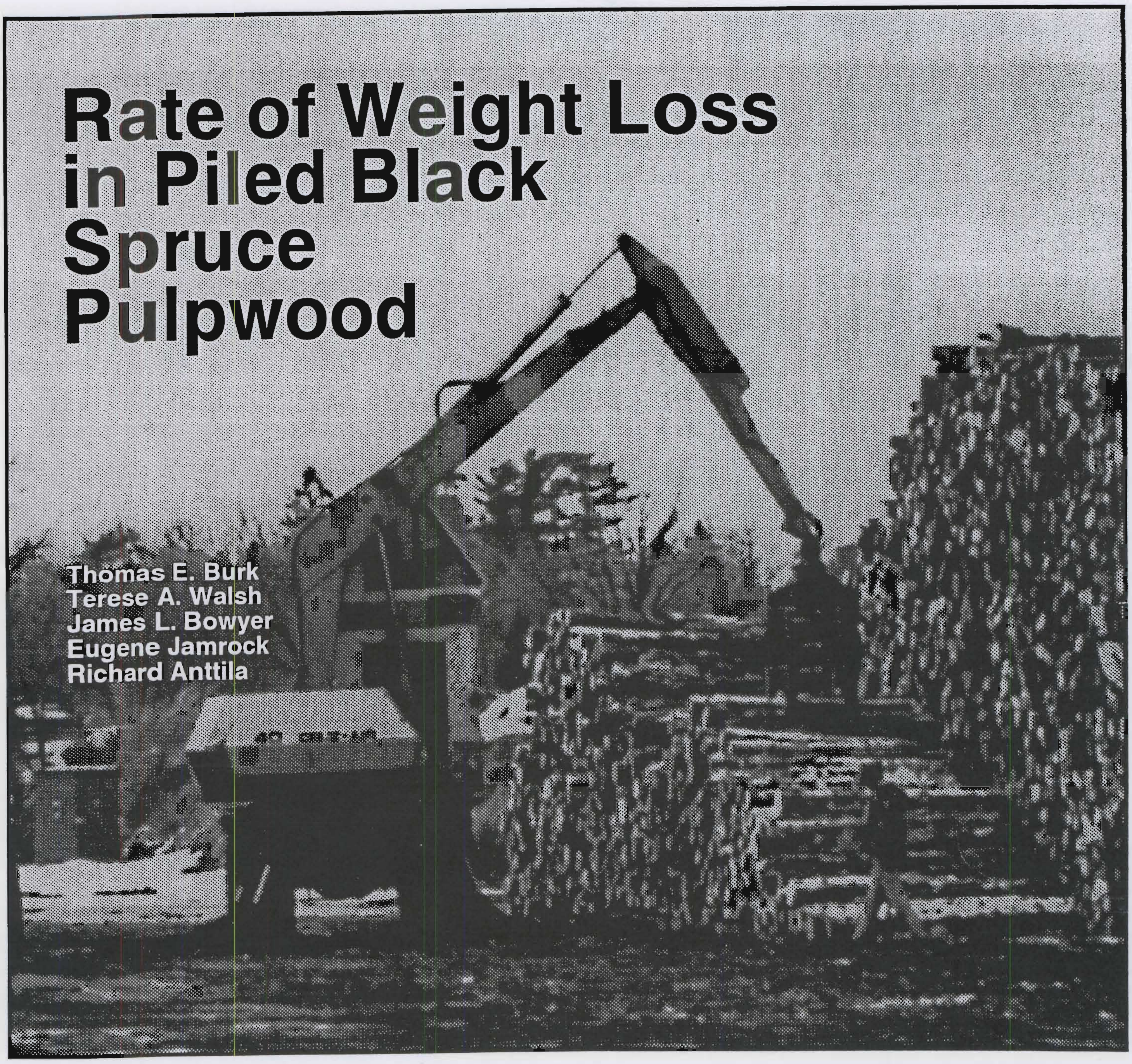
Rate of Weight Loss in Piled Black Spruce Pulpwood



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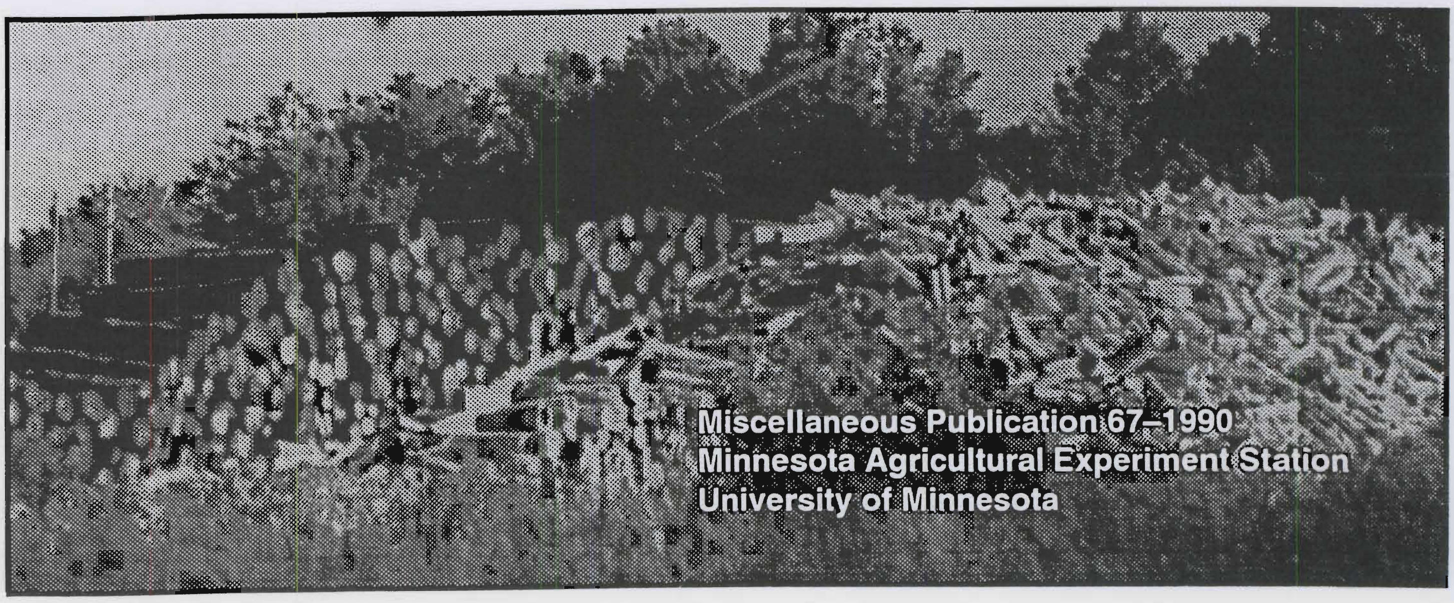

