Reviving an 18th Century Dream of Swedish-Grown Tea

Examining the possibilities of growing tea, *Camellia sinensis,* in Sweden based on climatic crop requirements using GIS

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Agricultural Programme – Soil and Plant Sciences
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Pånyttfödelsen av en 1700-tals dröm om svenskodlat te. En studie som undersöker möjligheterna att odla te i Sverige baserat på klimatiska förutsättningar med hjälp av GIS

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Abstract

Tea, *Camellia sinensis*, is one of the oldest tree crops in the world and has been cultivated for its leaves for thousands of years. It is a long-lived, evergreen perennial that grows well in warm and humid climates with high amounts of precipitation evenly spread throughout the year.

In Europe, tea cultivation has a much shorter history, reaching back to the second half of the 18th century. It was around this time that the Swedish botanist Carl Linnaeus began his attempts at growing tea in Uppsala, with one plant managing to survive the Swedish conditions for 18 years, but the attempts could be said to have been unsuccessful. In modern times, there have been at least four new attempts, which are still on-going, to grow tea in different regions of Sweden.

The purpose of this study was to evaluate the possibilities of growing tea in Sweden based on climatic crop requirements connected to temperature and precipitation, with the goal of answering two questions. Is it possible to grow tea in Sweden and if so, where in the country? The study was conducted using R to evaluate the study area for the criteria derived from the climatic crop requirements. The results were used to conduct a land suitability evaluation to divide the study area into four classes (*highly suitable, moderately suitable, marginally suitable and unsuitable*) based on a point system derived from how suitable the area would be for growing tea based on each criterion. The theoretical result of the study was complemented by interviewing Swedish tea growers to showcase the practical experiences of those growing tea in Swedish conditions.

The conclusion of the study was that it is possible to grow tea in Sweden, with the most suitable regions being areas close to the west coast and the north-western parts of Skåne.

Keywords: tea, Camellia sinensis, land suitability evaluation, GIS, tea cultivation, crop requirements

Sammanfattning

Te, *Camellia sinensis*, är en av de äldsta trädgrödorna i världen och har odlats för sina blad i tusentals år. Det är en långlivad, vintergrön perenn som växer bra i varma och fuktiga klimat som får mycket nederbörd jämnt fördelat under året.

I Europa har teodlingen en betydligt kortare historia som sträcker sig tillbaka till 1700-talets andra hälft. Det var även under den här perioden som den svenska botanikern Carl von Linné började sina försök att odla te i Uppsala. Han lyckades få en planta att överleva 18 år i det svenska klimatet, men försöken kan i övrigt sägas ha varit misslyckade. I modern tid har det påbörjats åtminstone fyra nya försök att odla te i olika delar av Sverige.

Syftet med den här studien har varit att utvärdera möjligheterna att odla te i Sverige baserat på klimatiska förutsättningar för tebusken, kopplat till temperatur och nederbörd. Målet har varit att svara på frågorna om det går att odla te i Sverige och i så fall vart i landet. Studien använde sig av R för att utvärdera studieområdet utifrån kriterierna som baserades på de klimatiska förutsättningarna som tebusken kräver. Resultatet användes för att utföra en *land suitability evaluation* som delade upp studieområdet i fyra klasser (*highly suitable, moderately suitable, marginally suitable and unsuitable*) baserat på ett poängsystem enligt hur bra odling av te skulle fungera baserat på varje kriterie. Det teoretiska resultatet från studien komplimenterades med praktiska erfarenheter genom att intervjua svenska teodlare.

Slutsatsen för studien var att det är möjligt att odla te i Sverige och att de mest passande områdena finns nära Västkusten och i de nordvästra delarna av Skåne.

