Research Project C-06-09

Designing, Developing, and Implementing a Living Snow Fence Program for New York State

Tasks 3-D, 3-D1, 3-D2, 3-D3, 3-E, 3-E1, 3-E2, 3-E3

Field Measurements and Analysis of Effectiveness of Operationally-Mature Snow Fence Vegetation in New York State

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Background

Task 3-D of research project C-06-09 calls for the collection of effectiveness data on living snow fences using the protocols developed in Task 3-C of this project. Sub-tasks 3-D1 through 3-D3 each call for data collection from 3-5 living snow fences of various ages and species. Task 3-E and sub-tasks 3-E1 through 3-E3 call for the analysis of this data to identify key factors for the success of living snow fences. This report fulfills the stated deliverables for Tasks 3-D, 3-E, and all associated sub-tasks, and provides data collected from 18 living snow fences across New York State of various species and ages. The key variables of height (H) and optical porosity (P) were measured in the field at each site, and site characteristics and climatic variables were measured remotely, using the protocols developed in Task 3-C and the related sub-tasks of this project. The data collected was analyzed to estimate the snow trapping function of the fences using the models of Tabler (2000, 2003). These models of snow trapping function require metric units of measurement, so all measurements and results were measured and reported in metric units. Tables 2 through 4 are reproduced in Appendix 1 using English units of measurement.

A stratified sample of fences was selected from the statewide list of living snow fence provided by NYSDOT to represent a broad range of fence ages, vegetation types, and locations. Fence age (years since planting) was the predictor variable for the response variables of fence height, optical porosity, and snow storage capacity. Simple linear regressions were preformed to test the null hypothesis that the slope of the regressions was equal to zero. The null hypothesis was rejected and regressions were reported as significant when the p value was less than or equal to 0.05 ($p \leq 0.005$). Scatter plots, r^2 values, and fitted equations for the regression models were produced in the Minitab statistical software program. Regressions for each response variable were preformed amongst all fences, and also grouped by vegetation type. It was expected that, amongst all fences, there would be a strong positive relationship between age and height, a strong negative relationship between age and porosity, and a strong positive relationship between age and capacity. In addition to linear regressions, non-linear regressions were preformed for the predictor variable of capacity/transport ratio versus the response variables of downwind drift length in drift model 1, and downwind drift length in drift model 2. A list of all regressions preformed and the corresponding r^2 values, p values, and S values were in included in Table 5.

Fence Location, Species, and Planting Pattern

The 18 living snow fences investigated for this research were located in six NYSDOT regions and 10 counties within in New York State (Figure 1, Table 1). Each fence was assigned an identification tag using the name of the town the fence was located in, followed by the vegetation type, and the age (years since planting) of the fence (i.e. Spencerport-conifer-6). If more than one fence was investigated in the same town, a letter, starting with "A", was added after the name of the town (i.e. Preble-A-willow-9). The highway number, side of the road the fence was planted on (i.e. south bound), and the approximate NYSDOT highway reference marker at which the fence begins were also included in Table 1. Photos taken at a number of sites are included in Appendix 2.

Seven shrub-willow cultivars, five conifer species, one honeysuckle cultivar, and one corn cultivar were investigated (Table 2). Fence age (years since planting) ranged from 1 - 11 years, constituting an eleven year chronosequence. Fence length ranged from 67 - 482 m and the mean was 237 m ±115 m. Eleven fences consisted of two rows; four fences consisted of a single row; two fences consisted of three rows; and the corn fence consisted of eight rows. Plant spacing and row spacing of shrub-willow fences was 0.61 m and 0.76 m respectively. The one exception was Grand-Gorge-willow-7, which consisted of a single row of shrub-willow at 0.31 m plant spacing. Amongst the six conifer fences, plant spacing ranged from 1.83 – 3.66 m. For conifer fences with multiple rows, three fences had 3.05 m row spacing and one fence had 2.13 m row spacing.

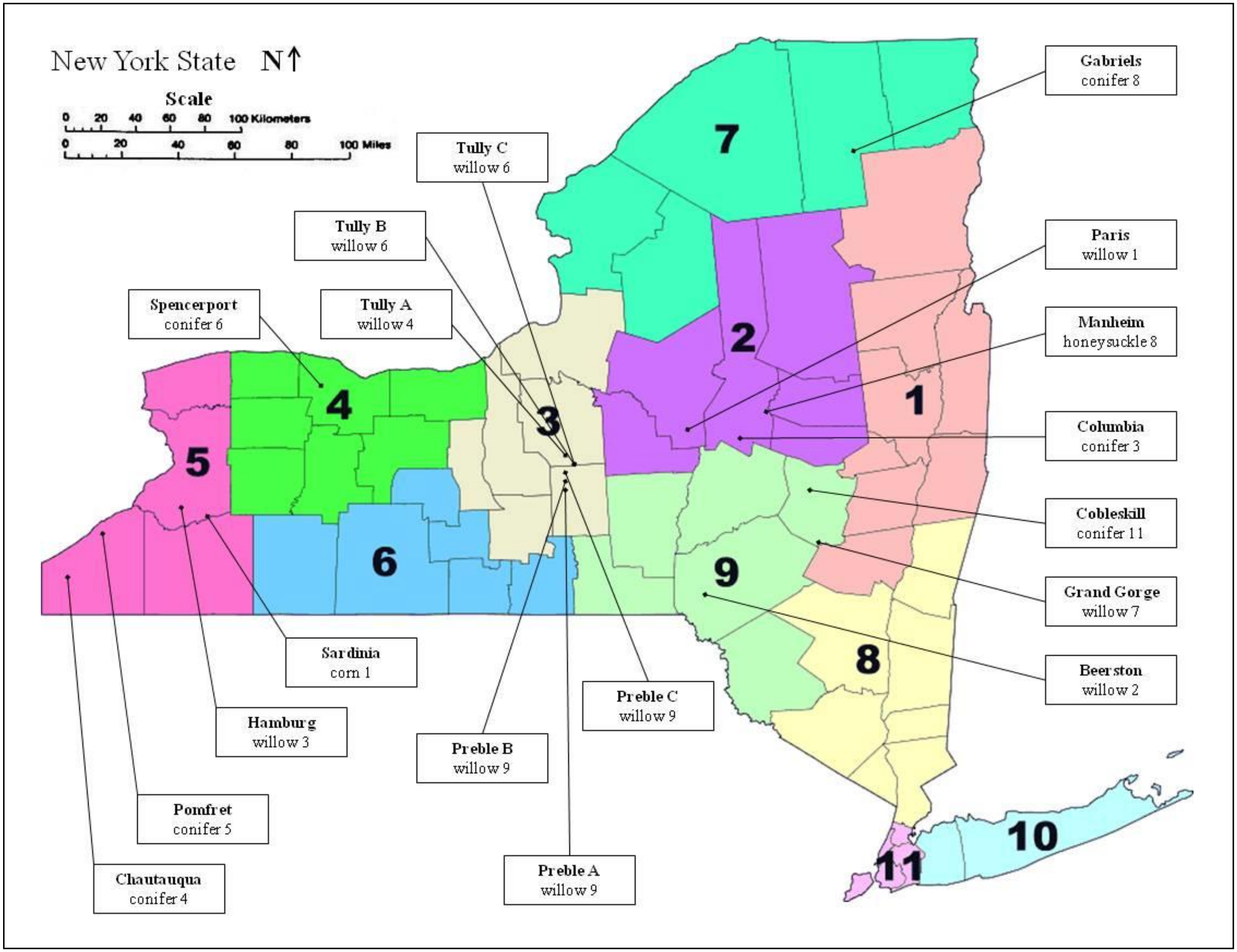

Figure 1: Map of New York State showing NYSDOT regions, approximate locations, and identification tags (town name, vegetation type, age) of the 18 living snow fences investigated for this research

Table 1: Fence identification tags and location data of 18 living snow fences investigated in this research, sorted by NYSDOT region and county

NYSDOT Region	County	Fence Identification Tag (Town - vegetation type - age)	Highway Number	Highway Side	NYSDOT Reference Marker Start
2	Herkimer	Columbia - conifer - 3	28	SB	28 2304 1067
2	Herkimer	Manheim - honeysuckle - 8	167	SB	167 2302 3024
2	Oneida	Paris - willow - 1	12	SB	12 260 41119
3	Cortland	Preble A - willow - 9	I-81	SB	81I 3202 3090
3	Cortland	Preble B - willow - 9	I-81	SB	81I 3202 3086
3	Cortland	Preble C - willow - 9	I-81	SB	81I 3202 3084
3	Onondaga	Tully A - willow - 4	I-81	SB	81I 3303 1020
3	Onondaga	Tully B - willow - 6	281	SB	281 3302 1011
3	Onondaga	Tully C - willow - 6	281	SB	281 3302 1011
4	Monroe	Spencerport - conifer - 6	531	WB	531 430 12017
5	Chautauqua	Chautauqua - conifer - 4	394	EB	17 5201 1055
5	Chautauqua	Pomfret - conifer - 5	60	SB	60 5201 3244
5	Erie	Hamburg - willow - 3	219	SB	219 531 21112
5	Erie	Sardinia - corn - 1	16	SB	16 5302 1009
7	Franklin	Gabriels - conifer - 8	86	SB	86 7201 1047
9	Delaware	Beerston - willow - 2	10	EB	10 930 11218
9	Delaware	Grand Gorge - willow - 7	30	SB	30 9502 1010
9	Schoharie	Cobleskill - conifer - 11	I-88	WB	88I 9507 1081

Table 2: Taxonomy and planting pattern of 18 living snow fences investigated in this study, sorted by vegetation type and age (years since planting)

Fence Identification Tag (Town - vegetation type - age)	Scientific Name	Common Name	Fence Length (m)	Plant Spacing (m)	Number of rows	Row Spacing (m)	Fetch Distance (m)
Sardinia - corn - 1	*Zea mays*	standing corn rows	350	0.10	8	0.75	340
Manheim - honeysuckle - 8	*Lonicera tatarica*	Arnold red honeysuckle	181	0.91	1	-	206
Paris - willow - 1	*Salix purpurea, Salix miyabeana*	var. SX64, Fishcreek	115	0.61	2	0.76	275
Beerston - willow - 2	*Salix miyabeana, Salix purpurea*	var. SX64, Fishcreek	410	0.61	2	0.76	128
Hamburg - willow - 3	*S. sachalinensis, S. dasyclados*	var. SX61, 98101-61	264	0.61	2	0.76	780
Tully A - willow - 4	*Salix miyabeana, Salix purpurea*	var. SX64, Fishcreek	482	0.61	2	0.76	750
Tully B - willow - 6	*Salix caprea hybrid*	var. S365	235	0.61	2	0.76	185
Tully C - willow - 6	*S. sachalinensis x S. miyabeana*	var. Sherburne	235	0.61	2	0.76	185
Grand Gorge - willow - 7	*Salix purpurea*	shrub-willow purpurea	158	0.31	1	-	171
Preble A - willow - 9	*S. miyabeana, S. sachalinensis*	var. SX64, SX61, 98101-61, 9870-42	192	0.61	2	0.76	480
Preble B - willow - 9	*S. miyabeana, S. sachalinensis*	var. SX64, SX61, 98101-61, 9870-42	115	0.61	2	0.76	370
Preble C - willow - 9	*S. miyabeana, S. sachalinensis*	var. SX64, SX61, 98101-61, 9870-42	116	0.61	2	0.76	538
Columbia - conifer - 3	*Picea abies*	Norway spruce	67	3.05	3	2.13	855
Chautauqua - conifer - 4	*Picea pungens*	blue spruce	185	3.66	3	3.05	620
Pomfret - conifer - 5	*Picea pungens*	blue spruce	140	3.66	2	3.05	437
Spencerport - conifer - 6	*Pseudotsuga menziesii*	Douglas-fir	373	1.83	1	-	157
Gabriels - conifer - 8	*Thuja occidentalis*	northern white cedar	345	2.13	1	-	470
Cobleskill - conifer - 11	*Abies concolour*	white fir	302	3.05	2	3.05	318
Mean *5.7*	-	-	*237*	*1.3*	*2*	*1.3*	*404*
Median *6.0*	-	-	*235*	*0.6*	*2*	*0.8*	*370*
Standard Deviation *3.0*	-	-	*117*	*1.2*	*1.6*	*1.0*	*230*