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Acknowledgements

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Availability

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RATE OF WEIGHT LOSS IN PILED BLACK SPRUCE PULPWOOD

Thomas E. Burk, Terese A. Walsh, James L. Bowyer
Eugene Jamrock and Richard Anttila

Abstract

Weight loss was monitored in six piles of black spruce pulpwood harvested in northern Minnesota. From these data, models were developed to estimate average rate of weight loss and predict how weight loss is affected by prevailing weather. The resulting equations are presented, evaluated, and their use illustrated.

Introduction

Pulpwood weight/value conversion factors are commonly based on a green weight standard in Minnesota. As wood naturally dries once it has been cut, conversion factors must be adjusted accordingly if an accurate valuation is to be made. Amount of weight loss will obviously depend on time since cutting and most probably on prevailing weather conditions during the storage/transport period. Droessler et al. (1986) have studied the problem and presented means of adjustment for aspen and balsam fir in Minnesota. This study extends that work to black spruce. An average daily rate of weight loss is computed and equations are presented that adjust that average for weather conditions. Equations are given for both exposed wood (wood in small piles) and buried wood (wood that is located deep within a pulpwood pile). Exposed and buried wood are treated separately in this study.

Field Procedure

Weight loss was monitored in piles of 100-inch black spruce pulpwood harvested during the winter immediately preceding data collection. The study covers three years (1985, 1986, 1987) with a different storage area (Williams, Little Falls, and Bemidji, Minnesota) involved each year. Each year, measurements began when snow and ice influence had dissipated and ceased when the wood was shipped in the fall. For each study year (and, thus, location) both an exposed and buried pile were tracked. The buried pile was weighed at the beginning date, buried in a typical large stock pile, and weighed again at the end date. The exposed pile was isolated so as to be totally exposed to the elements and was weighed on an approximately weekly basis.

Weighing was accomplished using a portable scale rigged in conjunction with a boom hoist. Rainfall, temperature and relative humidity data were collected daily over each study year.

Data were collected by Minnesota Department of Natural Resources (DNR) personnel working under the supervision of Eugene Jamrock and Richard Anttila of the DNR scaling office in Grand Rapids, Minnesota. Data were analyzed by a team of specialists from the Departments of Forest Resources and Forest Products, College of Natural Resources, University of Minnesota, St. Paul. Industrial cooperators were Champion International Corporation, Williams and Bemidji, Minnesota, and Hennepin Paper Company, Little Falls, Minnesota.

Data

A summary of the pulpwood pile measurements and associated weather data is presented in Table 1. Weather data were averaged over the periods between measurements. Figures 1-4 depict these data graphically. A lowess smoothing (Cleveland 1979) of the data for each location is superimposed on the last three scatterplots to ease interpretation of the rather noisy weather data; a smoothing window of approximately one-half the data was used. Only data from the exposed piles are displayed in Figure 1.

Measurements were begun and ended at different times during the year for each location. Initial pile weights were approximately 4,000, 3,000, and 5,000 pounds with the buried piles at each location starting at approximately the same weight as the exposed piles (Table 1). The cordwood measures for the three exposed piles were 1.01, 0.83, and 1.18 for Williams, Little Falls, and Bemidji, respectively, with the corresponding buried piles measuring 0.91, 0.84, and 1.09 cords. Thus, it was clear that the initial moisture contents of the piles were not equal. Weight

