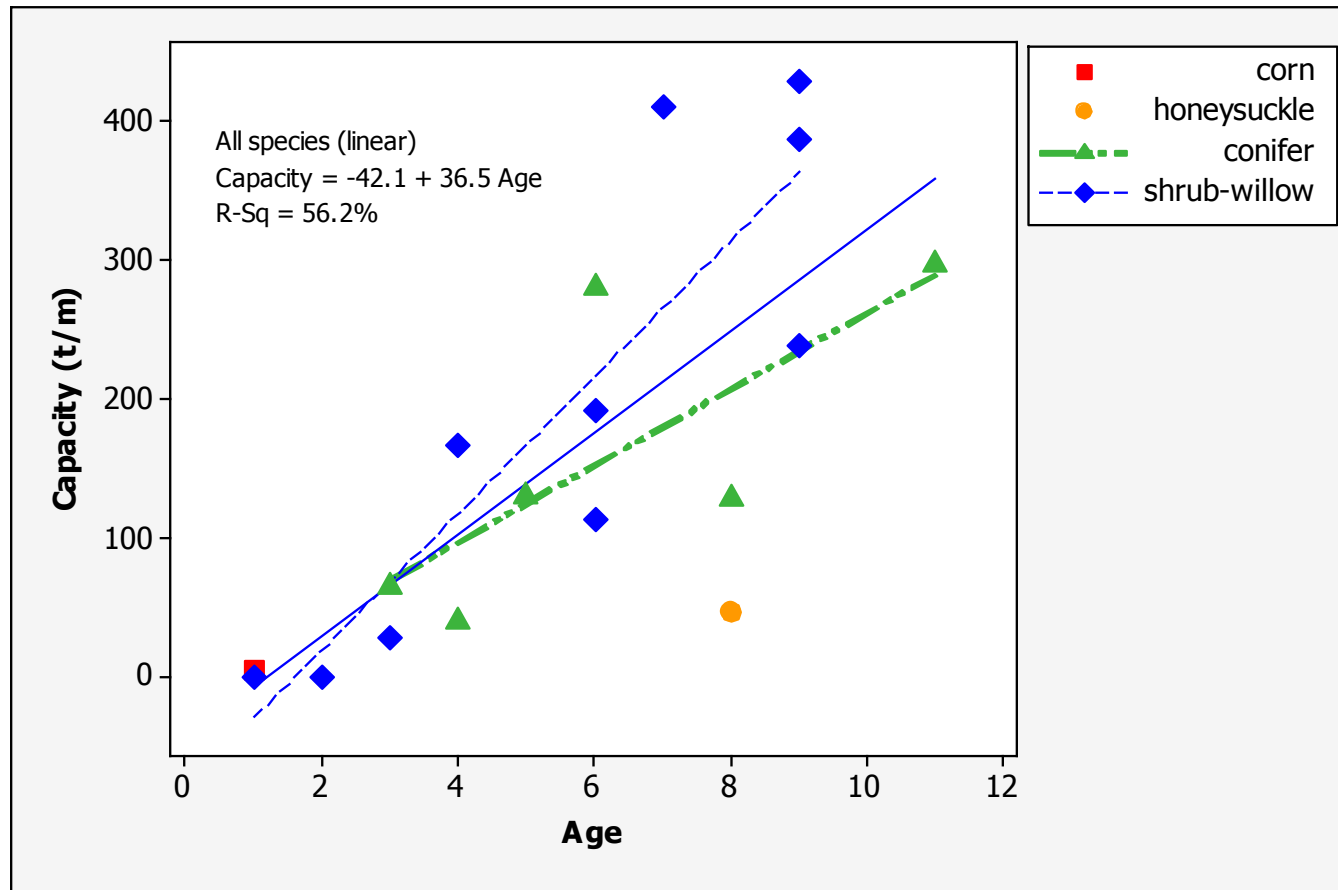
Snow Transport Model

- Snow transport ranged from 4 – 19 t/m
- Mean snow transport was 9 t/m
- Severity of blowing snow conditions⁴
 - Classified as “Very light” to “Light” across all sites

