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ORIGINAL RESEARCH

Northern European viticulture compared to Central European high altitude viticulture: annual growth cycle of grapevines in the years 2012–2013

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Abstract: As a result of global warming and grape breeding, viticulture is spreading to the Baltic Sea Region and Southern Scandinavia. The aim of the study, conducted in 2012–2013, was to determine the extent of the differences between the current climate and growth conditions of Tuusula and Ålsgårde vineyards that are located in the Baltic Sea Region, and the highest European vineyards that are located in Central Europe's Unterstalten. The research material consisted of measurements taken of the soil and air temperatures, and the thickness of the snow layer, all of which were taken simultaneously all year round (October 20, 2012–October 20, 2013). The study revealed that the soil temperature at Ålsgårde did not differ significantly from the soil temperature at Unterstalten during the growing season, but the soil temperature at Tuusula was significantly lower than that of Unterstalten ($P<0.001$). The air temperature at Ålsgårde during the growing season was significantly higher than that of Unterstalten ($P<0.001$), but the air temperature at Tuusula did not differ significantly from that of Unterstalten ($P>0.05$). In June, July, and August, the air temperatures at Tuusula and Ålsgårde were significantly higher than at Unterstalten ($P<0.001$). In midsummer, Tuusula experienced 1 hour and 31 minutes more daylight than Ålsgårde, and 3 hours and 19 minutes more than Unterstalten. The average snow cover in the winter months at Tuusula was 41 cm and in Unterstalten it was 50 cm. There was no permanent snow cover in the winter at Ålsgårde. Based on this study, the grapevine growing conditions in the Baltic Sea Region do not differ crucially from the growing conditions of vineyards that are located in the highest regions of Central Europe; consequently, the wine growing that is carried out by several European *Vitis vinifera* L. and hybrid varieties is already possible in Tuusula and Ålsgårde.

Keywords: Nordic wine growing, climate change, cool climate, daylight length

Introduction

The domestication of the European grapevine (*Vitis vinifera* L.) is known to have occurred in Asia Minor between 8,000–10,000 years ago, along with other crops that originated from the region.[1] During the Medieval Warm Period in the 1300s, the cultivation of grapevines spread from Asia Minor to the Baltics and East Prussia, at latitudes 54°–57°N.[2] The Little Ice Age and the wars that followed, between 1450 to 1850, destroyed this northern grapevine cultivation, of which remnants still survive in the Latvian city of Sabile, located at the latitude of 57°N and where, according to the Guinness Book of World Records, a wine-growing tradition has been preserved since the 1500s.[3] The warming of Europe's climate that has been observed over the

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past 30 years, and the resultant increase in the length of the growing season in the Baltic Sea Region[4–6] may be shifting the cultivation of grapevines in the north back to its medieval regions. The rising global temperature is expected to lessen the damage which late frost does to the breaking buds, even in the traditional viticulture areas in Central Europe.[7]

The growing season shortens as one goes northward, eastward, or into a higher altitude; one degree of latitude northward reduces the growing season by 2.4 days, one degree of longitude eastward reduces it by 0.7 days, and every 100 m (328 feet) of rise in elevation reduces it by 4.1 days.[5] Based on this, it is possible to estimate that the climate in the Baltic Sea Region would correspond to the climate that is prevalent at a height of 800–1,000 m (2,625–3,280 feet) above sea level in Central Europe. Some of Switzerland's wine-growing regions are located at this elevation. Europe's highest vineyard is located at Unterstalten, a total of 1,150 m (3,773 feet) above sea level.[8]

By comparing the growing conditions of localities that are situated in the Baltic Sea Region with the growing conditions experienced at Unterstalten, it is possible to estimate the kinds of climatic conditions that would exist for growing grapevines along the northern and southern coasts of the Baltic Sea in Denmark and Finland at this moment. Earlier, a study was conducted to investigate the costs involved in growing grapevines in Sweden, which do not differ significantly from the costs of doing the same in Denmark and Finland.[9]

An additional aim was to investigate how much the current climate and environmental conditions in the Baltic Sea Region of Southern Finland (Tuusula, 60°N, 63 m or 207 feet above sea level) and Northern Denmark (Ålsgårde, 56°N, 32 m or 105 feet above sea level) differ from the climate and environmental conditions of vineyards, which are located in Central Europe in Valais in Switzerland (Unterstalten, 46°N, 1,150 m or 3,773 feet) above sea level. Another aim was to examine whether there could be any benefits or drawbacks involved in using those Northern European localities that are near sea level when compared to a locality that is between 1,100–1,500 km further south but which is much higher up in the mountains.