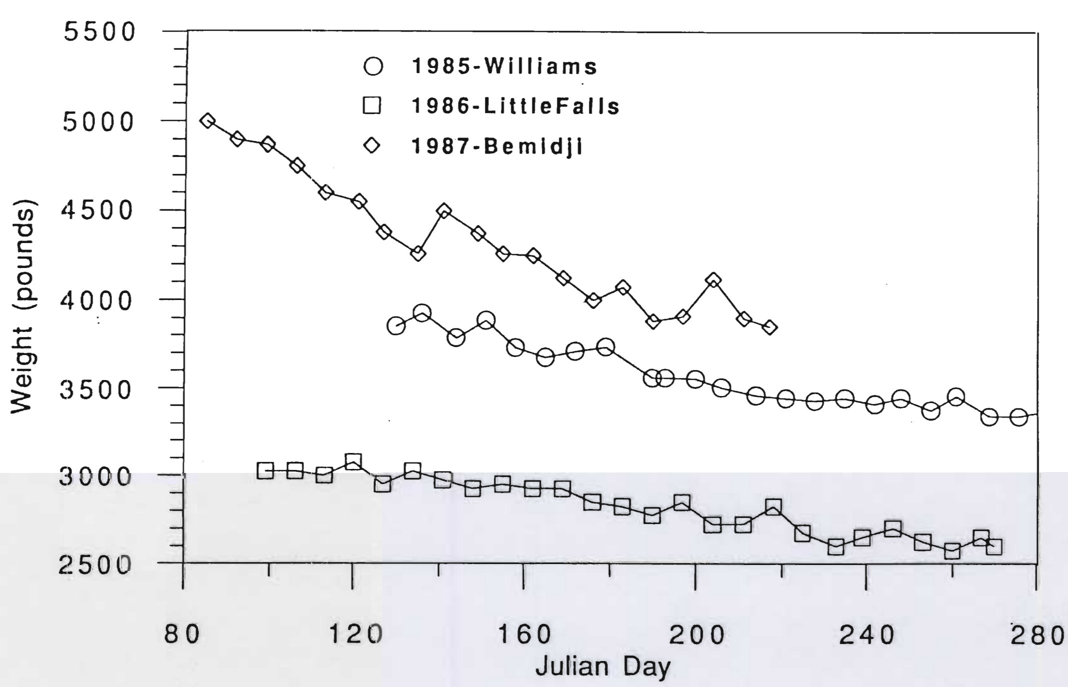

Figure 1. Weight of exposed stacks of piled pulpwood at three locations in Minnesota.

Table 1. Weight and associated weather data for piled, black spruce pulpwood weight loss studies conducted in northern Minnesota. Weight (pounds) at each Julian day is for pulpwood piles totally exposed to the elements. Corresponding buried pile initial and final weights at the three locations were, respectively, 3,650 and 3,235; 3,075 and 2,700; and 4,550 and 3,800.

1985 - Williams					1986 - Little Falls					1987 - Bemidji				
		Weather of Previous Period[a]					Weather of Previous Period					Weather of Previous Period		
Date	Weight	Rain	Temp.	Rel. Hum.	Date	Weight	Rain	Temp.	Rel. Hum.	Date	Weight	Rain	Temp.	Rel. Hum.
123	3875	–	–	–	94	3050	–	–	–	78	4975	–	–	–
130	3850	0.78	58	66	99	3025	0.03	46	67	85	5000	0.55	42	66
136	3925	1.45	53	78	106	3025	1.11	45	69	92	4900	0.08	28	64
144	3785	2.14	52	73	113	3000	0.90	43	73	99	4870	0.00	41	48
151	3885	1.37	57	73	120	3075	2.96	54	72	106	4750	0.00	51	48
158	3730	0.98	53	73	127	2950	0.04	55	69	113	4600	0.04	57	43
165	3675	0.32	57	72	134	3025	2.50	55	84	121	4550	0.23	55	47
172	3710	0.43	58	74	141	2975	0.57	54	74	127	4380	0.44	54	49
179	3735	4.13	58	82	148	2925	0.66	58	62	135	4260	0.09	60	51
190	3560	1.59	66	71	155	2950	0.13	70	69	141	4500	2.42	56	80
193	3560	0.03	62	68	162	2925	3.02	65	71	149	4375	2.04	55	78
200	3555	0.46	66	72	169	2925	0.33	63	76	155	4260	0.26	64	62
206	3505	1.35	63	70	176	2850	1.80	72	77	162	4250	0.12	61	68
214	3460	0.01	60	75	183	2825	0.05	71	78	169	4125	0.11	71	66
221	3445	3.78	66	79	190	2775	1.35	72	75	176	4000	0.19	74	71
228	3430	0.56	60	75	197	2850	1.95	70	73	183	4075	0.05	67	63
235	3445	2.18	58	79	204	2725	0.11	75	80	190	3880	0.68	68	80
242	3410	1.32	61	77	211	2725	1.12	73	79	197	3910	0.44	68	71
249	3445	1.85	58	84	218	2825	0.35	67	78	204	4120	5.99	74	78
256	3375	0.06	55	77	225	2675	2.13	67	74	211	3900	0.61	74	73
262	3455	0.14	60	78	233	2600	1.08	69	79	218	3850	0.32	75	71
270	3340	1.91	46	75	239	2650	1.83	63	79					
277	3340	0.51	41	79	246	2700	0.36	63	77					
284	3375	1.10	37	85	253	2625	1.25	58	66					
					260	2575	1.44	53	87					
					267	2650	4.47	57	82					
					274	2600	0.43	62	76					

[a]Summary of weather statistics for the period between successive measurements. Rain is total rainfall (inches), Temp. is average daily temperature (degrees Fahrenheit), and Rel.Hum. is average daily relative humidity (percent) during the period.

losses over time averaged 0.09, 0.09, and 0.18 percent per day for the exposed piles at Williams, Little Falls, and Bemidji, respectively and 0.07, 0.07, and 0.13 percent for the buried piles at the same three locations.[1] Several periods of weight gain occurred with the exposed piles. The weight loss trends for Williams and Little Falls were remarkably similar while the Bemidji pile initially appeared to lose weight at a greater rate and then shift to a similar, though more variable rate. With respect to the weather variables, average daily rainfall appeared to be generally lower for the study period at Bemidji, roughly 0.06 inches per day; Little Falls and Williams were again quite similar, with roughly 0.16 inches of rainfall per day (Figure 2). The temperature data were fairly consistent between sites and follow the expected yearly time course (Figure 3). Williams' temperatures were somewhat lower in the middle of the measurement period. Average relative humidity trends for the three sites were similar with little variability across time except for six substantially lower measurements near the beginning of the study at Bemidji (Figure 4).