Snow Severity Classifications⁴

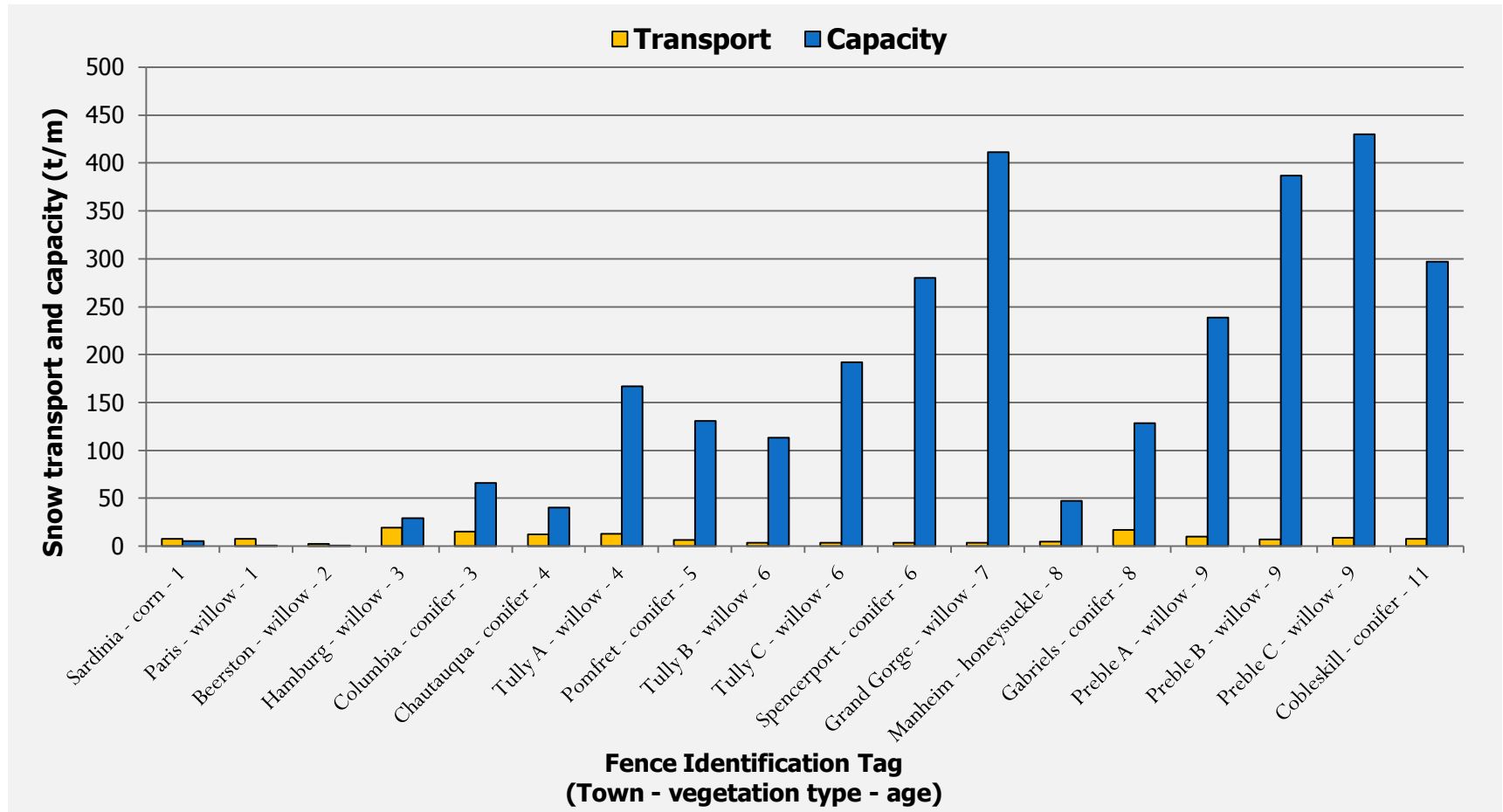
Class	Snow Transport (t/m)	Description
1	<10	Very light
2	10 – 20	Light
3	20 – 40	Light-to-moderate
4	40 – 80	Moderate
5	80 – 160	Moderately severe
6	160 – 320	Severe
7	>320	Extreme

