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Microclimate impact of harvester trails in *Picea abies* continuous cover stands in boreal Sweden

Mikroklimatets påverkan av körvägar i olikåldriga *Picea abies* bestånd i boreala Sverige

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PREFACE

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SUMMARY

This study aimed to compare the microclimate 20 cm above the ground in the harvester trail to the inner sections of selectively felled Norway Spruce (*Picea abies* (L.) H. Karst) stands in the Jämtland province in boreal Sweden. Data was provided by Klara Joelsson, who had placed the iButtons © hydrocrone 1923 instrument in the plots, which took readings of the relative humidity and temperature every 2 hours between the 6th of June and 19th of October 2015.

The general linear model showed that sites in the harvest trail experienced a temperature span increase (24,70%) as the daily maximum temperature increased (12%) and the daily minimum temperature decreased (-4,8%) to new extremes compared with the inner stand. Maximum daily relative humidity is rather unaffected (+0,85%), but Minimum relative humidity decreased (-7,1%).

A light index was calculated from fish-eye images with Gap Light Analyzer, in which the ratio of incoming (direct and diffuse) solar radiation just above the ground is compared to the amount above the canopy. With this could be shown that for every percent the ratio increased, the maximum daily temperature increased by 0,08 C°; the minimum temperature decreased by 0,02 C°); the temperature span recorded during the day increased by 0,10 C° and the daily minimum humidity decreased by 0,24 %rh.

The daily maximum temperature and temperature span is greatly influenced by the amount of transmitted light from the canopy, indicating that there may be a great deal of in-stand variation dependent upon smaller gaps.

Keywords: Gap Dynamics, Temperature, Humidity, Canopy cover, Natural Disturbance Emulation

SAMMANFATTNING

Denna studie ämnade jämföra mikroklimatet 20 cm ovanför marken i körvägen mot de inre delarna av blädade granbestånd (*Picea abies* (L.) H. Karst) i boreala Sveriges Jämtländska landskap. Data tillhandahölls av Klara Joelsson, som hade placerat ut en temperatur och fuktighetsmätare (iButtons © hydrocrone 1923) som tog mätningar varje två timmar mellan den 6:e juni och den 19:e oktober 2015.

Den allmänna linjära modellen visade att försöksytorna i körvägarna hade ett högre temperaturspann (24,70%) allteftersom den dagliga maximala temperaturen ökade (12%) och den dagliga minimala temperaturen minskade (-4,8%) mot nya extremer jämfört med de inre beståndsdelarna. Maximala dagliga relative humiditeten var mer eller mindre opåverkad (+0,85%), men den minimala relative humiditeten minskade (-7,1%).

Ett ljusindex beräknades från fisheye bilder med Gap Light Analyzer, i vilken en kvot skapas av inkommande (direkt och diffus) strålning från solen precis ovanför marken gentemot strålningen ovanför krontaket. Med detta kunde visas att för varje procents ökning av kvoten, ökade den maximala dagliga temperaturen med 0,08 C°; den minimala dagliga temperaturen minskade med 0,02 C°); det uppmätta temperaturspannet för dagen ökade med 0,10 C° och den dagliga minimala relative humiditeten minskade med 0,24 %rh.

Den dagliga maximala temperaturen och det dagliga temperaturspannet är mycket känsliga för förändringar i mängden genomsläppt ljus från krontaket, vilket kan tyda på en stor variation inom beståndet beroende av mindre luckor.

Nyckelord: Luckdynamik, Temperatur, Humiditet, Krontäckning, Efterlikning av naturliga störningar

INTRODUCTION

Global decline in biodiversity, undeterred by international endeavors (Butchart 2010), stands a mammoth challenge to be addressed by international policy makers, private corporations and national governants alike. The issue has gained momentum during the last couple of decades as usage of the forest certification schemes introduced by Environmental Non-Governmental Organizations to satisfy purchaser preference for sustainable produce has spiked among private companies (Cashore 2004). These forest certification schemes often require varying degrees of area offset production for conservational purposes.