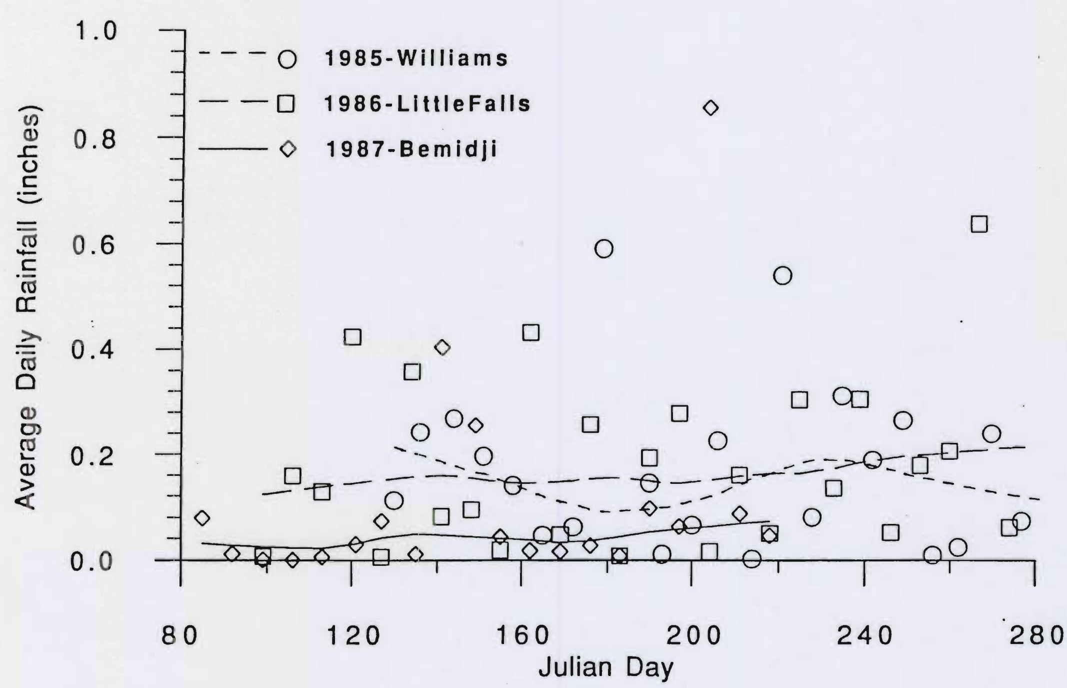

Figure 2. Average daily rainfall during the period prior to pulpwood pile measurement.

[1]Computed according to [1] as described below.

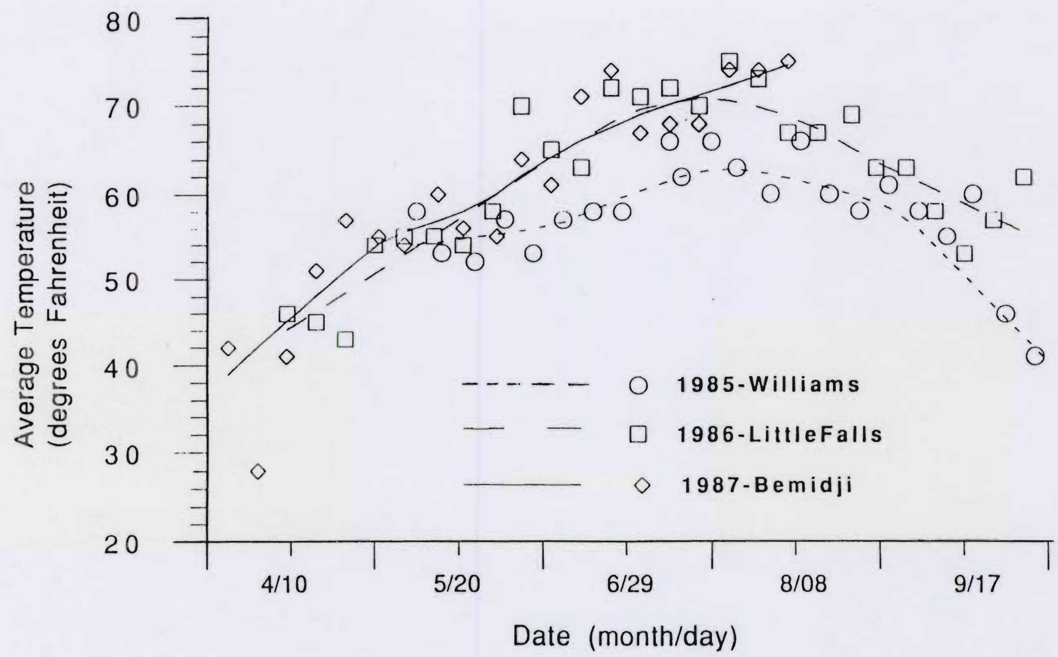

Figure 3. Average temperature during the period prior to pulpwood pile measurement.