Nyckelord: te, Camellia sinensis, land suitability evaluation, GIS, teodling, odlingsförutsättningar

Table of Contents

List of Tables

List of Figures

Abbreviations

AAT	Annual Accumulated Temperature
C3S	Copernicus Climate Change Service
CAAS	Chinese Academy of Agricultural Sciences
FAO	Food and Agriculture Organization of the United Nations
IGG	Intergovernmental Group on Tea
GDD	Growing Degree Days
IDW	Inverse Distance Weighted
SMHI	Swedish Meteorological and Hydrological Institute
WMO	World Meteorological Organization

1. Introduction

Tea is the second most consumed beverage in the world and the tea plant, *Camellia sinensis*, is one of the oldest tree crops used in cultivation. Compared to other tree crops, where the main objective is wood, fruits and nuts, tea is special in that it is the leaves that is the focus for harvest. (Carr 2018, De Costa et al. 2007).

The plant is indigenous to South-East Asia alongside other species of the *Camellia* genus, with tea specifically believed to originated from the mountainous region between the Yunnan Province, China and Assam, India (Hasimoto 1985, Meegahakumbura 2018, Ming & Bartholomew 2007). Tea has a long history in these regions, especially in China, with tea drinking and the ecology of tea trees being described in poems published in 130 B.C., as well as tea leaves being used as a tribute for the emperors dating back to 1066 B.C. (Carr 2018, Yamanishi 1995). Tea cultivation had spread throughout China by 650 A.D., and from there it continued to be introduced to new regions and countries by monks, travellers and traders (Carr 2018, Lu et al. 2016, Weatherstone 1992).

Tea cultivation has a history in Europe since the second half of the 18th century, but production can only be said to have started during the 19th century, with Portugal, Georgia, Turkey and Russia being pioneers. Today, tea farms can be found in many European countries, with the majority being small scale, single-estate tea (Carr 2018, Tea Grown in Europe Association 2022). In Sweden, there have been attempts to grow tea, starting with Carl Linnaeus during the second half of the 18th century. In modern times there have been at least four attempts, all of which are still on-going in different regions of Sweden.

A key aspect when it comes to introducing or attempting cultivation of a crop in a new region, is to evaluate the conditions necessary for it to be successful. This thesis aims to highlight the difficult aspects of tea cultivation in Sweden and to find regions where tea cultivation could be possible.

1.1 Linnaeus quest for tea

In the 18th century, tea trade had been established between China and many European countries, but with the great economical value held by the commodity, tea was a source of both conflicts and war (Carr 2018, Weatherstone 1992).

Similar to many other botanists in the 18th century, Carl Linnaeus firmly believed in the possibilities of growing tea in his own country, rather than finding a native substitute or staying reliant on foreign imports. Thus, during the mid-1740s, Linnaeus began looking for ways to bring seeds or living tea plants from China to Sweden (Hodacs 2023, Linnaeus & Rosenstein 1745).

Linnaeus tasked several travellers and some of his own students to gather seeds and tea plants during their travels and bring their findings back to Sweden. There were many failed attempts, with failure to procure neither seed nor plant, plants dying at sea from weather, falling of deck or being eaten by ship rats, or simply having the wrong plant brought back. In 1760, a handful of seeds arrived from China, but to Linnaeus great regret, none of them sprouted. It was not until 1763 that 14 living tea plants finally arrived in Uppsala. The plants grew well in the beginning, but by 1965 all but two plants had died. One of the remaining plants bloomed for the first time during that year, but the other died soon after. It is not known for how many years the final plant survived. It was last recorded alive in 1781, having survived the Swedish climate for 18 years (Drake 1927, Naturhistoriska riksmuseet 2014).

1.1.1 Taxonomy

The tea plant was first described by Linnaeus in 1753, where it was published in *Species Planturum* under the name *Thea sinensis.* It is unknown if the plants described are the same as the *Camellia sinensis* of today, as Linnaeus based the description on a drawing from *Amoenitates Exoticae* by Engelbert Kaempfer, since he had not seen the plant himself. In 1762, Linnaeus changed the name he had given the tea plant and distinguished two different tea species, *Thea bohea* and *Thea viridis* (Kaempfer 1712:606, Banerjee 1992).