Fence Height and Porosity

There was a significant positive linear relationship ($p < 0.001$) between age and height (**H**) amongst all fences as expected (Figure 2). The height of Sardinia-corn-1 was the lowest of any fence including a shrub-willow fence of the same age (Paris-willow-1) (Table 3). Manheim-honeysuckle-8 fell approximately 2 m below the height trend amongst all fences. Conifer fences were fairly evenly distributed above and below the trend. Shrub-willow fences were concentrated above or slightly below the trend. Preble-C-willow-9 had the largest observed height of any fence. Cobleskill-conifer-11 was slightly shorter than Spencerport-conifer-6, Grand-Gorge-willow-7, Preble-A-willow-9, and Preble-B-willow-9. In general, willow fences had a slightly faster height growth rate (Height = 8.644 + 0.5753 Age, $r^2 = 0.852$, $p < 0.001$) than the trend amongst all fences. Height of conifer fences generally increased with age, but there was no significant relationship between age and height amongst conifer fences ($p = 0.149$).

When the observed height of fences (**H**) was compared to predicted values of required fence height [$\mathbf{H_{req}} = (\mathbf{Q}/8.5)^{0.455}$] at 50% porosity, the observed height was greater than the required height for every fence investigated in this research(Figure 3, Table 3). The mean required height was 1.0 m plus or minus (±) 0.3 m, but the observed height was 3.8 m ±1.7 m. Paris-willow-1 had 0.5 m of excess height beyond the required amount, and Beerston-willow-2 had 1.3 m of excess height. Columbia-conifer-3 had 1.6 m of excess height. For all fences ages five and older, the observed height was approximately two to six times greater than the required height (Figure 3). Sardinia-corn-1 had 0.4 m of excess height. Manheim-honeysuckle-8 had 1.4 m in excess height despite being well below the trend of height growth amongst all fences.

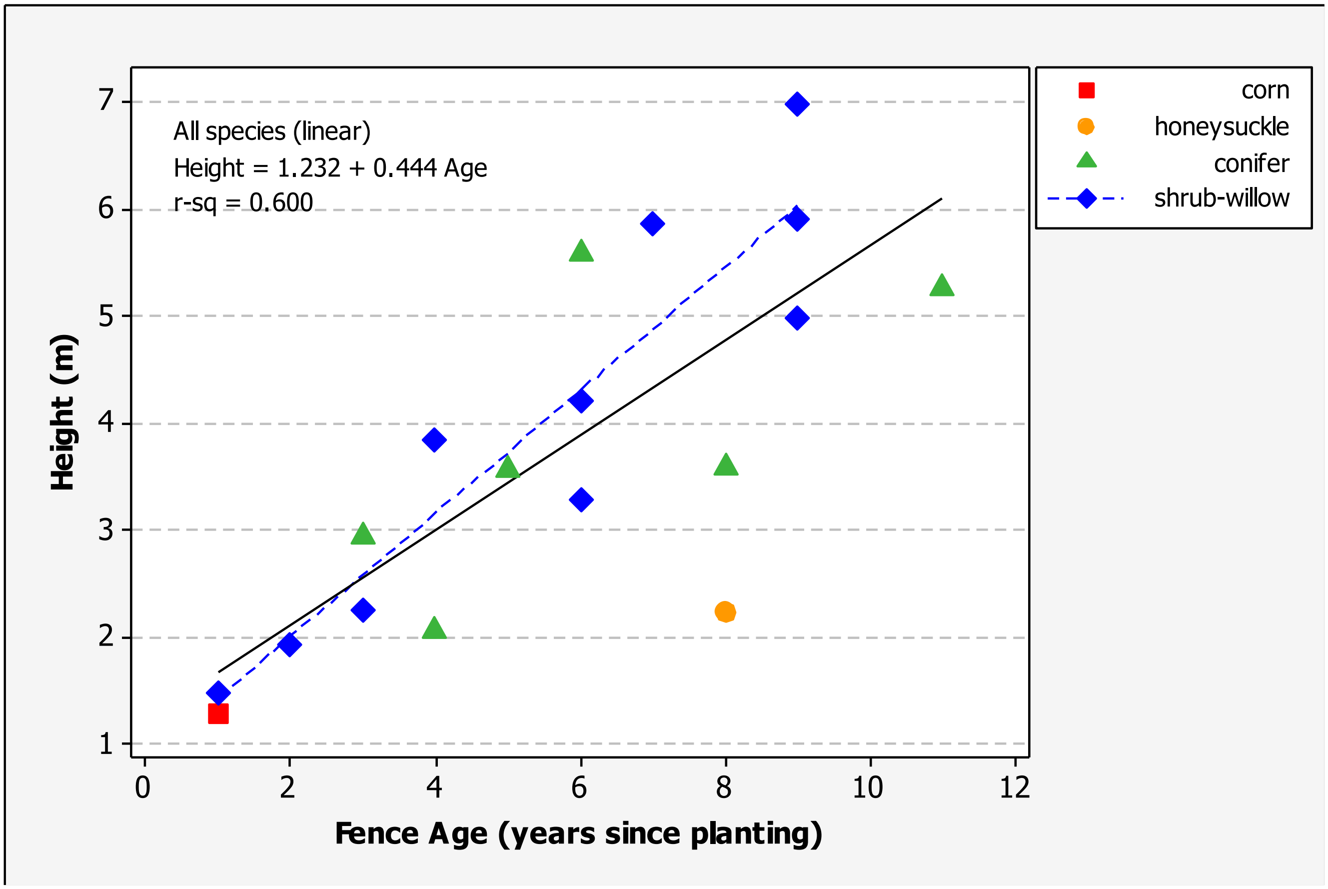

Figure 2: Age (years since planting) versus height (**H**) of 18 living snow fences of various species in New York State, grouped by vegetation type

Table 3: Summary of results for variables related to snow trapping function of 18 living snow fences of various species in New York State, sorted by vegetation type and age (years since planting)

	H_{req}	H	P	Q_c^*	Q^*	Q_c/Q^*
Fence Identification Tag (Town - Vegetation Type - Age)	Required Height (m)	Observed Height (m)	Porosity	Capacity (t/m)	Transport (t/m)	Capacity/Transport Ratio
Sardinia - corn - 1	0.9	1.3	0%	5	7	<1
Manheim - honeysuckle - 8	0.8	2.2	63%	47	5	10
Paris - willow - 1	1.0	1.5	92%	<1	8	<1
Beerston - willow - 2	0.6	1.9	88%	<1	3	<1
Hamburg - willow - 3	1.5	2.3	77%	29	19	1.5
Tully A - willow - 4	1.2	3.9	52%	167	13	13
Tully B - willow - 6	0.7	3.3	61%	113	4	30
Tully C - willow - 6	0.7	4.2	62%	192	4	50
Grand Gorge - willow - 7	0.7	5.9	47%	411	4	110
Preble A - willow - 9	0.9	5.0	33%	239	7	34
Preble B - willow - 9	1.0	5.9	39%	387	9	44
Preble C - willow - 9	1.1	7.0	26%	430	10	43
Columbia - conifer - 3	1.3	2.9	27%	66	15	4
Chautauqua - conifer - 4	1.2	2.1	61%	40	12	3
Pomfret - conifer - 5	0.9	3.6	41%	130	7	19
Spencerport - conifer - 6	0.7	5.6	29%	280	3	82
Gabriels - conifer - 8	1.4	3.6	39%	128	17	8
Cobleskill - conifer - 11	1.0	5.3	38%	297	8	39
Mean	*1.0*	*3.8*	*50%*	*185*	*9*	*27*
Median	*1.0*	*3.6*	*50%*	*167*	*8*	*16*
Standard Deviation	*0.3*	*1.7*	*20%*	*141*	*5*	*31*

Note* - The $\mathbf{Q_c}$ and **Q** values reported in this table were rounded to the nearest t/m for clarity. The capacity/transport ratios ($\mathbf{Q_c/Q}$) reported in this table are the rounded ratio of the *actual* capacity and transport values modeled in this study