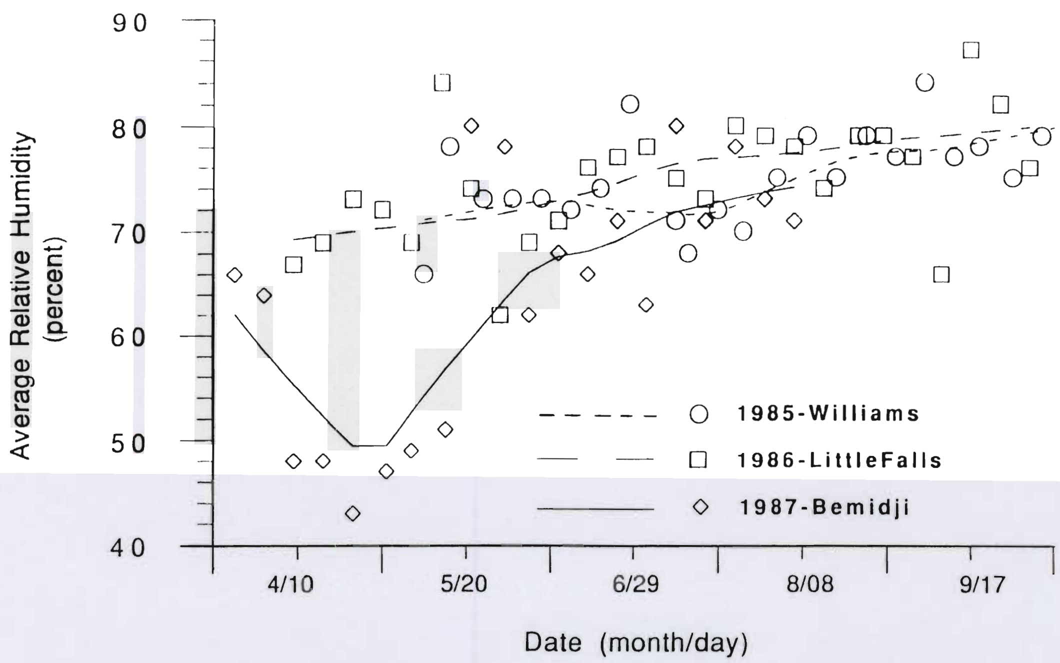

Figure 4. Average relative humidity during the period prior to pulpwood pile measurement.

Analysis Results

Exposed Piles

Initial examination of the exposed pile data centered on the equation

$$W_i = (1-\beta)^{t_i} W_{i-1} \qquad [1]$$

where: W = pile weight (pounds)
β = average daily weight loss between measurements (decimal percent)
t = number of days since prior measurement

and the subscript i denotes measurement number; such a formulation seems more realistic than assuming a linear relation between percent weight loss and time. This equation was solved for β so that an average daily weight loss could be computed for each measurement interval. These values were plotted for each study area over its respective study period (Figure 5); lowess smoothings were superimposed. Results for Williams and Little Falls are remarkably consistent with little trend across time. For Bemidji, β appears to start at a level similar to Williams and Little Falls, increase, and then fall again to near the initial level.

In addition to [1], weight loss based on assumptions of linearity in absolute $((W_i - W_{i-1})/t_i)$ and relative $((W_i - W_{i-1})/W_i/t_i)$ scales were computed and graphed. Results were similar to those found based on [1] so that further analysis efforts focused on [1].

Equation [1] in log-linear form was separately fit to the data from each location. A log-linear form was chosen to ease subsequent analysis and because residual analysis did not produce evidence that errors in [1] were definitely additive. However, all error comparisons and reporting was and is done in terms of weight or weight loss. In addition to the separate fits, a pooled fit was performed and the standard F-test of no differences between locations computed. The F-test had a p-value of 0.57 and was not rejected implying that the data do not support outright differences in drying rate for the three study sites.

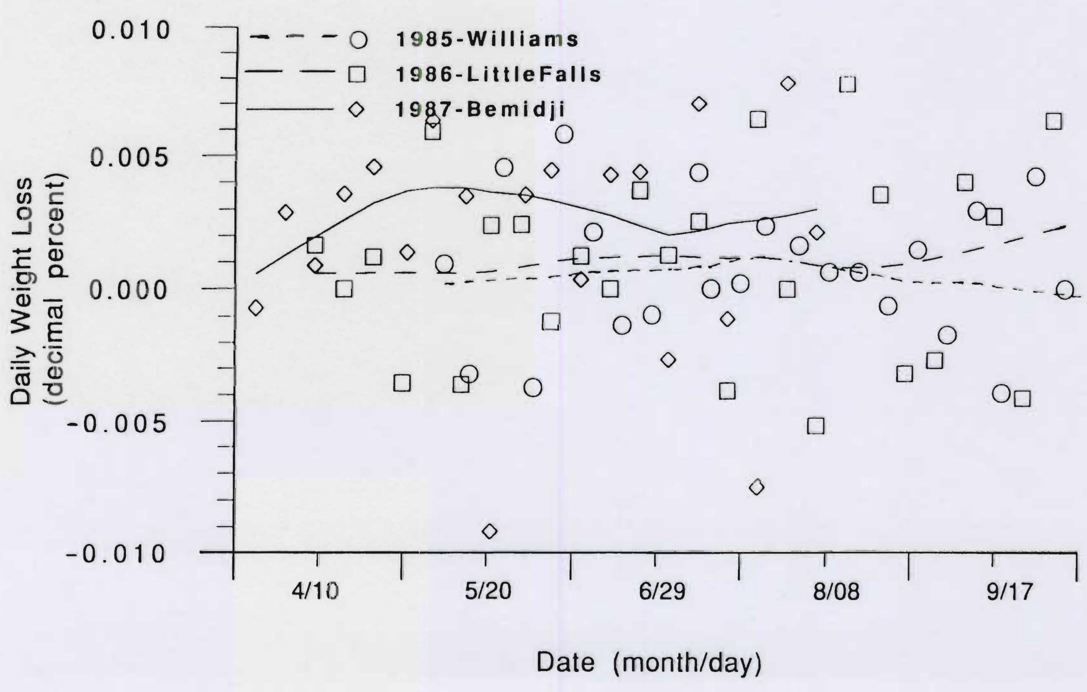

Figure 5. Daily weight loss of exposed stacks of piled pulpwood at three locations in Minnesota.