Materials and methods

Soil and air temperatures and the level of snow cover were measured throughout the year, and the results were used to examine the growing and climate conditions in the vineyards of Tuusula and Ålsgårde. The results were compared to the growing and climatic conditions in Europe's highest vineyard at Unterstalten (Table 1 and Figure 1). The main proportion of the grapevine's root system was planted 40 cm deep in the vineyard. During the years after planting, the surface roots grew about 20 cm deep but the main roots had grown to depths of 0.7–1.2 m.[10] The general feature of the composition of vineyard soil in Tuusula was that it was a sandy clay with a high organic matter content of 6%–8% and a pH level ranging from 5.8 to 6.2. At Ålsgårde's vineyard the soil was a loamy sand with high organic matter levels, but higher pH levels than at Tuusula, and at Unterstalten, the vineyard soil was a mineral soil with a high limestone content and a high pH level, but a lower level of organic matter than at Tuusula and Ålsgårde.

Soil and air temperatures were measured simultaneously throughout the entire year, between October 20, 2012 and October 20, 2013 at Tuusula, Ålsgårde, and Unterstalten. During the summer months (June 1–August 31) temperatures were recorded in order to compare them to the three localities' highest temperatures that summer. The growing season (April 15–October 15) was chosen because this is long enough for the vine's growth cycle to complete and for the grapes to ripen at the three sites. Therefore, it can be used when comparing the growth cycle's environmental conditions in the three localities. The dates October 20, 2012 to October 20, 2013 were chosen for the year-long study because they matched the vine's annual cycle from harvest to harvest. Thermo Button Temperature Data loggers type 22L (Proges Plus, Willem, France) were used to measure soil temperatures. The loggers recorded temperatures 12 times a

Table 1 Research locations and grape varieties

Community	Country	Location	Above sea level (m)	Distance to Unterstalten (km)	Grape varieties
Unterstalten	Switzerland	46°15′38″N, 07°54′04″E	1,150	0	Heida, Sylvaner, Muscat, Gamay, Pinot Noir, Chasselas
Ålsgårde	Denmark	56°04′36″N, 12°32′13″E	32	1,100	Madelaine Angevine, Solaris, Ortega, Kerner
Tuusula	Finland	60°24′10″N, 25°01′45″E	63	1,540	Solaris, Zilga, Nordica

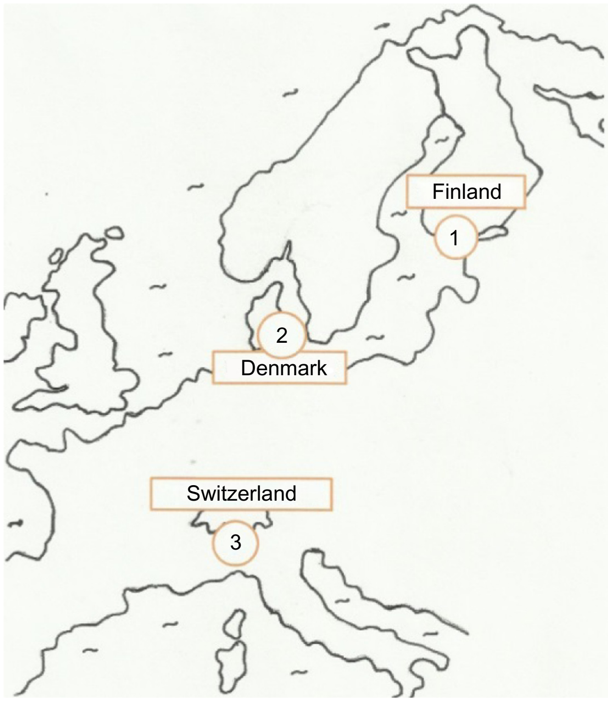

Figure 1 Research locations: 1) Tuusula, 2) Ålsgårde, and 3) Unterstalten.

day throughout the year. In order to monitor the air temperature, the thickness of the winter snow cover, and changes in the length of available daylight, the daily measurements that are issued by the Finnish Meteorological Institute (http://www.fmi.fi) and the international Foreca weather station (http://www.foreca.fi) were used for all three areas. Air temperatures were measured at an altitude of 2 m with a Pt100 automatic resistance thermometer (Nokeval, Nokia, Finland). The measurements were taken inside a ventilated radiation shield which protected them from insolation and rain.