However, the road to preserve and safeguard species may in the long term be fraught with difficulty. Our understanding is limited, and accordingly, it is appropriate to employ a precautionary approach in which economic, conservational and sociopolitical gains or losses are considered before the implementation of any intervention or change in usage of the land where there is strong scientific evidence for that environmental harm will be done (Cooney 2004). It is furthermore uncertain that the ecosystem will rebound to an earlier state after a change in species composition or environmental change – prompting interventions to maintain a desired state (Folke 2004). Therefore, it is key to strive towards maintaining landscape heterogeneity (Tews et al. 2004) and avoid further habitat degradation in order to ensure ecosystem function by maximizing biodiversity (the insurance hypothesis) (Yachi, Loreau 1999).

Although North American research has mostly touched reconstruction of fire regimes (Long 2008), Kuuluvainen (2002) states that boreal Fennoscandia is more heavily influenced by small scale disturbances such as insect outbreaks, gap dynamics, fire-surviving patches or ecosystem engineers such as beavers. These did play an exceedingly large role in determining forest structure on a local, regional and landscape scale prior to anthropogenic impact (Kuuluvainen 2002). This shift away from the understanding of there being an end stage species composition in a landscape represents part of the nonequilibrium paradigm shift (Wu & Louckes 1995), wherein patch dynamics are stressed as essential to the perseverance of processes in a dynamic and heterogenic landscape.

Due to the tremendous anthropogenic impact upon the landscape, it is of great interest to explore management options aimed at mitigating species extinction and loss of biodiversity. Many threatened forest species may be dependent upon habitat (such as those dominated by small scale disturbances), which have not been favored by the rationalization process of traditional forest management and the introduction of clear-felling (Noss 1999). Natural Disturbance Emulation (NDE) interventions are one such option, and aim to "reproduce and maintain the essential forest structural features that are present in the forest under a natural disturbance regime" (Kuuluvainen & Grenfell 2012). By acting discordant to the largely homogenous management of timber production forests, NDE has potential to increase structure complexity and provide habitat for species with specialist or asymmetric niches that are not sufficiently provided for with current standards. Picket (1980) proposed disturbances govern species composition by preventing dominant plant species from outcompeting inferior species by establishing a non-equilibrium state.

However, should Natural Disturbance Emulation be used by forest managers to preserve threatened native species, there must exist a clear frame of reference in what disturbances are considered appropriate for any given area. This is in part encompassed by the term “Natural Range of Variability”, which refers to “the ecological conditions, and the spatial and temporal variation in these conditions, that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal” (Landres et al. 1999).

In order to properly maintain or reconstruct the perceived natural range of variability, that is the disturbance processes present prior to human influence, it is useful to plan in a wider spatial and temporal scale as to assure the survival of those target species which are dependent upon disturbance-related structures. Successively, there has grown forth an idea of a ‘coarse’ respectively a ‘fine’ filter in order to structure management actions. The ‘coarse’ filter corresponds to interventions or management practice at a community level, whereas the ‘fine’ filter corresponds to actions taken to preserve target species whom are in need of additional, targeted support beyond the scope of general management (Noss 1987).

Gustafsson & Perhans (2010) cite Mather (1992, original source unavailable) in that general management in modern Swedish forestry is dominated by a clear-cut rotation, which has resulted in a widespread reduction in much of the heterogeneity found in untouched forests. Selection felling may provide us with a forest management alternative which better balances sustainable timber yield with biodiversity.

Seeking to evaluate the ecological performance of selection felling as a fine filter, Kuuluvainen, Tahvonen & Aakala (2012) draw the conclusion that selection felling better emulates the arrangement and complexity of older forests than stands in clear-cut harvesting rotations. This as, to mention a few, selection cutting is associated to: smaller changes in blueberry cover after the first cutting than if the stand were clearcut (Atlegrim & Sjöberg 1996); a higher retention of late successional species than retention forestry or clearcutting (Jalonen & Vanha-Majamaa 2001), and causes no reaction from forest soil animal communities (Siira-Pietikäinen & Haimi 2009).