Since the data at hand are longitudinal it was felt that account should be taken of potential autocorrelation between errors. Initial residual analysis had suggested possibly significant negative correlation within locations; contemporaneous correlation between locations was not examined. The approach suggested by Denby and Pregibon (1987) gave a first estimate of ρ (autocorrelation) of -0.3. Generalized least squares was then used with ρ = -0.1, -0.2, -0.3, -0.4, -0.5 and the ρ selected which gave minimum first order autoregressive absolute prediction error. The ρ and corresponding β were -0.3 and 0.001206, respectively. These results imply that the average daily weight loss for exposed, piled black spruce pulpwood is approximately 0.12 percent.

To evaluate the fit of [1], two types of errors were computed. First, [1] (with β estimated as just described) was applied repeatedly to the data series beginning with the initial known weight and progressing through each measurement period (denoted Type 1 error); note this allows errors to accumulate and is equivalent to predicting each weight from initial weight and number of days since initial weight. Second, each measurement weight was predicted from the previous measurement's actual weight (denoted Type 2 error). The Type 1 and Type 2 absolute prediction errors relative to actual were 3.5 and 1.9 percent, respectively, when averaged across the three locations (Table 2). Errors at Bemidji were somewhat higher than those for Williams and Little Falls. Type 1 error rate is likely more pertinent to the actual application of the equation. Since the errors have been computed using the data to which the equation was fit, we know they are probably under-estimates to some degree (Burk 1990).

Although seemingly not statistically significant, the observed trend difference for Bemidji, the associated rainfall difference, and the larger errors found there invited additional study. The approach taken was to model how the measured weather variables influenced β. For this purpose the following model forms were examined

$$1 - \beta = b_0 + \sum_{j=1}^{k} b_j (x_j - \bar{x}_j) \qquad [2]$$

$$1 - \beta = b_0 + \sum_{j=1}^{k} b_j \ln(x_j - \bar{x}_j + c_j) \qquad [3]$$

$$\ln(1 - \beta) = b_0 + \sum_{j=1}^{k} b_j (x_j - \bar{x}_j) \qquad [4]$$

$$\ln(1 - \beta) = b_0 + \sum_{j=1}^{k} b_j \ln(x_j - \bar{x}_j + c_j) \qquad [5]$$

where: b = regression coefficient
k = number of weather variables considered
x = weather variable (average daily rainfall, average temperature, average humidity)
$\bar{x}$ = average of weather variable for northern Minnesota
c = arbitrary constant to avoid taking logarithm of a negative number

Table 2. Weight prediction error rates (percent of actual) from data used in fitting the weight loss models. Type 1, 2, and 3 errors are defined in the text. The simple model is equation [1] while the enhanced model is equation [1] with β adjusted by rainfall (cf. [6]).

	Type 1 Error		Type 2 Error		Type 3 Error
	Simple[a]	Enhanced[a]	Simple	Enhanced	Enhanced
1985 - Williams	1.7	1.5	1.5	1.7	1.5
1986 - Little Falls	3.3	2.8	1.9	1.8	2.7
1987 - Bemidji	5.8	1.6	2.3	1.9	1.6
Average	3.5	2.0	1.9	1.8	2.0

[a]Results based on simple model and enhanced model, respectively.

Thirty-year averages for the weather variables were obtained from van der Leeden and Troise (1974) using dates of April 1 to October 31; the values were 0.085 inches of rain per day, 55 degrees Fahrenheit, and 71 percent relative humidity. Fitting was carried out by substituting each of [2] through [5] into [1] or its log-linear form and applying nonlinear or linear least squares. Generally there was little difference between the model forms in terms of performance or diagnostics. Rainfall by itself was always a highly significant variable. Relative humidity was usually significant and temperature seldom was. When pairs of variables were used, the second was usually not significant, though the signs of the coefficients were always correct. Residual analysis failed to detect any model deficiencies. To choose between models/ variable combinations, the Type 1 and 2 errors presented above were computed for each case. Based on that analysis, equation [5] with only the rainfall variable was chosen. The relationship determined between β and rainfall decreases slightly nonlinearly, implying a switch between weight loss and weight gain at roughly 0.3 inches of rain per day (Figure 6). Although this would appear to be a rather crude accounting of weather effects, the resolution of available data and the mode of intended application of the model argued against more complex formulations.

To again account for autocorrelated errors, generalized least squares was applied to the system

$$\ln W_i - \ln W_{i-1} = b_0 t_i + b_1 t_i \ln(x - \bar{x} + 3) + e_i \qquad [6]$$

$$e_i = \rho \, e_{i-1} + \upsilon_i$$

(where x is now average daily rainfall and the second line represents the assumption of first-order autocorrelation) for different values of ρ and an optimal value chosen using the criterion presented above. This gave coefficient estimates of