Age versus Capacity



- 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

Capacity/Transport Ratio



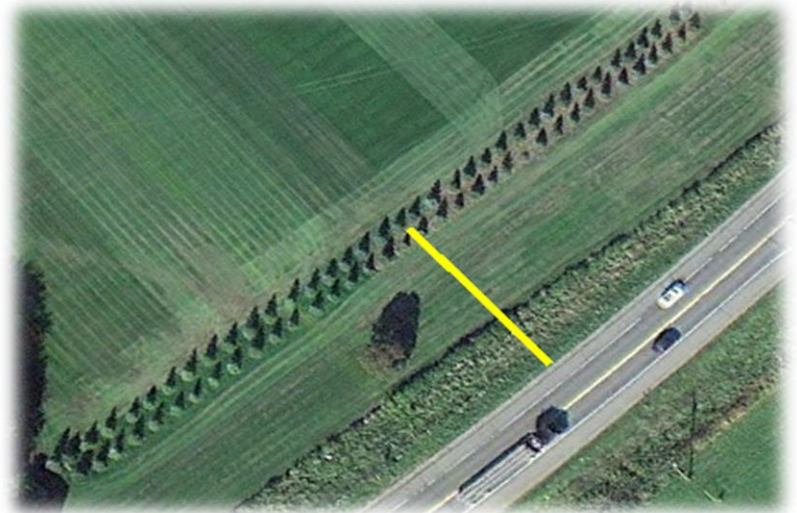
- Mean C/T ratio amongst all fences was 27:1
- All fences were fully functional (capacity > transport) by age 3
- C/T ratio between ~10:1 and 100:1 for all fences age 5 and older

Observed Setback Distance

- Observed setback distance ranged from $\sim 10 - 100$ 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