Studies such as these, although confined to short-term responses, indicate that selection felling shows promise as a suitable alternative to maintain ecological continuity in a landscape, as a part of the ‘fine filter’. To further evaluate these alternatives, it is of paramount importance that we continue to investigate those underlying environmental settings, ‘state factors’ (Jenny 1980) if you will, that govern the ecological dynamics and indeed entire ecosystem structure, in novel situations; under varying spatial and temporal scales – and anthropogenic influence.

In regards to a targeted species’ population persistence, knowledge of its niche is fundamental in administering appropriate interventions to successfully maintaining or increasing a population size (Schoener 2009). In the niches n-dimensional hypervolume, temperature and humidity levels are two environmental factors which may vary depending upon forest structure (Chen et al. 1999) and are easy to record, making them ideal to study. Bell et al. (2015) found that the amount of canopy cover (in effect level of sun-exposure) was an important factor in changing the community composition of Saproxylic beetles. Thus, increasing our understanding of how small scale forest disturbances are associated with the microclimate and potentially biodiversity should be given high priority in order to develop species-targeting support that can prevent further escalating the loss rate of species.

The study therefore aimed to determine whether 1) The air temperature or humidity is affected by the construction of a harvest trail in all-aged stands of Norway Spruce, *Picea abies* (L.) H. Karst, and 2) If these eventual effects are correlated to light intensity.

To that affect, this study evaluated the validity of the following hypotheses:

I. The Daily Air Temperature Range Span (Tspan) will increase with the construction of a harvester trail, as the Daily Air Temperature Maximum (TMax) and Minimum (TMin) will reach new extremes.

II. The Daily Maximum (RHMax) & Daily Minimum (RHMin) Relative Humidity will all decrease with the construction of a harvester trail.

III. TMax & Tspan will correlate positively with the constructed Light Index (LI).

IV. TMin, RHMax & RHMin will correlate negatively with the LI.

MATERIALS AND METHOD

Data Collection

Temperature and humidity data was collected at a height of 20 cm above the forest floor with the iButtons hydrocron 1923, calibrated to ±0,0625 degrees and ±0,04%rh. Measurements were taken every two hours between the 6th of June 2015 and the 19th of September 2015 and compiled to present the daily maximum and minimum values.

Four different treatments were included in the study; selective felling, clear-felling, thinning and control - divided at a total of 19 stands. Of these stands, nine had been selectively felled, with 20-30% outtakes per treatment, four clear-felled, four thinned and three were control stands. In the selectively felled stands, data was collected at four locations: two plots in-between the harvest trails and two plots centered on the trails. The plots in the harvest trails will here forth be referred to as "open", whereas the plots positioned in the stands will be referred to as "closed". The harvest trails had an average width of four meters. Every open plot has a closed sibling plot in the middle of the stand between the harvest road which the open plot is placed upon and the next.

Although this study deals primarily with all-aged continuous cover forestry with Norway Spruce, clear-felled, thinned and control plots are included to provide a frame of reference.

The study was conducted in Jämtlands and Västernorrlands counties, Sweden at latitude 63.0 -62.3 and longitude 15.2 – 16.4 degrees. All selected stands were dominated by Norway spruce (> 70%) mixed with birch (Betula pendula Roth. and B.pubescens Ehrh.), and random occurrence of scots pine (Pinus sylvestris L.), aspen (Populus tremula L.) and salix. Ground vegetation was mainly composed by bilberry and low herbs. The size of the stands varied from 2-16 ha, with an average size of 8 ha.