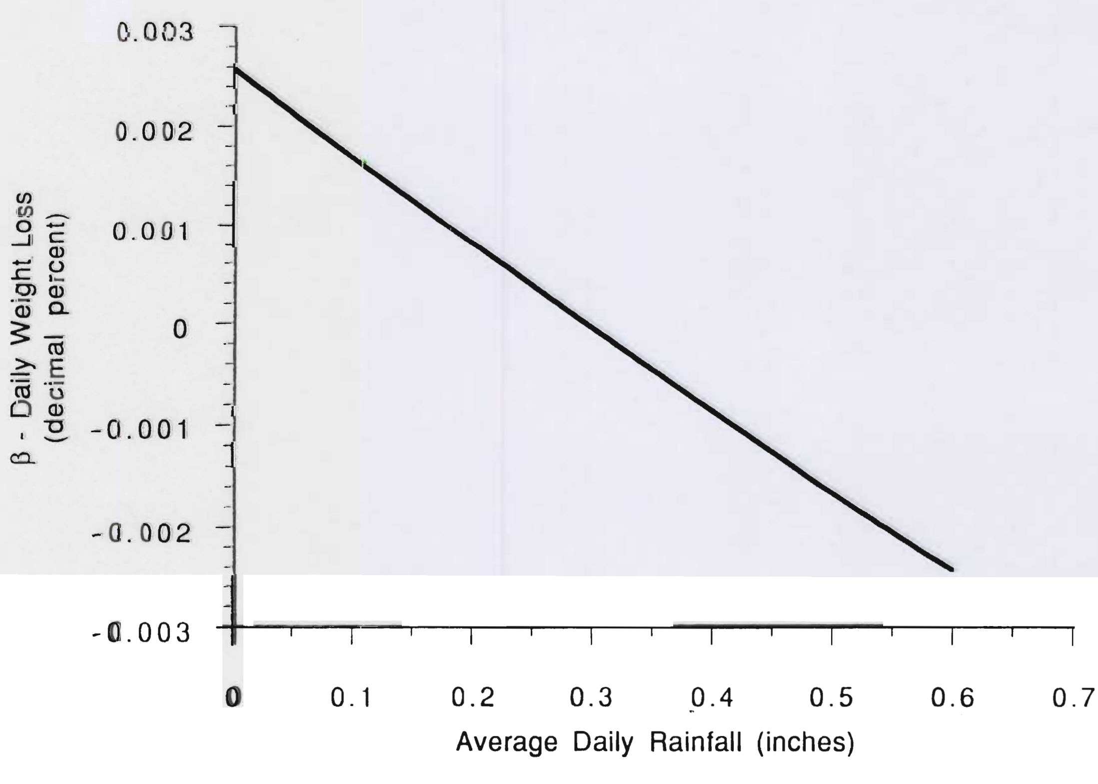

Figure 6. Relationship between daily weight loss parameter and average daily rainfall.

b_0 = -0.03125458
b_1 = 0.026796

based on a ρ of -0.5. With average rainfall the implied β is 0.001815, somewhat higher than the average β found for the study; this is a direct effect of rainfall being above normal, on average, for the study periods. Results for the two error types and [6] are presented in Table 2. A Type 3 error is also presented. This error is computed by predicting each weight from initial weight, number of days since initial weight, and the running average rainfall over the period. Results for the different error types differ little for a given model. The weather enhanced predictions improve on the simple model by approximately 40 percent (Type 1 error) although on an absolute basis the gain is only moderate. Not surprisingly, the biggest improvement is for Bemidji. The panels in Figure 7 show the actual data trends overlaid by predictions from the simple and enhanced models. The models were applied iteratively beginning at the initial measurements so these results are analogous to the Type 1 errors described above. Predictions fall both below and above actual data trends. The weather enhanced model predicts weight gains for several periods as seems appropriate. The weather enhanced model tracks the data better than the simple model in most cases, especially at Bemidji. Little Falls' data trends are described the poorest. Type 3 error-based projections (not shown) for the enhanced model are similar to those shown. Likewise, Type 2 error-based projections exhibit better data tracking as expected.

Buried Piles
It was not feasible to obtain periodic measurements on buried piles and thus there are simply three buried pile weight loss observations, one for each location. With only three points of comparison, it is ill-advised to attempt to interpret the results of a test of buried versus exposed weight loss. For example, a paired t-test indicates there is no significant difference (p-value ≈ 0.2) while, since all the differences are positive, any sensible nonparametric test would declare significance. The results of the t-test are particularly suspicious due to the high variation caused by Bemidji results. With only one observation per location, attempts to ascribe location differences to anything more specific than location (e.g., weather) would be rash.

Equation [1] was fit to the three buried pile observations and the resulting estimate of β was 0.000949 implying an average daily weight loss for buried, piled black spruce pulpwood of approximately 0.09 percent. As would be expected, applying this to the data results in overpredicting weight loss for Williams and Little Falls and underpredicting weight loss in Bemidji; all errors were approximately 4 percent of the final value.

For comparison, the weather enhanced model developed for exposed piles was applied to the buried pile data. Errors ranged from 4 to 5 percent with weight loss being overestimated in each case (final weight underestimated). Thus, an alternative method of handling buried piles would be to adjust the weather enhanced, exposed pile model by 4.5 percent. As buried piles become less like exposed piles as times progresses, this should be done with great caution for period lengths different from those realized in the present study.

Application

Two means of predicting weight loss of piled black spruce have been devised, one which requires knowledge of rainfall information, and is thus more accurate, and one that does not. An example of applying each will now be given. The subject pile will be assumed to have been weighed on April 10 at 4,500 pounds and shipped on September 7.