At the three sites, the loggers were insulated from moisture and placed at depths of 20 cm and 40 cm. At Unterstalten, some were also positioned on the surface. The temperatures which they measured were used to calculate the mean temperatures ($\overline{X}$) in the summer months, during the growing season, and across the whole year for 2013 and for the standard deviation (*SD*). The means were calculated from the daily minimum and maximum air temperatures, and these were used to calculate the matching means for the summer months, the growing season, and for the whole year, as well as for the standard deviation. The mean for the snow cover thickness in the winter months was calculated from twelve observations per month. Tuusula's and Ålsgårde's maximum length of daylight in terms of hours per month were compared to Unterstalten's length of daylight hours during the growing season.

A statistical treatment was compiled with a two-tailed *t*-test. As part of the test, $\overline{X}$ is the mean value of one of the variables, *SDx* is the standard deviation, *nx* is the sample size. $\overline{Y}$ is the mean of the other variable, *SDy* is the standard deviation, and *ny* is the sample size.

$$t = \overline{X} - \overline{Y}/SE$$

$$\text{and } SE = \sqrt{\frac{SDx^2}{nx} + \frac{SDy^2}{ny}}$$

$P<0.05$ was used to estimate statistical significance.

Results and discussion

Soil temperature depends on solar radiation energy, the evaporation of heat, and the soil structure. In the summer, more radiant energy is transferred into the ground than is evaporated from it. In the winter, permanent snow cover reflects solar radiation and prevents the ground from warming. As a result of the insulating effect of the soil and the soil's thermal diffusivity, there is less temperature variation in the deeper soil than on the surface of the earth and in the air.[11] In the summer, the daily temperature variations on the ground surface can reach 7°C at a depth of 2 cm, but at depths of 15 cm and 30 cm, daily variations and differences are small.[12] In this study, the soil temperatures in June, July, and August, and in the growing season during 2013, at a depth of 20 cm, were on average 0.5°C higher than at a depth of 40 cm (Tables 2 and 3).

In a comparison between the soil temperatures at the three different localities, at depths of 20 cm and 40 cm during June, July, and August, the soil temperatures at the most northern locality, Tuusula, were significantly higher than at Ålsgårde ($P<0.001$) or at the most southern locality, Unterstalten

Table 2 Vineyard soil temperatures at a depth of 20 cm over 2012–2013

Period	n	[a]Tuus	[b]Unter	[a]Tuus/[b]Unter		[c]Ålsg	[a]Tuus/[c]Ålsg		[c]Ålsg/[b]Unter	
		°C	°C	*t*	*P*-value	°C	*t*	*P*-value	*t*	*P*-value
June 1–August 31	519	15.6±1.2	17.3±2.2	15.46	<0.001	17.9±1.4	30.95	<0.001	4.98	<0.001
April 15–October 15	1,038	12.4±4.3	15.2±3.3	16.63	<0.001	15.4±3.3	17.84	<0.001	1.38	>0.05
October 20–October 20	2,047	7.1±6.3	9.5±6.1	12.40	<0.001	9.3±7.1	10.78	<0.001	0.70	>0.05

Notes: [a]Tuusula; [b]Unterstalten; [c]Ålsgårde.

Table 3 Vineyard soil temperatures at a depth of 40 cm over 2012–2013

Period	**n**	**[a]Tuus**	**[b]Unter**	**[a]Tuus/[b]Unter**		**[c]Ålsg**	**[a]Tuus/[c]Ålsg**		**[c]Ålsg/[b]Unter**	
		°C	**°C**	***t***	***P*-value**	**°C**	***t***	***P*-value**	***t***	***P*-value**
June 1–August 31	519	14.9±1.0	17.0±2.2	18.85	<0.001	17.4±1.1	39.88	<0.001	3.69	<0.001
April 15–October 15	1,038	11.9±4.2	14.8±3.3	18.11	<0.001	14.9±3.2	18.32	<0.001	0.71	>0.05
October 20–October 20	2,047	7.1±5.9	9.7±6.1	14.60	<0.001	9.3 ±6.7	10.14	<0.001	2.50	<0.05

Notes: [a]Tuusula; [b]Unterstalten; [c]Ålsgårde.

($P<0.001$). However, conversely, the soil temperatures that were measured during the growing season and around the year were significantly lower at Tuusula than at Ålsgårde or Unterstalten ($P<0.001$). On the other hand, soil temperatures measured during the growing season at Ålsgårde at depths of 20 cm and 40 cm did not differ significantly from those measured at Unterstalten ($P>0.05$). Also, there were only minor differences in the soil temperatures measured around the year at Ålsgårde and Unterstalten. Ålsgårde's soil temperature was significantly higher than Unterstalten's only at a depth of 40 cm ($P<0.05$) (Tables 2 and 3).