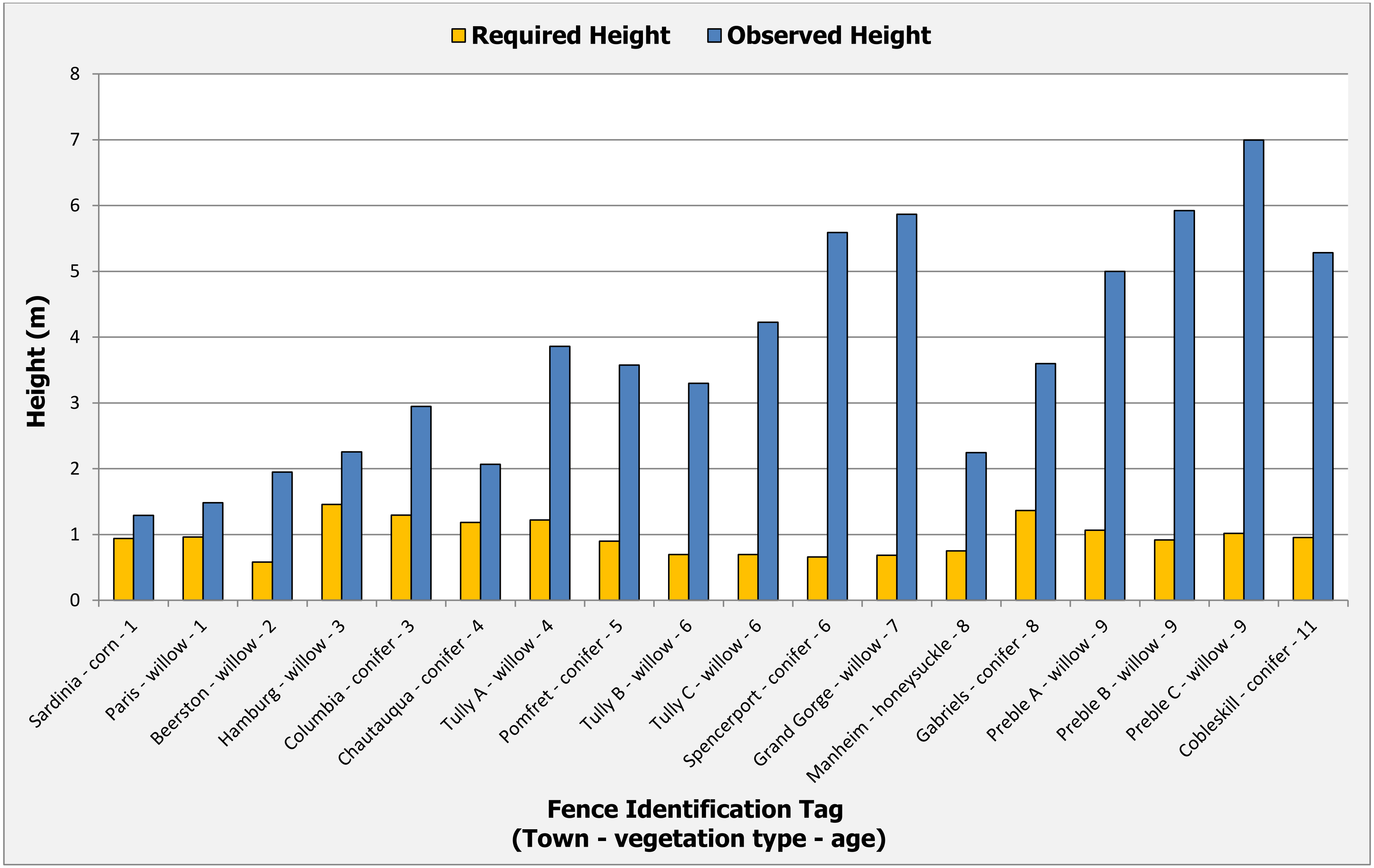

Figure 3: Observed height (**H**) compared to the predicted required height (**H_{req}**) of 18 living snow fences of various species and ages (years since planting) in New York State

There was a significant negative relationship ($p = 0.005$) between age and porosity (**P**) across 17 fences in this research(Figure 4). This was the expected result based on the fact that vegetation generally fills in open space (porosity) over time as plants grow. Sardinia-corn-1 was excluded from this regression due to the observed porosity value of 0% (non-porous) at age 1, which made it a distinct outlier from all other porosity values (Figure 4). This low porosity value was due to the small plant spacing, and eight-row planting pattern (five more rows than any other fence) (Table 2). Columbia-conifer-3 was substantially below the porosity trend amongst all fences, due to the small spacing, three-row configuration, and the large size of trees three years after planting. The other conifer fences were near or below the trend line. Shrub-willow fences were near or above the trend up to age 7. Of the three age 9 shrub-willow fences, one was near the trend line and two were below it.

Manheim-honeysuckle-8 fell substantially above the trend amongst all species due to the single-row configuration and 0.91 m plant spacing. By comparison, the three other single-row fences (one shrub-willow and two conifer fences) were similar ages, but had had lower porosities than Manheim-honeysuckle-8 (Table 3). Compared to the trend amongst all fences, porosity of shrub-willow fences declined more rapidly and consistently (Porosity = 0.976 – 0.0712 Age, $r^2 = 0.892$, $p < 0.001$) (Figure 4). There was no significant relationship between age and porosity amongst conifer fences ($p = 0.877$) indicating that porosity for fences of this vegetation type changed very little between ages 3 and 11.

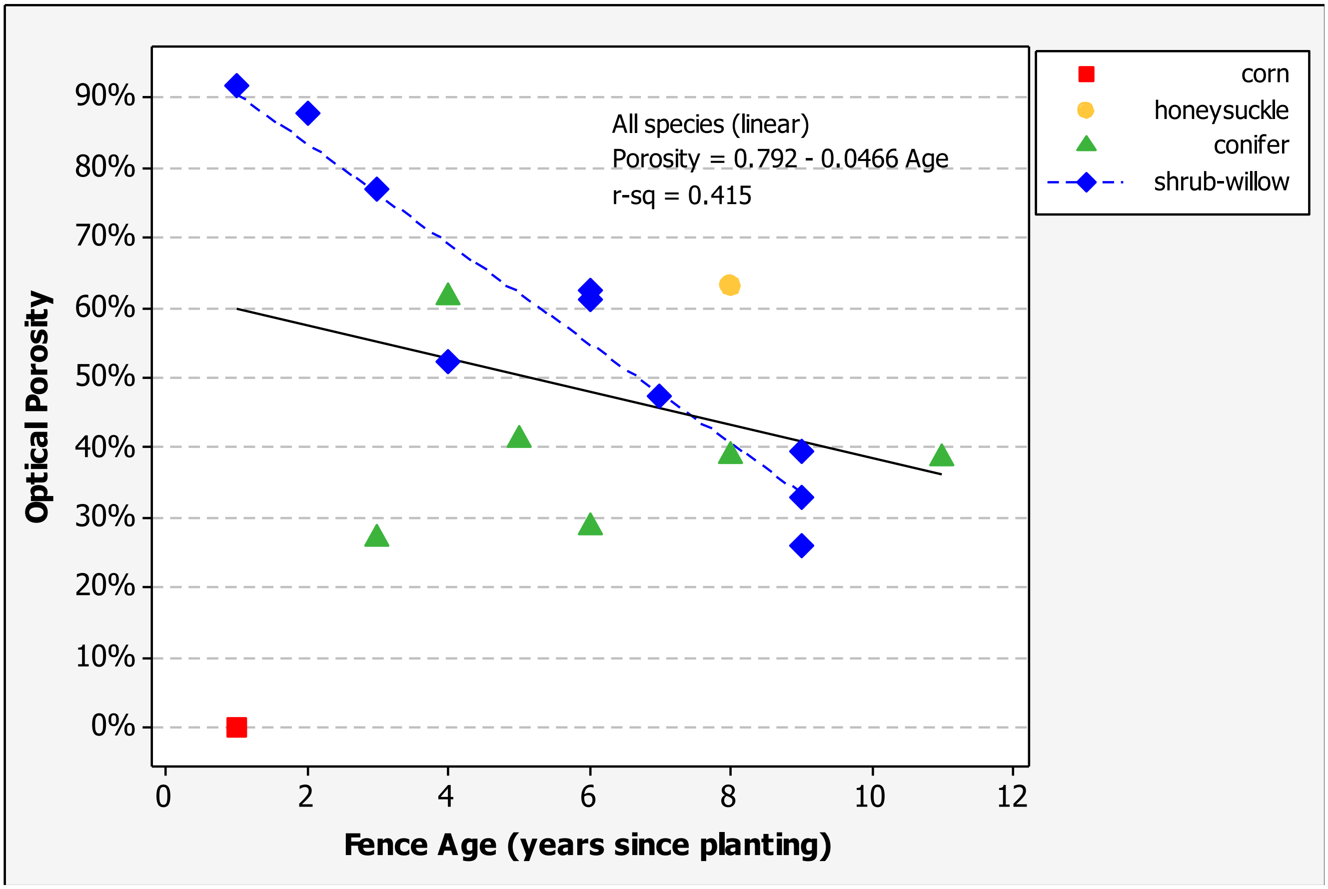

Figure 4: Age (years since planting) versus optical porosity (**P**) of 18 living snow fences of various species in New York State, grouped by vegetation type

Fence Capacity and Snow Transport

There was a strong positive linear relationship ($p < 0.001$) between age and capacity ($\mathbf{Q_c}$) amongst all fences investigated in this research(Figure 5). The trend in capacity was similar to the trend in height as expected, capacity being primarily driven by height and slightly modified by porosity [$\mathbf{Q_c} = (3 + 4\mathbf{P} + 44\mathbf{P}^2 - 60\mathbf{P}^3)\ \mathbf{H}^{2.2}$]. Conifer fences were near or below the trend line of all fences, the one exception being Spencerport-conifer-6 which was ~100 t/m above the trend. Shrub-willow fences were near the trend line of all fences, with the exceptions of Grand-Gorge-willow-7, Preble-B-willow-9 and Preble-C-willow-9, all three of which had capacity over 350 t/m and were ~100 t/m above the trend. Manheim-honeysuckle-8 was ~150 t/m *below* the capacity trend of all fences, and had a capacity similar to age 3 conifer and shrub-willow fences. Capacity of shrub-willow fences increased over time at a slightly faster rate than the trend amongst all fences (Capacity = -77.9 + 49.0 Age, $r^2 = 0.769$, $p = 0.001$). Capacity of conifer fences increased at a slightly slower rate than the trend amongst all fences (Capacity = -12.2 + 27.5 Age, $r^2 = 0.554$, $p = 0.090$).

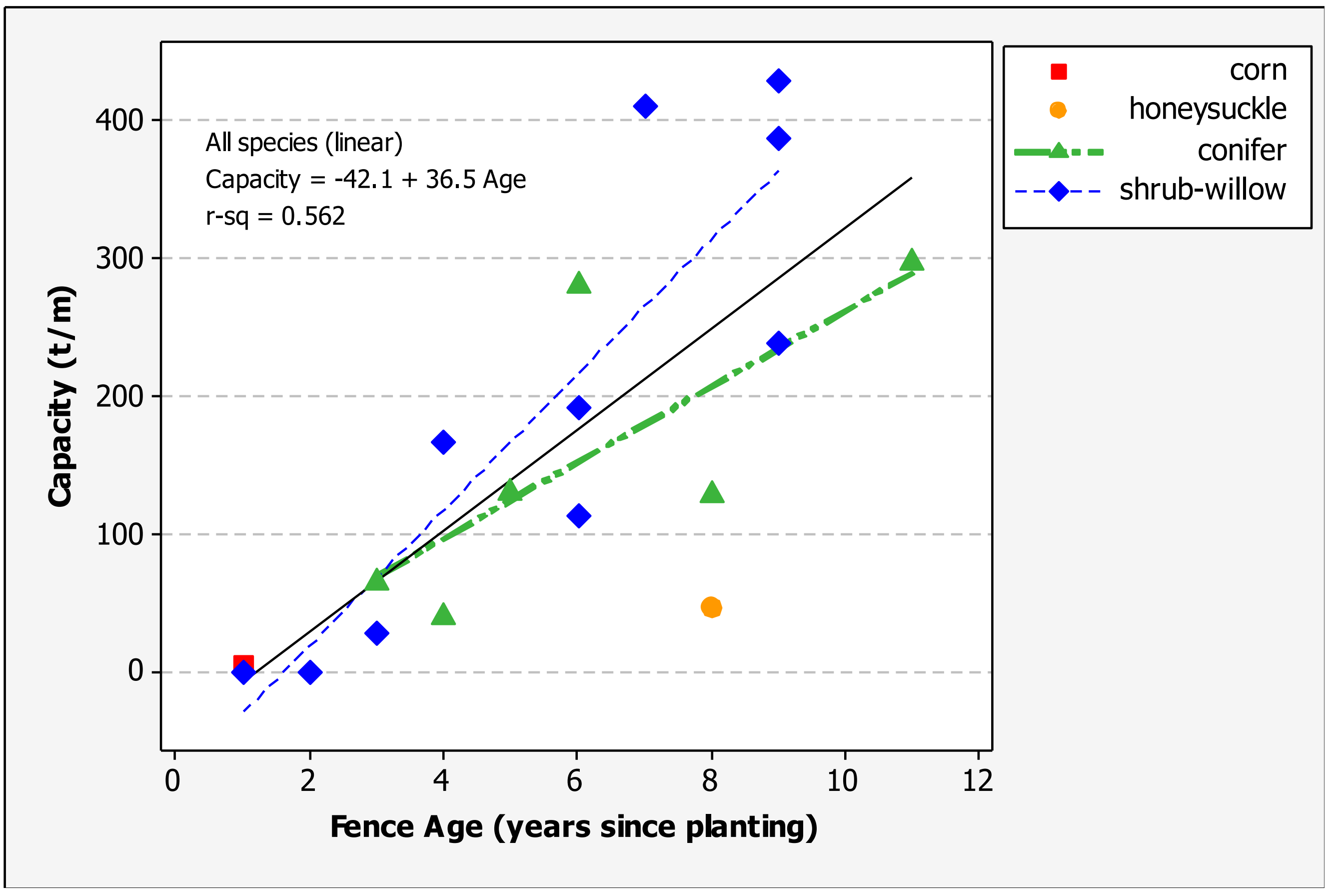

Figure 5: Age (years since planting) versus capacity ($\mathbf{Q_c}$) of 18 living snow fences of various species in New York State, grouped by vegetation type