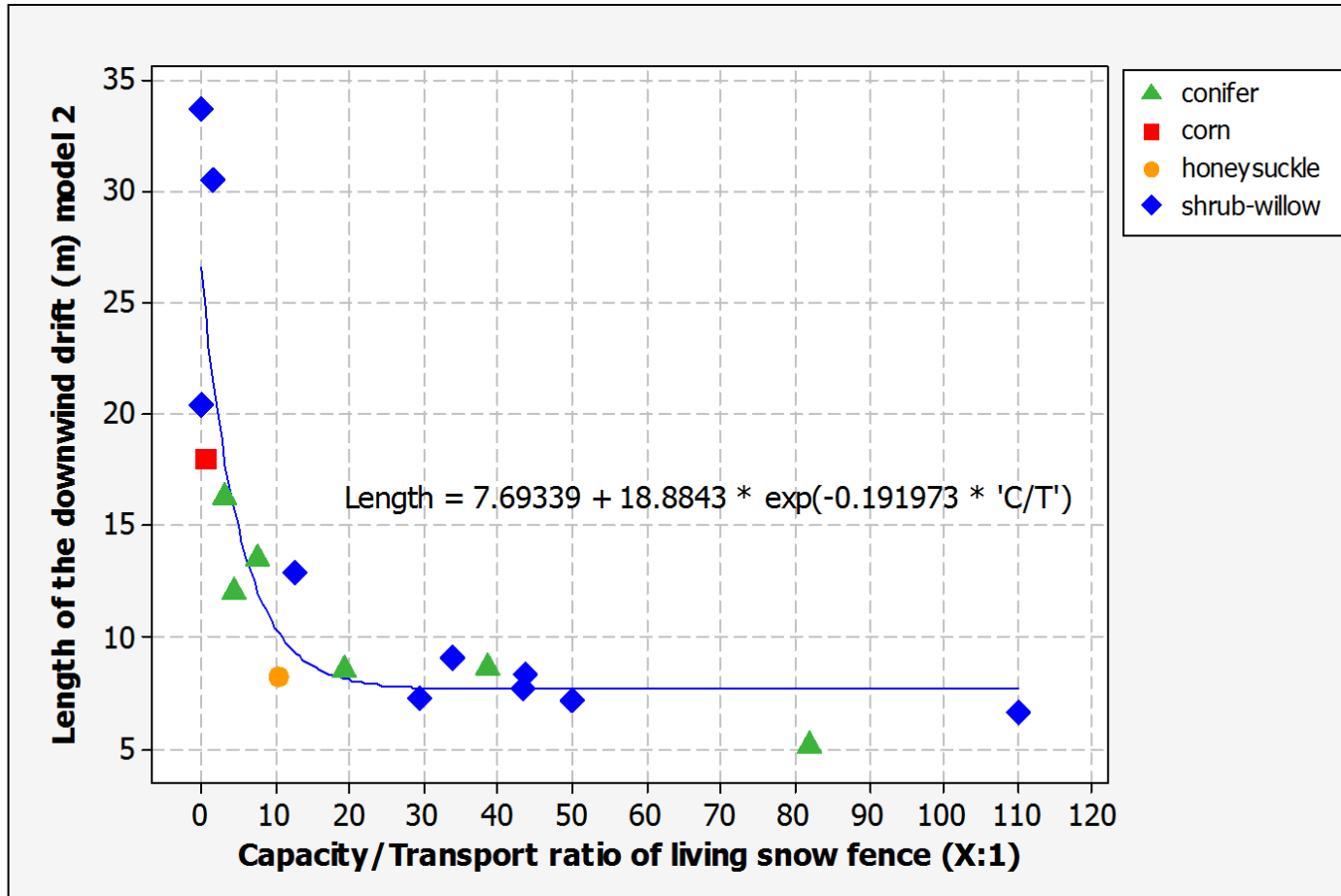


Blue spruce setback 60 m



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



Full Functionality at Early Ages

- 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...
 - Based on growth rates in biomass plantings, not quantified in context of LSF
- 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

Full Functionality at Early Ages

Implications of early functionality

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



Three year old Norway spruce living snow fence fully functional

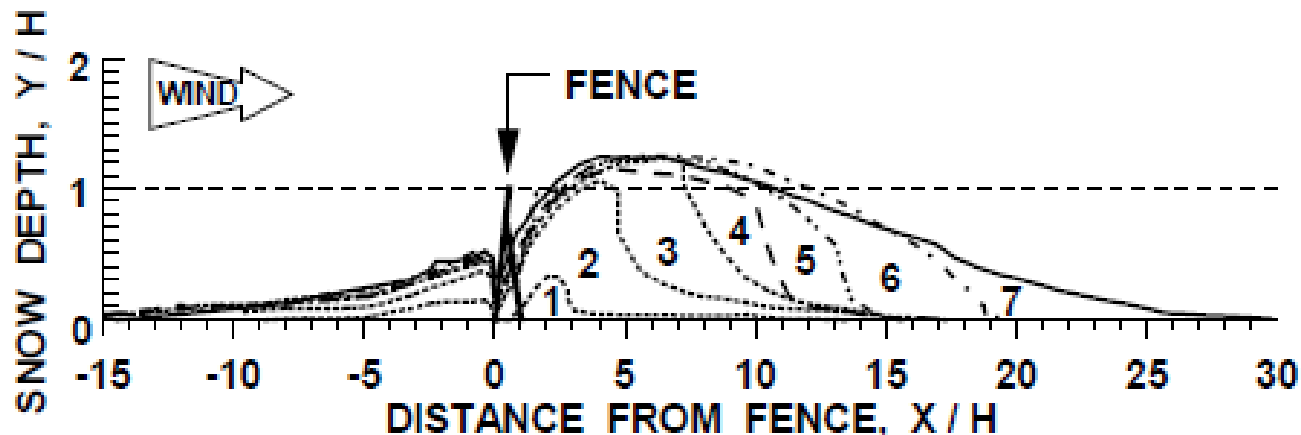
Capacity/Transport Ratio

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

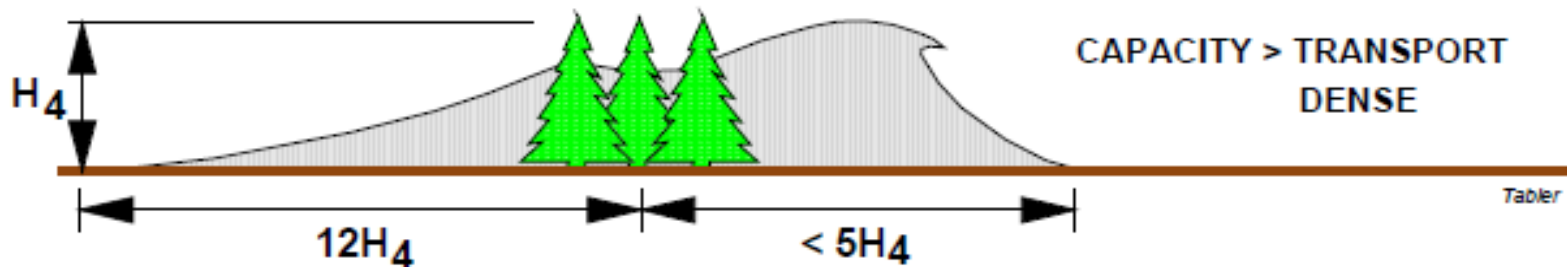
- High C/T ratios will reduce drift lengths from the maximum of $35H$, and reduce the required setback distance



Drift Length Model

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



A large four year old willow fence

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