These changes in soil temperatures depending on the time of the year occur because in the north, during the summer, the soil collects a great deal of warmth and during the summer months, this warmth can raise the temperature of the ground surface layer higher in northern localities than it can in the south. However, during winter, when the air grows colder, the soil cools, and the ground gains a layer of snow cover, so the differences in soil temperatures levels are off or are even inverted. This becomes apparent from the temperatures that were measured in Tuusula, Ålsgårde, and Unterstalten across the year (Tables 2 and 3). Global warming seems to have produced a clear change in the soil temperature classification for southernmost Finland, because based on the measurement results, the ground at the northernmost locality, Tuusula, would appear to belong to a colder soil temperature regime labeled as "frigid" according to the soil taxonomy system's soil temperature classification, while the soil at Ålsgårde and Unterstalten belongs to the warmer "mesic" temperature regime.[13,14]

Grapevines require warmth and light in order to thrive. During the spring, in the north there is less warmth but more light than in the south. According to predictions, the whole planet will grow warmer but the effect will impact upon Northern Europe most noticeably. During the last century, the global temperature has risen by 0.6°C–1.0°C,[15–17] and the growing seasons in European countries have been prolonged.[6,18] Global warming has also been clearly detectable in the Baltic Sea and its surrounding countries,[19] which has prolonged the growing season in these areas. As a consequence of this, wine-growing conditions are becoming suitable for many hybrid and some *V. vinifera* L. grape varieties in Northern Europe.

As early as March, the sunlight in Tuusula gives off enough energy to allow plants to absorb enough light to start the process of photosynthesis, but the ground is still too cold for them. At that latitude (60°N), weeping starts in vines when the ground temperature rises to 7°C at a depth of 40 cm, which typically occurs at the end of April.[10] The study showed that at Tuusula, Ålsgårde, and Unterstalten, the length of daylight increased rapidly in April and May, and the day was at its longest during the summer months. Similarly, the air temperature grew warmer very quickly in April and May, and the air was at its warmest during the summer months (see Figures 2 and 3). Based on Foreca's meteorological observations (http://www.foreca.fi), the absolute minimum air temperature during the spring was −13°C in Tuusula, −6°C in Ålsgårde, and −6°C in Unterstalten. After budding had started, the minimum temperature at Tuusula was 9°C (measured June 11, 2013), 8°C at Ålsgårde (measured June 15, 2013), and 7°C at Unterstalten (measured June 5, 2013). Berries were harvest ripe (19°–22°Brix) at Tuusula on September 14, 2013, at Ålsgårde 2 or 3 weeks later, and at Unterstalten as exceptionally late as November 4, 2013 due to the late, cold spring in 2013. Acidity concentrations in berries depend upon grape varieties and environmental factors, and a cool climate is commonly known to increase the acidity of

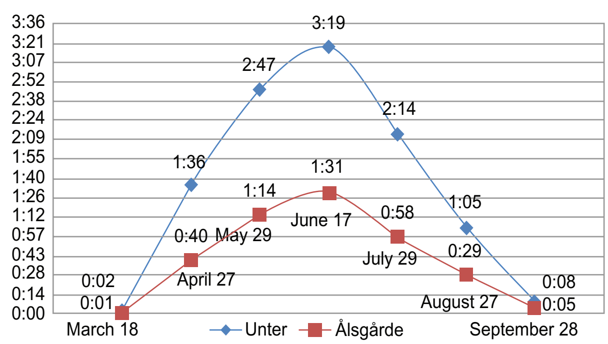

Figure 2 Monthly maximum differences in lengths of day between Unter (Unterstalten) and Tuusula, and Ålsgårde and Tuusula (hour: minute).