Snow transport ($\mathbf{Q}$) across all sites ranged from 3 - 19 t/m, and the mean was 9 t/m ±5 t/m (Table 3, Figure 5) [$\mathbf{Q} = 1500(0.17)(\mathbf{S_{we,AS}})(1\text{-}0.14^{\mathbf{F}/3000})$]. This range of seasonal snow transport values was classified as “very light” (<10 t/m), or “light” (10 - 19 t/m), by Tabler (2003) in terms of the severity of blowing snow problem. Snow transport (**Q**) of Sardina-corn-1 was 7 t/m, which was greater than the fence capacity of 5 t/m. The height (**H**) of Sardinia-corn-1 exceeded the required fence height ($\mathbf{H_{req}}$), but the *low* porosity value of 0% (non-porous) reduced the storage capacity. The capacities of age 1 and age 2 shrub-willow fences (Paris-willow-1 and Beerston-willow-2) were both below 1 t/m which was less than the snow transport at these sites. The height of these fences again exceeded the required fence height, but *high* porosity values of 92% and 88% negated any substantial storage capacity. All fences in this researchage 3 and older had capacity values that exceeded transport (Table 3, Figure 6) indicating that fences were fully functional ($\mathbf{Q_c \geq Q}$) at early ages.

The capacity/transport ratio ($\mathbf{Q_c/Q}$) of Hamburg-willow-3 was 1.5:1 (Figure 7), meaning that after three growing seasons, the storage capacity of this fence was 1.5 times the quantity of snow transport occurring at the site in average year. The $\mathbf{Q_c/Q}$ ratio of Columbia-conifer-3 was 4:1 after three growing seasons. The $\mathbf{Q_c/Q}$ ratio for Tully-A-willow-4 was 13:1, nearly 10 times the $\mathbf{Q_c/Q}$ ratio at Hamburg-willow-3, which was the same vegetation type and only one year younger. The second youngest conifer fence Chautauqua-conifer-4 had a $\mathbf{Q_c/Q}$ ratio of only 3:1, but the third youngest conifer fence (Pomfret-conifer-5) was 19:1. For all fences age five and older, the $\mathbf{Q_c/Q}$ ratio was between 8:1 and 110:1, indicating that fences had large amounts of excess storage capacity at early ages. The largest $\mathbf{Q_c/Q}$ ratios were observed at Grand-Gorge-willow-7 (110:1), and Spenerport-conifer-6 (82:1). All capacity/transport ratios were partly a result of the capacity of the fences, but also the transport values which were slightly different at each site. For example, Spencerport-conifer-6 was near the median age, had one of the *highest* capacity values, but also equaled the *lowest* transport value which combined to give it the second highest $\mathbf{Q_c/Q}$ ratio amongst all fences. Overall, the fences investigated in this research had snow storage capacity greater than the site transport after three growing seasons, and continued to add excess storage capacity in a linear trend over the eight subsequent years of the chronosequence, further increasing the $\mathbf{Q_c/Q}$ ratio.

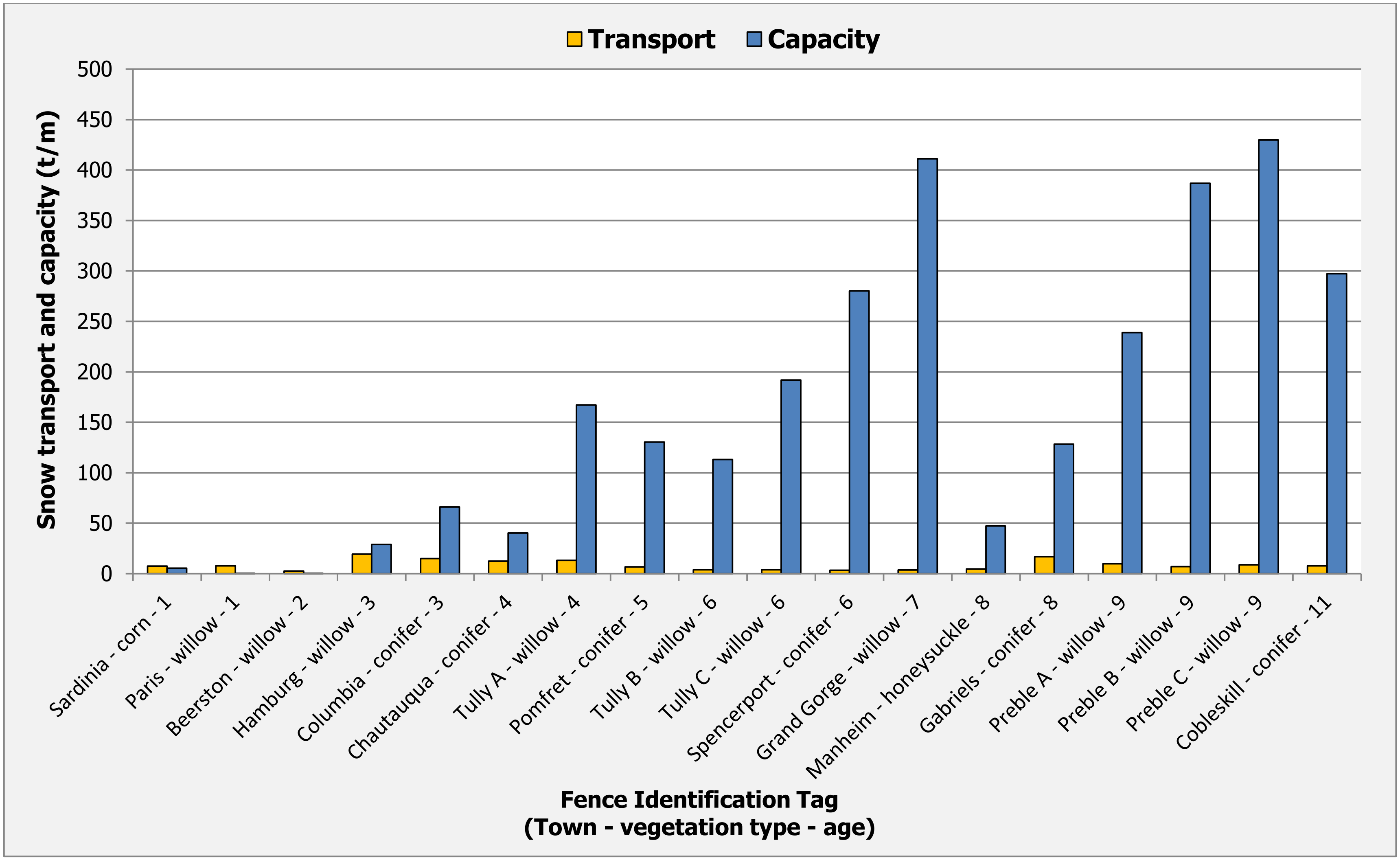

Figure 6: Fence capacity (**Q_c**) relative to the quantity of snow transport (**Q**) at each site for 18 living snow fences of various species and ages (years since planting) in New York State

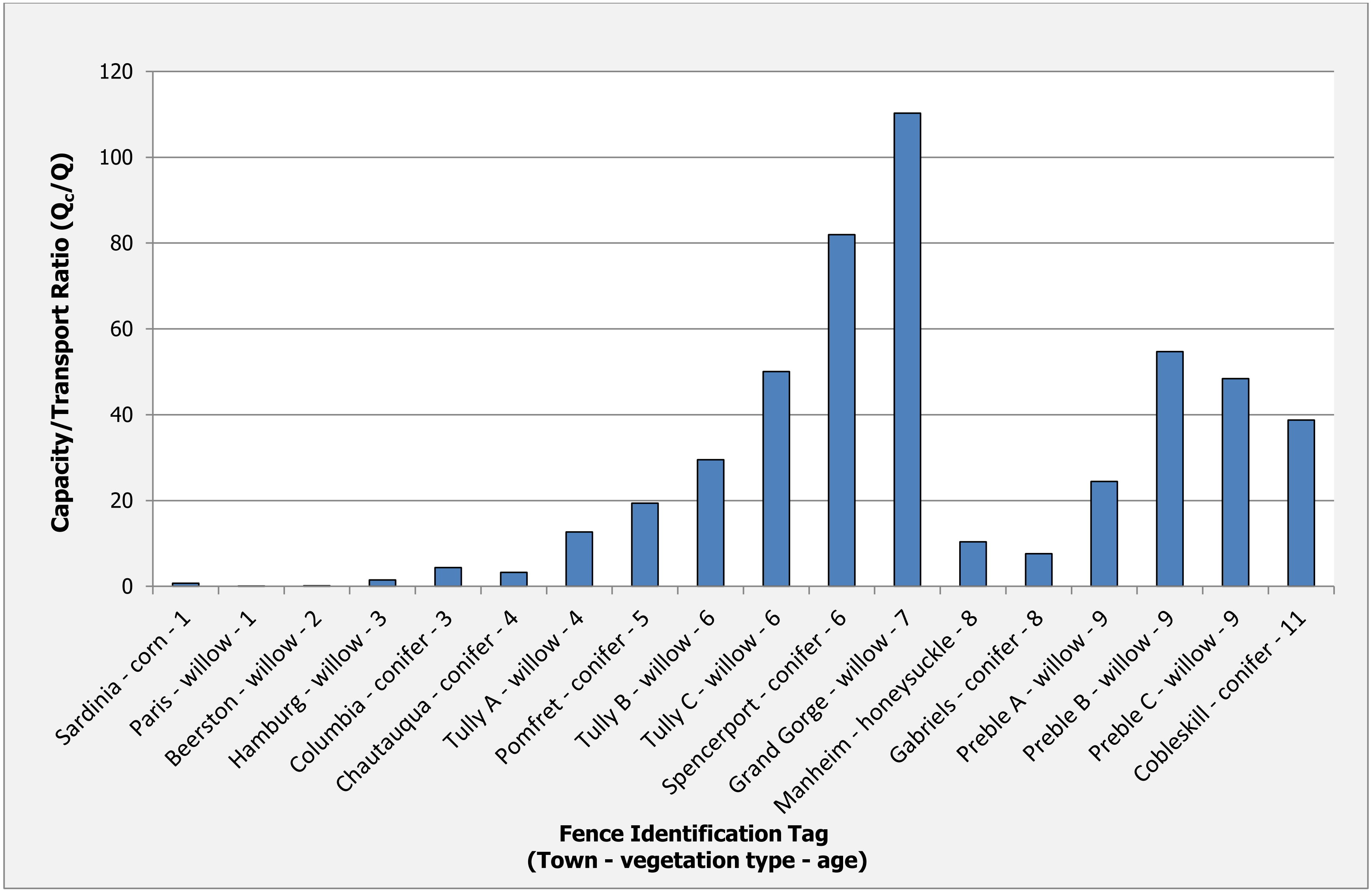

Figure 7: Capacity/Transport ratio (**Q_c/Q**) of 18 living snow fences of various species and ages (years since planting) in New York State