Fish-eye photographs of canopy cover were taken in a horizontal angle at a height of between 40 and 50 centimeters from the forest floor with a Canon EF 8-15/4,0 L USM Fisheye. The focal point was locked at 8 mm. Some photographs however bypassed the lock, resulting in 5 images with 9mm focus and 4 images with a 10 mm, causing a situation where the fisheye image was larger than the containing photograph.

Gap Light Analyzer & Magnetic Declination

Gap Light Analyzer (GLA) was used to calculate Transmitted Total Radiation (% Trans. Tot): the ratio between the incoming radiation to a covered horizontal plane at ground level wherein the effect of canopy shading is taken into account, compared to the incoming radiation to its uncovered counterpart. GLA sorts pixels into a binary format by the user adjusting contrast levels manually until the working image correctly resembled the original albeit in black and white. Certain image features had to be adjusted manually, as in some images there has been dark clouds or mosquitos which were incorrectly classified as foliage.

Several variables are required by GLA in order to calculate the amount of transmitted light. Those which were adjusted from the default are given below: Growing season was given by the Swedish Meteorological and Hydrological Institute between 2006 and 2015 for sites in the north of Sweden as between the 24th of April and 9th of October (SMHI 2016).

Declination figures for compass direction required by GLA were calculated by data from the World Magnetic Model. The tool was provided by the National Oceanic and Atmospheric Administration (2016). It was used to retroactively correct magnetic north to a mean of 4° 37' declination eastward between 08/06/2015 and 19/08/2015 for the site 62°44'N, 14°25'E. Height was given as 384 meters above mean sea level. This averts from the intended loci at 62°45'2" N, 15°25'18" E, roughly corresponding to the nearby town of Bräcke, due to an error. The intended declination was 5°4'36" E. However, the declinations just barely overlap with an uncertainty of 0°28'. North was determined onsite by a compass, after which the camera was adjusted in order to always maintain North at 0° in the image.

As recommended by the GLA manual, Sky-region brightness was modelled by a Uniform Overcast Sky (UOC) model in order to give as close a value as possible to those calculated by GLAs predecessor, GLI/C. The UOC model assumes the entire sky is equally bright. Projection distortion was given as polar. All other parameters were left at default spare latitude, longitude and elevation which were individual measurements taken for each image.

Statistical Analysis

The resulting data was analyzed using Minitab 17.

For hypotheses I & II, recorded values for maximum and minimum daily air temperature, humidity & temperature span were compared between the open and closed selectively felled sites using a general linear model analysis of variance in order to take into account both fixed (Closed selection felling plots & Open selection felling plots), and random factors (Sites and Dates). The baseline level coefficient, for the open selection felling plots, was then calculated with the formula: Reference level coefficient = -1 * (Closed selection felling plot coefficient). The difference is thus = 2 * baseline coefficient.

In order to compare the recorded values against the light index constructed by GLA, variable averages were calculated for every plot (in all treatments). This as to avoid the major disorder which was caused by temperature variations between days and clouded the general trend. Minitab was then asked to fit a regression model between value averages for Daily (Maximum Temperature, Minimum Temperature, Temperature Span, Maximum and minimum relative humidity) and the light index.

RESULTS

The associated p-values for the closed treatment factor in the conducted ANOVA are all less than 0,000 for a two-sided confidence interval (95%). With $\alpha = 0{,}025$, it was hence possible to confidently cast aside the null-hypothesis that there should be no difference between the means of the open and closed plots in the selectively felled stands. These means are presented below (table 1).