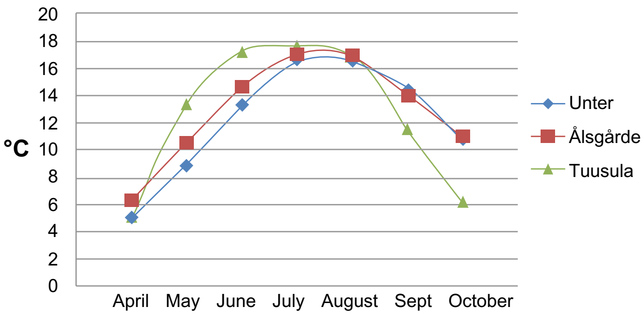

Figure 3 Average monthly air temperatures of the growing season in Unter (Unterstalten), Ålsgårde, and Tuusula.
Abbreviation: Sept, September.

grapes, although it also increases health-promoting phenolic compounds in grapes. Levels of polyphenols such as anthocyanins, flavonols, flavones, and flavanones are exceptionally high in Northern European berries (eg, bilberry, chokeberry, and lingonberry).[20–22] The cool climate and great thermal difference in the daily highest and lowest temperatures also seem to contribute to polyphenols in grapes, which is something that is currently being studied.

Daylight length comparison shows that between March 18, 2013 and September 28, 2013, which is almost the whole growing season, the days were longer in Tuusula and Ålsgårde than in Unterstalten. During the 2013 midsummer period, between June and August, the sun's radiant energy per month at Tuusula was 18 kWhours/m^2 less than at Unterstalten, and at Ålsgårde it was 15 kWhours/m^2 less than at Unterstalten.[23] The difference between the lengths of daylight between Tuusula and Unterstalten was at its greatest on June 17, 2013, when the day in Tuusula was 3 hours and 19 minutes longer than at Unterstalten, and 91 minutes longer than at Ålsgårde (Figure 2). The longer day can compensate for the shorter growing season in the north and can also raise the air and soil temperature. This became evident in the study when it was found that the mean soil and air temperatures were significantly higher at Tuusula and Ålsgårde during the summer months (June, July, and August) than at Unterstalten ($P<0.001$) (Table 4).

At the beginning of the growing season, the air temperatures at Tuusula were higher than at Unterstalten, and temperatures were also slightly higher at Ålsgårde than at Unterstalten (Figure 3). During the growing season, the mean air temperatures were clearly higher at Ålsgårde than at Unterstalten ($P<0.001$); however, there was no significant difference between the mean air temperatures at Tuusula and Unterstalten ($P>0.05$) (Table 4). Huglin-Indexes[24] that were calculated from the minimum and maximum temperatures during the growing season were at 1799 at Tuusula, 1771 at Ålsgårde, and 1651 at Unterstalten. Unterstalten's low Huglin-Index could be the result of an extended cold spring which had some effect on Unterstalten's growing season. Based on both the air and soil temperatures and the Huglin-Indexes the conclusion can be drawn that the length of the growing season and climate conditions at the 56°N and 60°N latitudes, near sea level, are almost the same as those for 46°N at 1,100 m (3,618 feet) above sea level.[5] Because of the cold periods in January and March, Tuusula's annual mean air temperature of 5.0°C was 1.8°C lower than at Unterstalten and 3°C lower than at Ålsgårde. There was no significant difference between the annual air temperatures at Tuusula and Unterstalten ($P>0.05$). However, the annual mean air temperature at Ålsgårde was significantly higher than at Unterstalten ($P<0.05$) (Figure 4 and Table 4).

There were similarities and differences between the winter months (November–April) at the three study sites. The mean air temperatures for November were similar to each other at Tuusula, Unterstalten, and Ålsgårde, but the cold periods of December and March resulted in differences of 2°C–4°C, until the mean air temperatures became more typical for that time of year in April. The colder winter continues to keep the soil temperature classification at Tuusula lower than it is in Denmark, and lower even than the mountainous areas of Switzerland.[13] It is worth noting that the most pronounced decreases in air temperatures for the two Scandinavian countries, Finland and Denmark, occurred at the same time in December and March (Figure 4).

The thickness of the snow layer for Tuusula, Ålsgårde, and Unterstalten was monitored between January and April. The highest monthly mean thickness in the snow layer in January (52 cm) was found at Unterstalten, but in February and March the place with the most snow was Tuusula

Table 4 Local air temperatures in Tuusula, Unterstalten and Ålsgårde

Period	n	^{a}Tuus	^{b}Unter	^{a}Tuus/^{b}Unter		^{c}Ålsg	^{a}Tuus/^{c}Ålsg		^{c}Ålsg/^{b}Unter	
		°C	°C	*t*	*P*-value	°C	*t*	*P*-value	*t*	*P*-value
June 1–August 31	91	17.3±2.5	15.5±2.7	4.67	<0.001	16.8±2.3	1.40	>0.05	3.50	<0.001
April 15–October 15	181	13.8±5.2	13.1±4.2	1.41	>0.05	14.4±3.7	1.27	>0.05	3.12	<0.001
October 20–October 20	365	5.0±10.5	6.8±7.9	1.16	>0.05	8.0±7.7	4.40	<0.001	2.15	<0.05

Notes: ^{a}Tuusula; ^{b}Unterstalten; ^{c}Ålsgårde.