Setback Distance and Predicted Drift Length

There was no significant relationship between observed setback distance (**D**) and the predictor variables of height (**H**), capacity ($\mathbf{Q_c}$), snow transport (**Q**), capacity/transport ratio ($\mathbf{Q_c/Q}$), nor predicted setback ($\mathbf{D_{35}}$) ($p > 0.417$). This indicates that there is no standard methodology or model being consistently applied in the selection of setback distances for living snow fences in New York State. The choice of setback distances was likely influenced by site conditions and limitations, but likely also reflects the literature on living snow fences which provides no consensus nor precise guidelines on this topic. Observed setback (**D**) ranged from 9 m to 95 m. The range of *predicted* setback values ($\mathbf{D_{35}}$) was considerably smaller at 18 m - 46 m. The mean of observed setback distances was 34 m ±24 m (Table 4). The mean of *predicted* setbacks was 30 m, which was only 4 m less than the observed mean. However, the standard deviation of predicted values was only ±8 t/m, compared to the larger standard deviation of observed values of ±24 t/m. Observed setback values thus showed a large maximum value, a large range, and a large standard deviation.

When the length of the downwind drift (**L**) was predicted for all fences using *drift model 1*, the mean drift length was 42 m ±12 m (Table 4). The range of predicted drift lengths produced by drift model 1 was 25 m to 68 m. The drift length values produced by drift model 1 were *larger* than the observed setback distance for 12 out of 18 fences in this study, and larger than the predicted setback ($\mathbf{D_{35}}$) for 14 of 18 fences.

[Drift Model 1: $\mathbf{L} = ([10.5 + 6.6(\mathbf{Q}/\mathbf{Q_c}) + 17.2(\mathbf{Q}/\mathbf{Q_c})^2]/34.3)(12 + 49\mathbf{P} + 7\mathbf{P}^2 - 37\mathbf{P}^3)(\mathbf{H})$]

Table 4: Observed setback, predicted setback, and drift model outputs of 18 living snow fences of various species in New York State, sorted by vegetation type and age (years since planting)

Fence ID Tag (Town - Vegetation Type - Age)	Observed Setback Distance (**D**) (m)	Predicted Setback Distance (**D_{35}**) (m)	Predicted Drift Length Model 1 (m)	Predicted Drift Length Model 2 (m)	Capacity/Transport Ratio (**Q_c/Q**)
Sardinia - corn - 1	71	29	25	18	<1
Manheim - honeysuckle - 8	38	24	25	8	10
Paris - willow - 1	26	30	52	34	<1
Beerston - willow - 2	27	18	68	20	<1
Hamburg - willow - 3	28	46	47	30	1.5
Tully A - willow - 4	42	38	41	13	13
Tully B - willow - 6	10	22	34	7	30
Tully C - willow - 6	10	22	44	7	50
Grand Gorge - willow - 7	95	22	57	7	110
Preble A - willow - 9	13	33	43	9	34
Preble B - willow - 9	10	29	54	8	44
Preble C - willow - 9	9	32	53	8	43
Columbia - conifer - 3	52	41	28	12	4
Chautauqua - conifer - 4	59	37	28	16	3
Pomfret - conifer - 5	31	28	34	9	19
Spencerport - conifer - 6	37	21	44	5	82
Gabriels - conifer - 8	17	43	36	14	8
Cobleskill - conifer - 11	41	30	48	9	39
Mean	*34*	*30*	*42*	*13*	*27*
Median	*31*	*30*	*43*	*9*	*16*
Standard Deviation	*24*	*8*	*12*	*8*	*31*

There was no significant relationship ($p = 0.136$) between capacity/transport ratio and the drift length outputs produced by drift model 1 (Figure 8). When the capacity/transport ratio of fences was between 0 and 15:1 in drift model 1, the drift length output ranged between 25 m and 68 m. When capacity/transport ratio was greater than 15:1 in drift model 1, drift length generally *increased* and ranged between 25 m and 57 m. This general increase in drift length was *not* consistent with the expected trend of decreasing drift length in response to increasing capacity/transport ratio in accordance with the stages of drift formation from Tabler (2003).

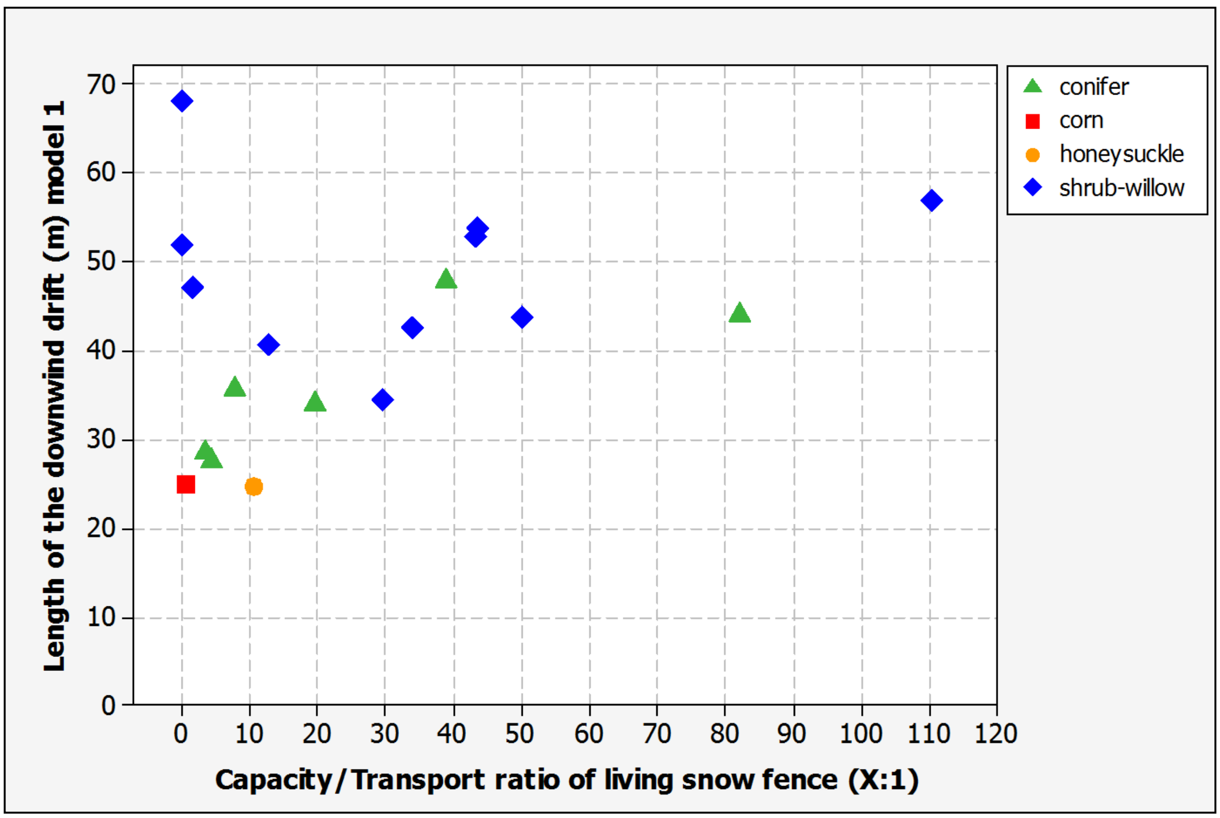

Figure 8: Capacity/Transport ratio versus length of the downwind snow drift as predicted by drift model 1 for 18 living snow fences of various ages (years since planting) and species in New York State

When drift length (**L**) was predicted for all fences using *drift model 2*, the mean drift length was 15 m ±8 m. The range of predicted drift lengths produced by model 2 was 5 m - 34 m. The drift length values produced by drift model 2 were *smaller* than the observed setback distance for 16 out of 18 fences in this study, and smaller than the predicted setback ($\mathbf{D_{35}}$) for 16 of 18 fences (Table 4).

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

There *was* significant negative relationship (p = 0.006) between capacity/transport ratio and the drift length outputs produced by model 2 (Figure 9). The relationship between capacity/transport ratio and drift length in drift model 2 was best fit to an asymptomatic trend line. The standard error of the non-linear regression was S = 4.037, indicating that the predicted drift length values fell a standard distance of approximately ±4 meters from the trend line.

When capacity/transport ratio ($\mathbf{Q_c/Q}$) of fences was between 0 and 15:1 in drift model 2, drift length declined rapidly from 34 m to 8 m. When capacity/transport ratio was greater than 15:1 in drift model 2, drift length was less than 10 m. The overall trend in capacity/transport ratio versus drift length produced by drift model 2 met the expected outcome according to the stages of drift formation in which drift length *decreases* with increasing capacity/transport ratio. The consistency of drift lengths below 10 m in drift model 2 indicates that fences with capacity/transport ratios greater than 15:1 likely do not exceed the first stage of drift formation (Figure 11), and the majority of seasonal snow transport is stored on the upwind side of the fence and in close proximity downwind of the fence. The variable of porosity is included in drift model 2, but porosity did not have a substantial effect on drift lengths, indicating that capacity/transport ratio was the key variable influencing drift length for the fences and conditions investigated