If no rainfall data are available or the increase in accuracy obtained by using rainfall data is not important, equation [1] may be applied with β = 0.001206 for exposed piles. For the example, t_i = 150 days so that

$$W(\text{August } 10) = (1 - 0.001206)^{150}\, 4500 = 3755 \text{ pounds}$$

For buried piles, β = 0.000949 giving

$$W(\text{August } 10) = (1 - 0.000949)^{150}\, 4500 = 3903 \text{ pounds}$$

If the average daily rainfall over the period was 0.06 inches, an adjusted β could be computed as

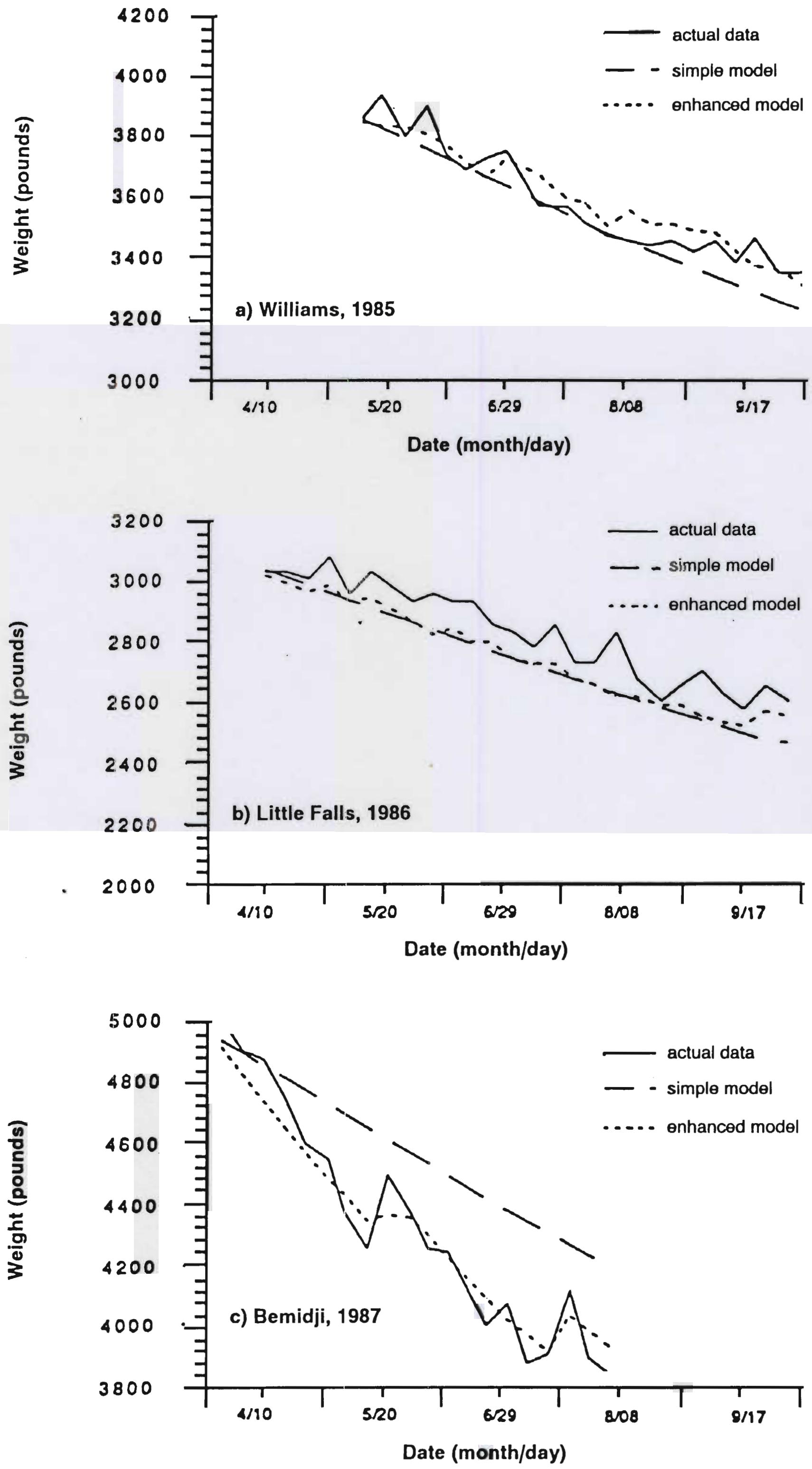

Figure 7. Comparisons of model predictions with actual data from (a) Williams, (b) Little Falls, and (c) Bemidji, Minnesota. Model application corresponds to that for type 1 error (see text).

$$\beta(\text{adjusted}) = 1.0 - 0.9692288*(0.06\text{-}0.085+3)^{0.026796} = 0.0020383$$

giving a weather adjusted estimate for an exposed pile of

$$W(\text{August } 10) = (1 - 0.0020383)^{150}\ 4500 = 3314 \text{ pounds}$$

For buried piles, applying the average 4.5 percent adjustment

$$W(\text{August } 10) = 3314/0.955 = 3470 \text{ pounds}$$

More accurate determinations could be made if the 150 day period was broken down into shorter intervals, a weather adjusted β computed for each, and weight loss computed repeatedly across the intervals (compare Type 1 and Type 3 errors in Table 2). Such a procedure should not be applied if interest lies in buried piles.

Discussion

The rate of weight loss in exposed piles of black spruce pulpwood appears to vary little across locations in northern Minnesota given average rainfall conditions. Rainfall affects drying in the predicted way. The average **weekly** weight loss for exposed piles of black spruce (0.8 percent) is similar to that found for aspen (0.7 percent) by Droessler et al. (1986); the same authors found a value of 1.6 percent for balsam fir.

The models presented do a reasonable job of describing weight loss for the three years/ locations studied. Rainfall conditions for two of the three years were somewhat above average while rainfall in the third year was somewhat below average. The degree to which the three piles studied represent the variability inherent in pulpwood piles in northern Minnesota is unknown and thus the reliability of the models should be examined wherever possible. It should be noted that all piles in the study were in the range of 0.8 to 1.2 cords. Application of study results to pile sizes outside this range should be done cautiously. For buried piles, observations were only available for time periods of approximately 140, 160, and 180 days. Caution should be exercised when estimating weight loss of buried piles for period lengths much different that those in the study. The models presented here appear somewhat more accurate than those of Droessler et al. (1986) though the difference may be purely a function of the lower variability in the present data.

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