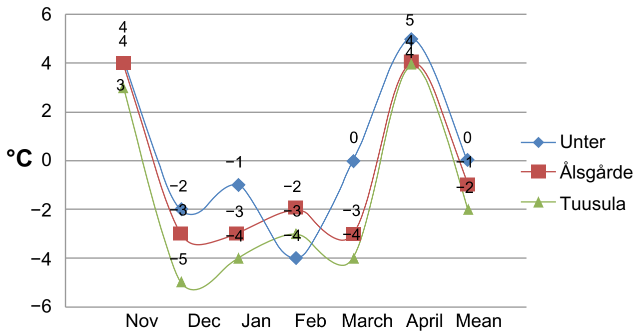

Figure 4 Average monthly air temperatures over 2012–2013 in Ålsgårde, Unter (Unterstalten), and Tuusula, and mean value of the 6 months.
Abbreviations: Nov, November; Dec, December; Jan, January; Feb, February.

(60–65 cm). By mid-April, all of the snow had melted away in Tuusula, but snow still remained at Unterstalten until the end of April. Due to the close proximity of the sea and the resultant higher air temperature, as well as the heat-retaining mineral soil (a loamy sand),[25] there was no permanent snow cover at Ålsgårde throughout the entire year (Figure 5). Many researchers have found that thick snow cover on vineyards provides more advantages than disadvantages. In the winter, when the snow layer is combined with the ground layer, it functions as insulation and prevents the evaporation of heat from the ground. A layer of snow 70–100 cm thick prevents the soil from freezing below a 20 cm surface layer even at temperatures of −20°C to −30°C.[26–28]

It became apparent from the results of this study that the ground surface temperature at Unterstalten was at its lowest, between −1.0°C and −1.5°C, in February, under a snow cover that was 61 cm thick; this was the coldest month in the area. The soil temperatures at the depths of 20 cm and 40 cm remained above zero for the whole of winter (~0.5°C–1.0°C); consequently, the vine roots did not freeze.[29] The annual soil temperatures were higher than the annual mean air temperatures. This corresponds with earlier observations made at a depth of 50 cm, where the soil's mean temperatures are about 1°C higher than the annual mean air temperatures.[30]

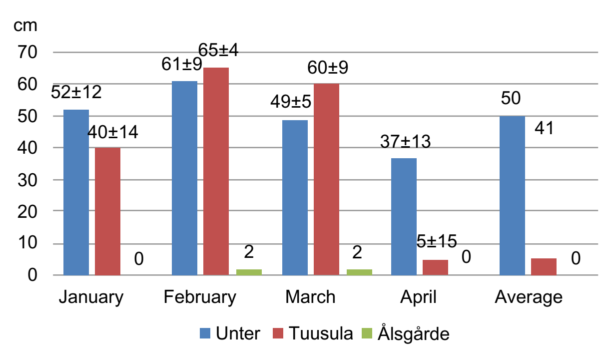

Figure 5 Average depths (±SD) of snow layer of 4 winter months in Unter (Unterstalten), Tuusula, and Ålsgårde in 2013.
Abbreviation: SD, standard deviation.

Conclusion

The current climate and growing conditions for vineyards that are located near sea level in the Baltic Sea Region are similar to the climate and growing conditions of vineyards that are located at the highest elevations of Central Europe. Even though the mean air and soil temperatures measured throughout the year at the northernmost locality, Tuusula, were clearly lower than those in Unterstalten, the differences between Ålsgårde and Unterstalten were minimal. The air temperatures at Tuusula and Ålsgårde during June, July, and August were higher, and the days were longer than at Unterstalten. Ålsgårde is in Denmark and is near sea level. Yet the environmental conditions for grape breeding were even more favorable there than at Unterstalten, which is situated high in the mountains in Switzerland. Based on this study, it is already possible to grow grapes in the Baltic Sea Region, using several quickly-ripening *Vitis vinifera* L. and hybrid varieties. In the coming decades, predicted global warming, the lengthening of the growing season in the north, and longer days will improve the chances of successful viticulture and will also allow grape growing to move further north. The present cool climate and the large thermal differences in the daily highest and lowest temperatures seem to promote health-promoting polyphenols in Northern European grapes.

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Disclosure

The author reports no conflicts of interest in this work.

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