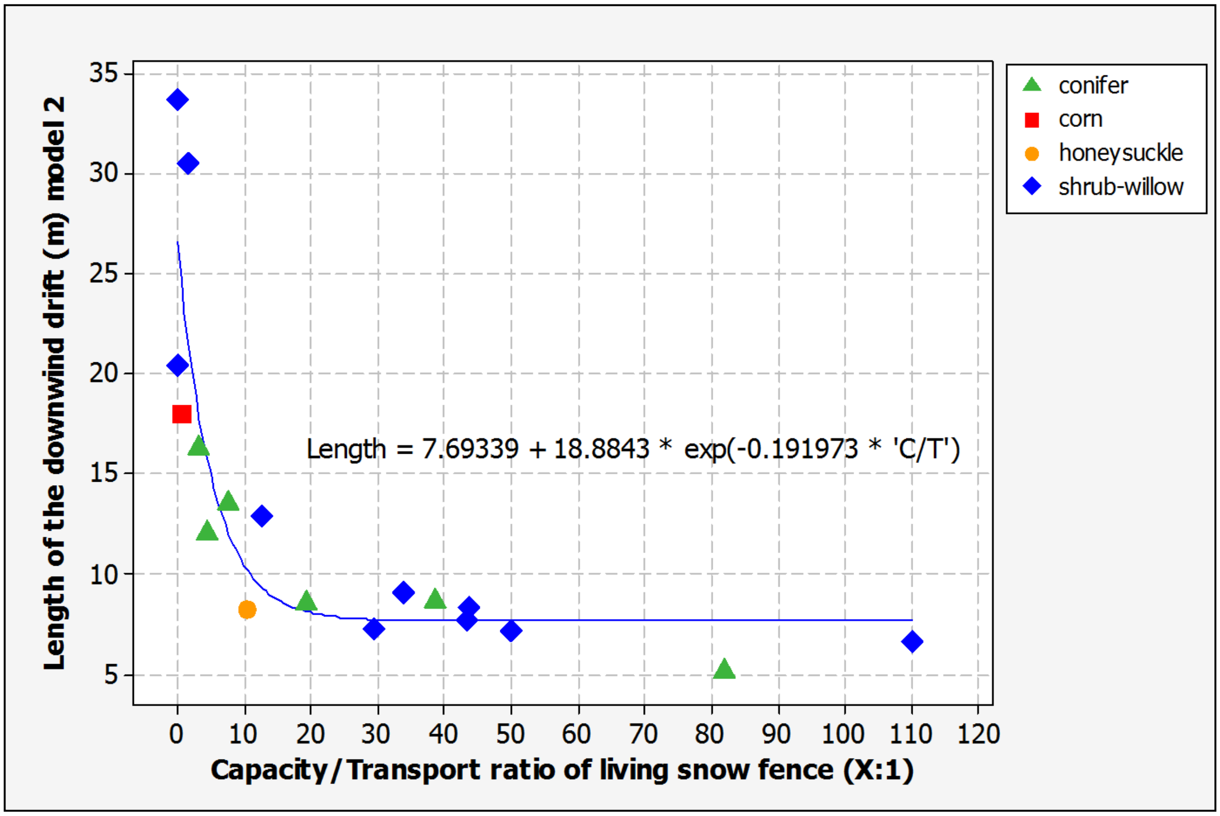

Figure 9: Capacity/Transport ratio (**Q_c/Q**) versus length of the downwind snow drift as predicted by drift model 2 for 18 living snow fences of various ages (years since planting) and species in New York State

Table 5: Summary of regressions, p values, r^2 values, and S values for all fences, shrub-willow fences, and conifer fences

	All Fences		Shrub-willow Fences		Conifer Fences	
Simple Linear Regressions (predictor versus response)	p	r^2	p	r^2	p	r^2
Age versus Height	<0.001	0.600	<0.001	0.852	0.149	-
Age versus Porosity	0.005	0.415	<0.001	0.892	0.877	-
Age versus Capacity	<0.001	0.562	0.001	0.769	0.090	0.554

	All Fences	
Non-Linear Regressions (predictor versus response)	p	S
Capacity/Transport Ratio versus Drift Length (drift model 1)	0.136	-
Capacity/Transport Ratio versus Drift Length (drift model 2)	0.006	4.037

Discussion

Functionality and Benefits of Living Snow Fences

Height and porosity are the key structural variables that influence snow trapping, the primary benefit of living snow fences. The time lag until height and porosity values equate to fully functional snow fences, where fence capacity is greater than or equal to average annual snow transport ($\mathbf{Q_c} \geq \mathbf{Q}$), is an important consideration in the use and design of living snow fences. The results of this research showed that the height and porosity of shrub-willow and conifer living snow fences in New York State was sufficient to create fully functional fences ($\mathbf{Q_c} > \mathbf{Q}$) three years after planting (Figures 1,2,4,5,6). This result confirms Volk et al. (2006) which states that known shrub-willow growth rates and stem counts will produce functional snow fences 2 - 3 years after planting with proper establishment. By contrast, the majority of literature states that living snow fences take five to seven years or longer to begin functioning (USDA 2012), and even longer to become fully functional ($\mathbf{Q_c} \geq \mathbf{Q}$). Living snow fences investigated in this research were fully functional at younger ages than what is commonly reported in the literature, due in part to light transport conditions across all 18 research sites. Sites with higher transport conditions may increase the time until fences become fully functional, but fence capacity ($\mathbf{Q_c}$) was over 100 t/m for 11 snow fences investigated , and eight fences had capacity large enough to be fully functional even in “severe” transport conditions of 160 – 320 t/m (Tabler 2003).

Living snow fences therefore have the potential to become fully functional at ages much younger than what is commonly reported in the literature when best management practices are employed. This includes techniques mentioned in previous publications (see Tabler 2003, Gullickson et al. 1999) that are still being actively developed and improved for living snow fences. Such techniques include: thorough site assessments including soil sampling; selection of species ideal for living snow fences and closely matched to site conditions; thorough site preparation techniques including the suppression of existing vegetation, soil preparations, and soil amendments; proper planting techniques for each vegetation type; prevention of browse by deer and other animals; and proper post-installation monitoring and maintenance for 2-3 years after planting to ensure that fences become established and achieve optimal growth rates (Heavey and Volk 2013).

Thus living snow fences and shrub-willow fences in particular have the potential to produce benefit-cost ratios and net present values that exceed those reported by Daigneault and Betters (2000), and reduce or contain the annual budget for snow and ice control in New State and other states in which is billions spent annually nationwide. Two potential drawbacks of using shrub-willow fences are that they require a relatively high degree of maintenance in the years immediately after planting, and may have shorter life cycles than conifer fences, potentially decreasing their benefit-cost ratios and net present values. The large snow trapping capacity shortly after planting of willow fences is enhanced by proper monitoring and maintenance. Living snow fences planted with conifer *seedlings* may require similarly high levels of post-planting care to reduce weed competition for sunlight and physical resources, but conifer fences planted with larger potted or balled trees may require less post-planting care, potentially offsetting some of the costs associated with purchasing and installing larger trees.

Living snow fences are generally expected to have longer functional life cycles than structural snow fences, an important factor in their economic feasibility (Tabler 2003). Shrub-willows are "pioneer species", which may limit their functional life cycles as living snow fences as a natural tradeoff to rapid juvenile growth rates. However, with a potential life cycle of 20 years or longer, and the full functionality and large amounts of excess storage capacity at early ages observed in this research, shrub-willow living snow fences should be able to produce favorable economic returns on investment *when best management practices are employed*. The coppice potential of shrub-willow fences also represents an opportunity for regenerating fences and extending their lifecycles. Conifer living snow fences, in contrast to shrub-willows, are generally more “climax species” that may have much longer functional life cycles as living snow fences, potentially increasing their benefit-cost ratios and net present values. Installing large conifer trees, as opposed to seedlings, will create snow trapping more quickly, but will also increase the cost of purchasing and installing the trees.

The corn and honeysuckle fences in this research were limited to one fence of each vegetation type, but the height growth and capacity of fences in this limited sample was notably less than shrub-willow and conifer fences. Corn fences are ultimately limited to the height and capacity that can be achieved in one growing season. Sardinia-corn-1 also appeared to have been reduced from its full height (and capacity) by early winter 2012/2013 when the fence was investigated, with the tops of the corn broken off or folded over, likely from a combination of weather conditions (rain saturation, snow loads, wind, freeze/thaw cycles, etc) and herbaceous plant characteristics (lack of woody tissue). The outcome of this characteristic of vegetation type was that the fence did not have enough storage capacity to be fully functional when combined with the non-porous 8 row planting configuration. A second strip of corn left standing at a distance of 50 m upwind or downwind of the first strip, as recommended by Tabler

(2003), would have likely increased the storage capacity of this fence to fully functional levels ($\mathbf{Q_c}$>$\mathbf{Q}$) despite the reduced height, but would have also increased the (annual) cost of this fence.

The living snow fence Manheim-honeysuckle-8 had sufficient capacity to be fully functional under the estimated site transport, but was well below the trend in height and capacity amongst all fences, and above the trend in porosity. The fence also had a large bottom gap due to the plant morphology, plant spacing, and single-row configuration. The observed bottom gap does not meet the desired morphological characteristic for living snow fences of a ground-level branching pattern, which may negatively impact the snow trapping function of this fence by allowing wind and snow to pass through the bottom gap until it becomes filled in with snow. In general, honeysuckle appears to be a vegetation type that creates living snow fences with functional snow storage capacity in a reasonable time frame for light snow transport conditions, but with the potential for bottom gaps and high porosity if multiple rows are not used, and slower growth rates and lower capacities relative to shrub-willow and conifer fences.

Setback and Drift Length

Despite slight differences in the rate of height growth and porosity exclusion amongst different vegetation types, fences investigated in this research had sufficient capacity to be considered fully functional ($\mathbf{Q_c}$>$\mathbf{Q}$) by age 3 (three years after planting), and continued to add excess capacity in a linear trend for the remaining 8 years of the chronosequence. These fences are expected to continue to add more height growth and excess capacity in the future, further increasing the observed capacity/transport ratios which were between 8:1 and 110:1 for fences age 5 and older. These findings have important implications for the design of living snow fences in regards to drift length and the required setback distance which is driven by the interplay of height, porosity, and capacity/transport ratio (Tabler 2003).

The range of observed setback distances (**D**) in this research was three times the range of *predicted* setback values [$\mathbf{D_{35}} = (\sin\boldsymbol{\alpha})35\mathbf{H_{req}}$]. This indicates that there is likely more variation than necessary in the setbacks observed in the field. This variation is likely due in part to site limitations, but also likely reflects the lack of consensus in the literature on how to determine a proper setback for living snow fences. The maximum observed setback distance was *twice* the maximum predicted value ($\mathbf{D_{35}}$) (Table 4), indicating that some setback distances are excessively large since predicted setback ($\mathbf{D_{35}}$) is a conservatively large estimate of setback that does not account for reduced drift lengths created by large capacity/transport ratios. There was no significant relationship between observed and predicted setback; nor between observed setback and height, capacity, or capacity/transport ratio; indicating that setback of living snow fences in New York State is not being consistently selected based on the model of predicted setback ($\mathbf{D_{35}}$), nor any other structural variable that would influence the length of the downwind drift. This again reflects the literature outside of Tabler (2003) which rarely provides the model of predicted setback, or any other method for determining an appropriate setback distance for living snow fences. In some cases, the setback of living snow fences in New York State is dictated by the available right of way space, the ability (or inability) to work with land owners to acquire additional planting space, and the presence of utilities or other landscape features than can limit planting space, further complicating the choice of setback and the interpretation of this data.

In many locations however, existing right of way space, which is often 10 m or more, may be sufficient to accommodate the entire length of the downwind drift on living snow fences based on the results of this research. Results showed that the capacity/transport ratios of living snow fences in New York State were between 8:1 and 110:1 for fences age five and older, indicating large amounts of excess storage capacity (**Q_c**>>**Q**) at early ages. Large amounts of excess storage capacity is associated with drifts that terminate in the early stages of drift formation, and resulting drift lengths that are a fraction of equilibrium drift length (35H) (Figures 10, 11).