Tabell 1. Översikt av resultaten från variansanalyserna (tvåvägs med 95% signifikans). Medelvärden och standardavvikelser givna för enbart stängda eller öppna försöksytor. Två decimaler. DF= 2481

Table 1. *Oversight of results from the Analyses of Variance (Two-way with 95% significance level). Plot averages and Standard deviations from Closed or Open sites only. Two decimals. DF=2481*

Variable (averaged for all days)	**TMax (C°)**	**TMin (C°)**	**TSpan (C°)**	**RH Max (%rh)**	**RH Min (%rh)**
Closed	16,4	7,09	9,31	97,73	68,05
St. Dev. Closed	4,25	2,79	4,27	5,39	17,8
Open	18,31	6,81	11,5	98,48	63,33
St. Dev. Open	5,41	2,84	5,58	4,95	19,31
Regression factor difference / Mean for Closed Plots	12%	-4,80%	-24,80%	0,90%	-7,10%
R-sq.	82,84%	90,01%	80,98%	81,91%	87,59%

The fitted general linear model found that the mean TMax for open sites was 1,9662 degrees higher than that of the closed sites. The mean TMin was found to be 0,3382 degrees higher among closed sites than open sites. The mean TSpan increased by 2,3044 degrees in sites where a harvester trail had been constructed. Thus, the findings were found to be in accordance with hypothesis I; the temperature span increases with the construction of a harvester trail as the minimum and maximum daily temperatures reach new extremes.

Furthermore, the fitted GLM showed that the mean RHMax was found to increase by 0,8336 %rh from the closed to the open sites and that the mean RHMin was found to decrease by 4,81 %rh. These findings are not in complete accordance with hypothesis II, which consisted of two objectives: i) the mean maximum relative humidity would decrease with the construction of a harvester trail, (False); and ii) the mean minimum relative humidity would decrease with the construction of a harvester trail (True).

It is also useful to compare the amount of contribution provided by each factor (Site, Date, Treatment) to the plotted variables regression (table 2). For every variable, the date is the overwhelmingly single largest contributor to the regression, explaining 80-90% of the data points, whereas whether a plot was placed in the harvest trail or inside the stand played a much smaller role along with site. Both plot treatment and site contributed <5% each.

Tabell 2. Bidrag till förklaringsgraden uppdelat efter factor. P<0,000 för alla värden.
Table 2. *Contribution to coefficient of determination by factor. P<0,000 for all values.*

Factor	Tspan	Tmax	Tmin	Max RH	Min RH
Treatment Contribution (%)	4,69	3,76	0,24	0,52	1,59
Site Contribution (%)	4,92	1,88	3,52	1,31	1
Date Contribution (%)	71,37	77,2	86,25	80,08	85
R-sq. (%)	80,98	82,84	90,01	81,91	87,59

Hypothesis III & IV concerned correlations between microclimate variables and the amount of transmitted light. The data points (averages for every plot) have been plotted against percent transmitted radiation in fig. 1 attached in the appendix to give an overview of the results. Hypothesis III regarded suggested positive correlations between the variables TMax and TSpan and the constructed light index. The regression analysis revealed that the average TMax over all days indeed shows an increase by 0,08 C° for every percent increase in light index (R-sq. 64,23%, P<0,000), whereas the average temperature span over all days shows an increase of 0,10 C° for every percent increase in light index (R-sq. 62,87%, P<0,000). Thus, hypothesis III cannot be discarded.

The variables which were prior to the report suggested to have a negative correlation to the light index (TMin, RHMax & RHMin) were handled by hypothesis IV. Of these, the average RHMin showed a decrease of 0,24 %rh per percent increase in the light index (R-sq. 65,97%, P<0,000); the average TMin did show a decrease by 0,02 C° per percent increase in light index. The finding was however connected to a quite low R-sq. value (R-sq. 29,83%, P<0,000). Finally, the average RHMax cannot be said to show any correlation to the light index (R-sq. 0,08%, P=0,849).

DISCUSSION

As was expected in hypothesis I, temperature variables are very responsive to the construction of a harvester trail. The mean maximum temperature increased by 12% with the construction of a harvest trail, whereas the mean minimum temperature fell slightly. These findings are in agreement with those of Chen et al. (1995), who found edges to be associated with higher daily maximum and lower minimum temperatures. This is probably due to the minimum temperature being restricted by thermal radiation from the ground and surrounding biomass during nighttime inversion while the maximum temperature is rather dependent upon the amount of much more powerful incoming solar radiation from during the day.