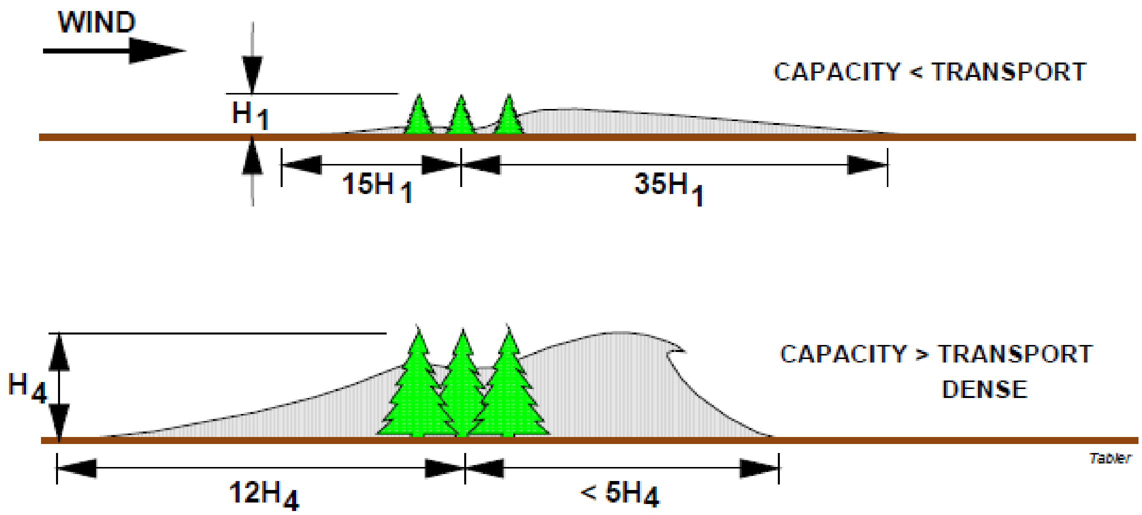

Figure 10: Changes in snowdrift shape and length as a result of changes in fence height, optical porosity, and capacity (**Q_c**) relative to snow transport (**Q**) of living snow fences (Diagram from Tabler, 2003)

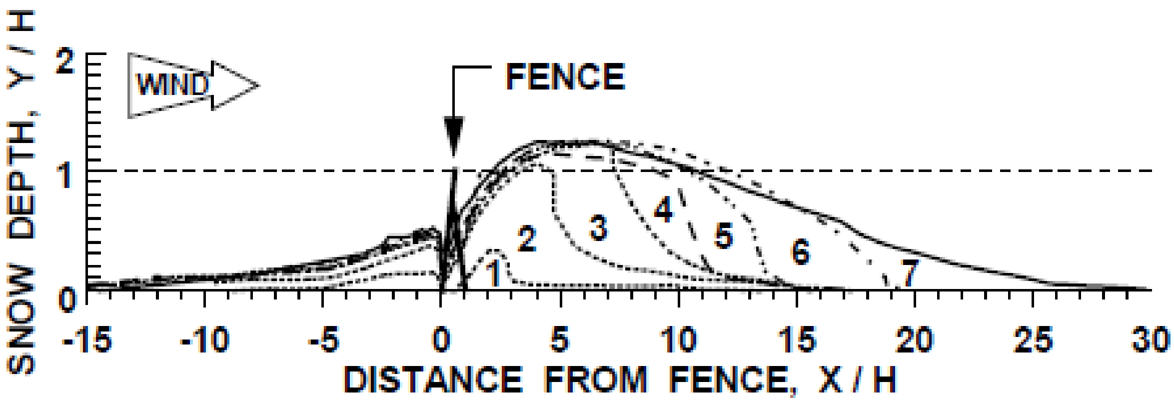

Figure 11: Progressive stages of snow drift formation around a 50% porous barrier (Diagram from Tabler, 2003)

Tabler (2003) is not explicitly clear as to whether drift model 1[$\mathbf{L} = ([10.5 + 6.6(\mathbf{Q}/\mathbf{Q_c}) + 17.2(\mathbf{Q}/\mathbf{Q_c})^2]/34.3)(12 + 49\mathbf{P} + 7\mathbf{P}^2 - 37\mathbf{P}^3)(\mathbf{H})$], or drift model 2 [$\mathbf{L} = ([10.5 + 6.6(\mathbf{Q}/\mathbf{Q_c}) + 17.2(\mathbf{Q}/\mathbf{Q_c})^2]/34.3)(12 + 49\mathbf{P} + 7\mathbf{P}^2 - 37\mathbf{P}^3)(\mathbf{H_{req}})$)], is the correct methodology for expressing predicted drift lengths in units of meters, so both possibilities were investigated as part of this research. Drift model 1 produced a series of predicted drift length values that was not significantly correlated with capacity/transport ratio, and did not produce the expected response of a negative relationship between the two variables. The drift lengths produced by model 1 were *larger* than the predicted setback ($\mathbf{D_{35}}$) 78% of the time. This is the opposite of the expected result which should show a *reduced* drift length compared to the conservatively large predicted setback value ($\mathbf{D_{35}}$) which does not account for the influence of capacity/transport ratio.

The drift length values produced by model 1 are not logical when considered in context of the stages of drift formation relative to capacity/transport as ratio discussed in Tabler (2003). When capacity/transport ratio was greater than 15:1 in drift model 1, drift length generally *increased* (Figure 8), producing illogical drift length outputs such as drifts 44 m in length when capacity/transport ratio was 50:1; and drifts 57 m in length when capacity/transport ratio was 110:1 (Table 4) under light snow transport conditions. Drift model 1 therefore *canno*t be considered a valid model of predicting drift length in units of meters, and should not be used to predict drift lengths for living snow fences.

In contrast to drift model 1, *drift model 2* produced a logical series of predicted drift length outputs for the fences and conditions investigated in this research. In drift model 2, there *was* a significant negative relationship between capacity/transport ratio and drift length (Figure 9), as expected based on the work of Tabler (2003) (Figure 10, Figure 11). The drift lengths produced by model 2 were *smaller* than the predicted setback 89% of the time, indicating the expected response to capacity/transport ratio in accordance with the stages of drift formation, in which drift length *decreases* in response to increasing capacity/transport ratio. Drift model 2 is therefore the correct interpretation of Tabler (2003) based on the results of this research, and a valid model for estimating the drift length in meters and appropriate setback distance of living snow fences of different heights, porosities, and capacity/transport ratios. The drift length values produced by model 2 are logical and consistent with the stages of drift formation described by Tabler (2003), in that very large capacity/transport ratios produce drift lengths that are substantially *smaller* than predicted setback values ($\mathbf{D_{35}}$), indicating that excess capacity of the fence is correctly reducing the predicted length of the downwind drift, which is synonymous with termination of seasonal drift growth in the early stages of drift formation as a result of excess storage capacity (Figure 10, Figure 11).

Drift model 2 showed that when capacity/transport ratio exceeds 15:1, drift length is always less than 10 m. If validated in future research, this is an important result for the design of living snow fences in New York State and beyond. When capacity/transport ratio exceeds 15:1 and drift length does not exceed 10 m. This is likely synonymous with the *first* stage of drift formation illustrated in Figure 11, where approximately 10% or less of the potential fence capacity (**Q_c**) is occupied by the seasonal snow transport (**Q**) at the site, and the length of the downwind drift is reduced to a fraction of the maximum 35H setback that is commonly prescribed in the literature. The final piece of this of this research to validate the predicted drift lengths of drift model 2 would be to monitor drift formation around living snow fences of known heights and porosities and compare predicted drift lengths from model 2 to *observed* drift lengths measured in the field. This task was originally included in the objectives of this research, but was not able to be accomplished due to frequent warming and rain events during the winters of 2011/2012 and 2012/2013 which negated any sustained drift growth over the course of the snow season.

If validated with observed values, the data and calculations of this research, the observed capacity/transport ratios, and the predicted influence on drift length from drift model 2 can be easily incorporated into the analysis and design of living snow fences. This offers the potential of a much needed methodology for more precise selection of setback distances to replace the vague and inaccurate generalizations offered in the current literature, and the limited usefulness of the predicted setback model (**D_{35}**). The trend of fence capacity observed in this research was shown to exceed snow transport after just three growing seasons, and increase capacity/transport ratios to levels of 100:1 or greater over the next eight years. For living snow fence design, drift model 2 can be used to estimate drift length and required setback distance for any fence of a known or estimated capacity/transport ratio. Likewise, the capacity/transport ratio and other variables of living snow fences of various vegetation types and ages can be estimated using the time series graphs and regression equations from this study, then applied to drift model 2 for design purposes. This would allow snow fence design teams to model the length of the downwind drift over time at different capacity/transport ratios, and select a setback distance that is most appropriate for the site conditions including available planting space and the long term snow and ice control goals of the site.

Using an even more simplified design approach based on the results of this research, if the chosen species and planting pattern of a planned living snow fence is expected to produce a capacity/transport ratio greater than 15:1 in a reasonable time frame, any setback distance 10 m or greater could be assumed adequate to store the estimated snow transport (Figure 9). This may allow the installation of living snow fences in areas where substantial blowing snow problems exist, but available planting space is limited. Calculations of exceedance probabilities could also be easily incorporated into this methodology by simply using a design transport that is some multiple of the estimated site transport when determining the capacity/transport ratio. However, the large capacity/transport ratios observed in this research demonstrate that exceedance probabilities for living snow fences in New York State of common vegetation types such as shrub-willow and conifer fences may be somewhat of an unnecessary calculation, considering that a capacity/transport ratio of 2:1 is equivalent to a less than 0.1% exceedance probability (Tabler 2003), and this capacity/transport ratio is likely to occur very early in the fences life cycle under light transport conditions. Reduced setback distances may limit storage capacity and increase the exceedance probability during the early years of a living snow fence's life, but capacity would still be greater than zero even with a reduced setback, providing some level of passive snow control before the fence produces large capacity/transport ratios that compensate for the reduced setback distance. However, reduced setback distances could cause drifts around the fence to form on the roadway before the fence grows to the point where large ratios are achieved representing a potential hazard to drivers and a serious safety consideration. The influence of capacity/transport ratios on exceedance probabilities should therefore be considered anotherimportant area of future research for living snow fences. The influence of site topography is an important consideration in the design of living snow fences which can limit or increase the snow storage capacity of the fence and influence the choice of setback distance.

Limitations of this Research

The estimates of snow transport in this research were modeled using the key assumptions of the relocation coefficient ($\mathbf{C_r}$) at all sites being equal to the statewide average of 0.17 provided by Tabler (2000); fetch area at all sites being measured at a perpendicular angle to the fence; Tabler's (2000) model of snowfall over the drift accumulation season [$\mathbf{S_{we,AS}}$ = (-695.4 + 0.076***Elev** + 17.108***Lat**)(0.10)(0.0254)]; and assumptions of what does and does not constitute wind obstructions that would cause snow deposition and limit the size of the fetch. Another notable limitation of this research is that only fences that could be identified through a combination of remote sensing and field investigations were measured and reported on. This represents a bias for sites that likely had superior plant selection, site quality, planting techniques, and post-planting care. However, the observations of this study, and perhaps even more ideal outcomes for living snow fences, *should* be obtainable for most new living snow fence installations when proper site analysis, design, plant selection, planting patterns, installation and management practices are employed (see Heavey and Volk 2013).