Maximum relative humidity was little affected by the uptake of a harvester trail. As RHMax is usually reached during the night (Chen et al. 1995), this is probably strongly related to that the minimum temperature only fell by 4,8%. The mean RHMin does however fall more decidedly, by some 7,1%.

The regression analysis looking more closely at variable connections to the light index also gave valuable understanding of the forest structures affecting temperature. The average TMax increased by 0,08 C° for every percent light index, insinuating that a loss of canopy cover will lead to an increase in direct solar radiation exposure on ground vegetation. This is supported by Vales and Bunnells (1988, fig. 1) finding that the global radiation increased substantially during periods when the instrument placed below the canopy was skimmed by a sunfleck, thereby significantly increasing the amount of received energy.

Gap Light Analyzer builds upon Andersons (1964) method of estimating the amount of light transmitted by the canopy from hemispherical photographs. However, when Andersons (1964) method was used Vales & Bunnell (1988), they warned that hemispherical photographs estimate the composition of the global radiation poorly as they deviate significantly from the actual measurements. The light index used in this study is as mentioned earlier calculated as a ratio between the amount of transmitted radiation divided by the total amount of radiation above the canopy. Thus, without actual measurements of the lights composition, some care should be taken when implying that even a slight increase in the light index could cause sunflecks which have greatly affected the exposure of the thermometer, even though there may have been an improvement in models since.

Vales and Bunnell (1988) also shared our general understanding of that TMax is positively correlated to the light index, expressing that the proportion of transmitted global radiation decreased exponentially to the mean crown completeness. This is further supported by Reifsnyder, Furnival and Horowitz (1971), who demonstrated that the percentage transmitted radiation declined when comparing the relatively open Red Pine stand (30% transmitted) to the more closed Hardwood stand (9% transmitted).

RHMin is extremely sensitive to forest gaps or canopy cover reductions, as a decrease by 0,24 %rh per % increase in light index was deduced from the data. To furthermore highlight the importance of aboveground biomass and canopy cover in forest habitats, an increase in average temperature span by 0,10 C° per percent increase in light index was also found. These variables which are very sensitive to increases in the amount of transmitted radiation clearly show how the microclimate is effected by stand structure and may indicate stands have a rich internal microclimate variation dependent upon smaller gaps.

This conclusion should however be considered with some degree of scepticism, as there are several included treatments which differ to such an extent that stand characteristics are fundamentally different (clear-cut and thinned plots mostly include a cohort of similarly aged trees, whereas all-aged continuous cover forestry and control plots include trees of all ages). This may affect how humidity or heat is transferred horizontally within the stand by advective winds.

Further studies should be done examining the edge-effect of harvester trails to determine how far away from the trail environmental variables are significantly affected, and, if deemed necessary, look into whether harvester trails should be placed further apart in order to maintain a desired microclimate in-between. Chen et al. (1995) found that clearcut edge effects can extend in far excess of 30 meters into Douglas fir forests. Effects from smaller gaps may not be carried as far into the adjacent stand due to an eventual lower wind speed.

Through the development of models for how forest structures are connected to certain species, and relating environmental variables to these different structures, it may be possible to with much higher certainty define the set niche for a species. These requirements could later be used in assessing habitat fragmentation or availability – and ultimately, serving as a guide to those interventions which are necessary to maintain a desired state (Folke 2004). As the microclimate might be strongly affected even by smaller canopy gaps it is appropriate to look closer at how forest managers can emulate the small-scale disturbances which governed the fennoscandic boreal landscape prior to human impact (Kuuluvainen 2002).

It could also be of interest to look into whether spatial or temporal variabilities in the stand microclimate are connected to a higher biodiversity or play a role in resource partitioning between forest dwelling species.

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APPENDIX

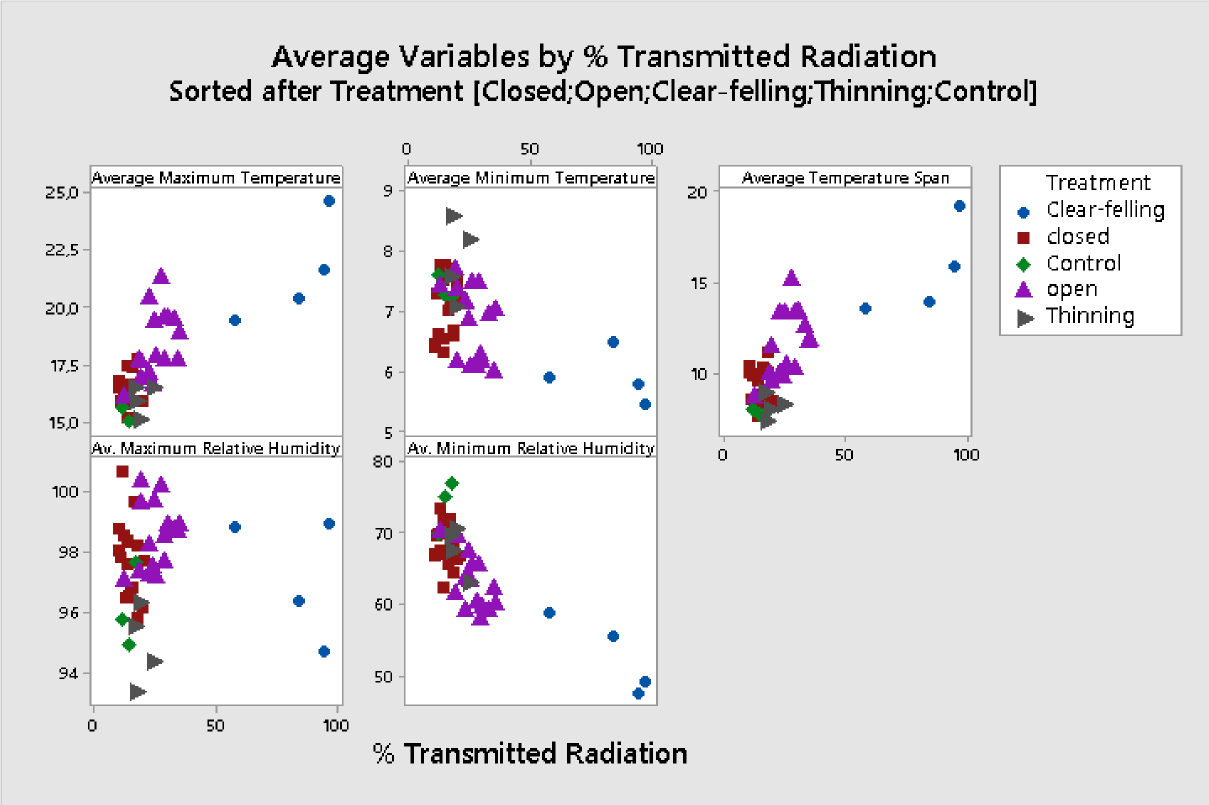

Fig. 1. Variablernas medelvärde för varje försöksyta mot procent strålning som passerat krontaket. Sorterat efter behandling. Genomsnittliga maximala dagstemperaturer och temperaturspann visar en klar positiv korrelation mot procent genomsläppt strålning, medan genomsnittliga minimala dagstemperaturer och minimala dagliga relativa humiditet visar klara negativa korrelationer. Genomsnittligt maximalt daglig relativ humiditet visar ingen korrelation.

Fig. 1. *Variable averages for every plot over percentage transmitted radiation. Sorted by treatment. Average maximum temperature & temperature span show a clear positive correlation to percent transmitted radiation, whereas average minimum temperature and minimum relative humidity show a clear negative correlation. Average maximum relative humidity shows no correlation.*