Finally, the winters of 2011/12 and 2012/2013 produced frequent temperature spikes well above 0^o C across New York State, as well as sporadic rain events. These conditions essentially eliminated the possibility of collecting useful data on snow quantities and downwind drift lengths around the living snow fences investigated in this study in those years, but some limited data was collected. Small snow drifts were measured around living snow fences Tully-willow-4, Preble-willow-9, Columbia-conifer-3, and Manhiem-honeysuckle-8 in late February 2013, but snow deposition around the fences was negligible, estimated at substantially less than 1 t/m in all cases. The maximum height of drifts around these fences was approximately 0.3 m and the maximum length of discernible downwind drifts was approximately 2 m.

CONCLUSION

Living snow fences can reduce or contain snow control costs and improve highway safety by disrupting wind patterns and causing controlled deposition of blowing snow in drifts before it reaches the roadway. The key structural variables influencing the snow trapping function of living snow fences are height and optical porosity. This research measured height and porosity on a stratified sample of 18 living snow fences of various ages (years since planting) and vegetation types in New York State. This data was analyzed using the models of Tabler (2000 and 2003) to estimate and interpret the snow trapping function of the fences. Height and capacity of fences increased linearly with increasing age as expected. Shrub-willow fences increased in height and capacity at a slightly faster rate than the trend amongst all fences. Porosity of fences decreased linearly with age as expected, with shrub-willow fences decreasing at a slightly slower rate than the trend amongst all fences. The estimated snow transport quantities at all sites was classified as very light to light (<20 t/m). Three years after planting, fence capacity was greater than the observed transport at each respective site, indicating that fences were fully functional at ages much earlier than what is commonly reported in the literature. For all fences age five and older, capacity/transport ratios were between 8:1 and 110:1. This substantial amount of excess storage capacity was expected to reduce the length of the downwind drift based on the stages of drift formation described by Tabler (2003). The survival and time until living snow fences become fully functional is highly dependent on proper plant selection and best management practices, which can heavily influence the economic performance and feasibility of living snow fences.

Two models of drift length were investigated, and drift model 2 was found to be a valid model for predicting the influence of capacity/transport ratio on drift length in accordance with the stages of drift formation. This model, which used the *required* fence height ($\mathbf{H_{req}}$) as a coefficient for expressing drift length in units of meters, consistently predicted drift lengths less than 10 m when capacity/transport ratios exceeded 15:1. These drift lengths are much smaller than the setback distances commonly recommended in the literature, and setback distances observed in the field in this research. If this result can be validated in future studies of observed snow deposition and drift length, it can be easily incorporated into the design of living snow fences to more accurately select appropriate setback distances based on predicted drift lengths as influenced by capacity/transport ratios. This would be a significant contribution to literature, which currently provides no consensus or precise methodology for modeling and selecting appropriate setback distances for living snow fences. This result may also allow more living snow fences to be installed in areas where there are substantial blowing snow problems, but limited right of way space for planting. The time-series graphs and regression equations produced in this research also have the potential to be useful design tools for modeling living snow fence structure and function at various ages.

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Appendix 1 – English Unit Tables

Table 6: English Units - Taxonomy and planting pattern of 18 living snow fences sampled in this study, sorted by vegetation type and age

Fence ID Tag (Town - vegetation type - age)	Scientific Name	Common Name	Fence Length (ft)	Plant Spacing (ft)	Number of rows	Row Spacing (ft)	Fetch Distance (ft)
Sardinia - corn - 1	*Zea mays*	standing corn rows	1148	4"	8	2' 6"	1115
Manheim - honeysuckle - 8	*Lonicera tatarica*	Arnold red honeysuckle	594	3'	1	-	676
Paris - willow - 1	*Salix purpurea, Salix miyabeana*	var. SX64, Fishcreek	377	2'	2	2' 6"	902
Beerston - willow - 2	*Salix miyabeana, Salix purpurea*	var. SX64, Fishcreek	1345	2'	2	2' 6"	420
Hamburg - willow - 3	*S. sachalinensis, S. dasyclados*	var. SX61, 98101-61	866	2'	2	2' 6"	2559
Tully A - willow - 4	*Salix miyabeana, Salix purpurea*	var. SX64, Fishcreek	1581	2'	2	2' 6"	2461
Tully B - willow - 6	*Salix caprea hybrid*	var. S365	771	2'	2	2' 6"	607
Tully C - willow - 6	*S. sachalinensis x S. miyabeana*	var. Sherburne	771	2'	2	2' 6"	607
Grand Gorge - willow - 7	*Salix purpurea*	shrub-willow purpurea	518	1'	1	-	561
Preble A - willow - 9	*S. miyabeana, S. sachalinensis*	var. SX64, SX61, 98101-61, 9870-42	630	2'	2	2' 6"	1575
Preble B - willow - 9	*S. miyabeana, S. sachalinensis*	var. SX64, SX61, 98101-61, 9870-42	377	2'	2	2' 6"	1214
Preble C - willow - 9	*S. miyabeana, S. sachalinensis*	var. SX64, SX61, 98101-61, 9870-42	381	2'	2	2' 6"	1765
Columbia - conifer - 3	*Picea abies*	Norway spruce	220	10'	3	7'	2805
Chautauqua - conifer - 4	*Picea pungens*	blue spruce	607	12'	3	10'	2034
Pomfret - conifer - 5	*Picea pungens*	blue spruce	459	12'	2	10'	1434
Spencerport - conifer - 6	*Pseudotsuga menziesii*	Douglas-fir	1224	6'	1	-	515
Gabriels - conifer - 8	*Thuja occidentalis*	northern white cedar	1132	7'	1	-	1542
Cobleskill - conifer - 11	*Abies concolour*	white fir	991	10'	2	10'	1043
Mean *5.7*	-	-	*778*	*4' 3"*	*2*	*4' 4"*	*1325*
Median *6.0*	-	-	*771*	*2'*	*2*	*2' 7"*	*1214*
Standard Deviation *3.0*	-	-	*384*	*4'*	*1.6*	*3' 3"*	*755*

Table 7: English Units - Summary of results for variables related to snow trapping function of 18 living snow fences of various species in New York State, sorted by vegetation type and age

	H_{req}	H	P	Q_c*	Q*	Q_c/Q*
Fence ID Tag (Town - Vegetation Type - Age)	Required Height (ft)	Observed Height (ft)	Porosity	Capacity (tons/ft)	Transport (tons/ft)	Capacity/Transport Ratio
Sardinia - corn - 1	3'	4' 3"	0%	1	2	<1
Manheim - honeysuckle - 8	2' 7"	7' 3"	63%	16	2	10
Paris - willow - 1	3' 3"	4' 11"	92%	<1	3	<1
Beerston - willow - 2	2'	6' 3"	88%	<1	1	<1
Hamburg - willow - 3	5'	7' 6"	77%	10	6	1.5
Tully A - willow - 4	4'	12' 10"	52%	56	4	13
Tully B - willow - 6	2' 3"	10' 10"	61%	38	1	30
Tully C - willow - 6	2' 3"	13' 10"	62%	65	1	50
Grand Gorge - willow - 7	2' 3"	19' 4"	47%	138	1	110
Preble A - willow - 9	3'	16' 5"	33%	80	2	34
Preble B - willow - 9	3' 3"	19' 4"	39%	130	3	44
Preble C - willow - 9	3' 7"	23'	26%	144	3	43
Columbia - conifer - 3	4' 3"	9' 6"	27%	22	5	4
Chautauqua - conifer - 4	4"	6' 11"	61%	13	4	3
Pomfret - conifer - 5	3"	11' 10"	41%	44	2	19
Spencerport - conifer - 6	2' 3"	18' 4"	29%	94	1	82
Gabriels - conifer - 8	4' 7"	11' 10"	39%	43	6	8
Cobleskill - conifer - 11	3' 3"	17' 5"	38%	100	3	39
Mean	*3' 3"*	*12' 6"*	*50%*	*62*	*3*	*27*
Median	*3' 3"*	*11' 10"*	*50%*	*56*	*3*	*16*
Standard Deviation	*1'*	*5' 7"*	*20%*	*47*	*2*	*31*

Note* - The $\mathbf{Q_c}$ and **Q** values reported in this table were rounded to the nearest ton/ft (short ton per linear foot) for clarity. The capacity/transport ratios ($\mathbf{Q_c/Q}$) reported in this table are the rounded ratios of the *actual* capacity and transport values, the same as reported in Table 3

Table 8: English Units **-** Observed setback, predicted setback, and models of drift length of 18 living snow fences of various species in New York State, sorted by vegetation type and age

Fence ID Tag (Town - Vegetation Type - Age)	Observed Setback Distance (**D**) (ft)	Predicted Setback Distance (**D_{35}**) (ft)	Predicted Drift Length Model 1 (ft)	Predicted Drift Length Model 2 (ft)	Capacity/Transport Ratio (**Q_c/Q**)
Sardinia - corn - 1	233	95	82	59	<1
Manheim - honeysuckle - 8	125	79	82	26	10
Paris - willow - 1	85	98	171	112	<1
Beerston - willow - 2	89	59	223	66	<1
Hamburg - willow - 3	92	151	154	98	1.5
Tully A - willow - 4	138	125	135	43	13
Tully B - willow - 6	33	72	112	23	30
Tully C - willow - 6	33	72	144	23	50
Grand Gorge - willow - 7	312	72	187	23	110
Preble A - willow - 9	43	108	141	30	34
Preble B - willow - 9	33	95	177	26	44
Preble C - willow - 9	30	105	174	26	43
Columbia - conifer - 3	171	135	92	39	4
Chautauqua - conifer - 4	194	121	92	52	3
Pomfret - conifer - 5	102	92	112	30	19
Spencerport - conifer - 6	121	69	144	16	82
Gabriels - conifer - 8	56	141	118	46	8
Cobleskill - conifer - 11	135	98	157	30	39
Mean	*112*	*98*	*138*	*43*	*27*
Median	*102*	*98*	*141*	*30*	*16*
Standard Deviation	*79*	*26*	*39*	*26*	*31*

Appendix 2 – Photos of Living Snow Fences

Figure 12: Living snow fence Sardinia-corn-1 from the leeward side of the fence in winter 2012/2013

Figure 13: Living snow fence Columbia-conifer-3 in winter 2012/2013

Figure 14: View leeward side of living snow fence Tully-A-willow-4 in winter 2012/2013

Figure 15: Small snow drifts formed around living snow fence Manheim-honeysuckle-8 in winter 2012/2013

Figure 16: Living snow fence Gabriels-conifer-8 (northern white cedar) in late fall 2012

Figure 17: Wide angle view of living snow fence Cobleskill-conifer-11 in fall 2011

All Photos by Justin P. Heavey