The plant has been through a number of reclassifications, as the taxonomy of the plant has been up for debate and is still being discussed to some degree. The scientific name currently in use is *Camellia sinensis* (L.) O. Kuntze and it includes the two main varieties used in tea production, *Camellia sinensis* var. *sinensis* (China-type), and *Camellia sinensis* var. *assamica* (Assam-type), as well as the lesser-known *Camellia sinensis* var. *dehungensis* and *Camellia sinensis* var. *pubilimba* (Ming & Bartholomew 2007, POWO 2022).

1.2 Global production and economical value

In 2021, the annual worldwide production of tea amounted to 6.5 million tonnes of tea leaves, with the major producers being China, India, and Kenya, shown in Figure 1.1 and Figure 1.2, with 87% of the production occurred in Asia, 11.7% , in Africa, and the remaining 1.3% split between Europe, the Americas and Oceania (FAO 2022, FAO 2023).

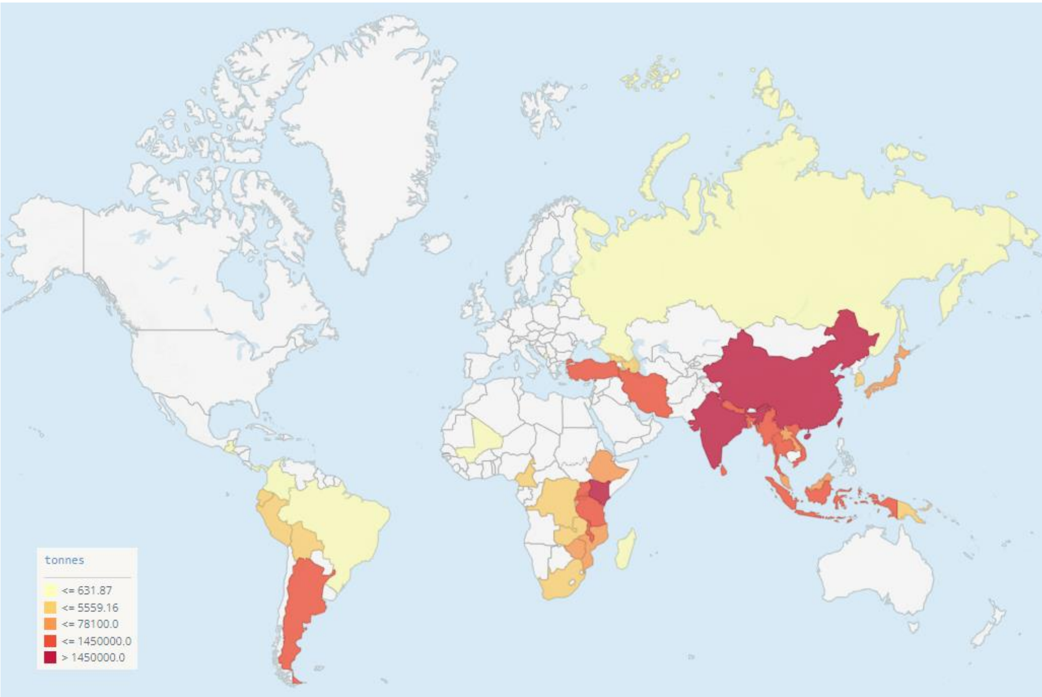

Figure 1.1. Map of the world's largest tea producing countries in 2021 (FAO 2023). (CC BY-NC-SA 3.0 IGO)

Tea is grown commercially in more than 30 countries but is largely produced by smallholders in low-income countries. It is an important source of income for people in rural areas, creating work opportunities particularly during harvest season. Due to global demands, export also play an important role for the countries where tea is produced, with the global tea trade being valued at USD 9.5 billion (Ahmed et al. 2018, Carr 2018, Han et al. 2018, FAO 2022).

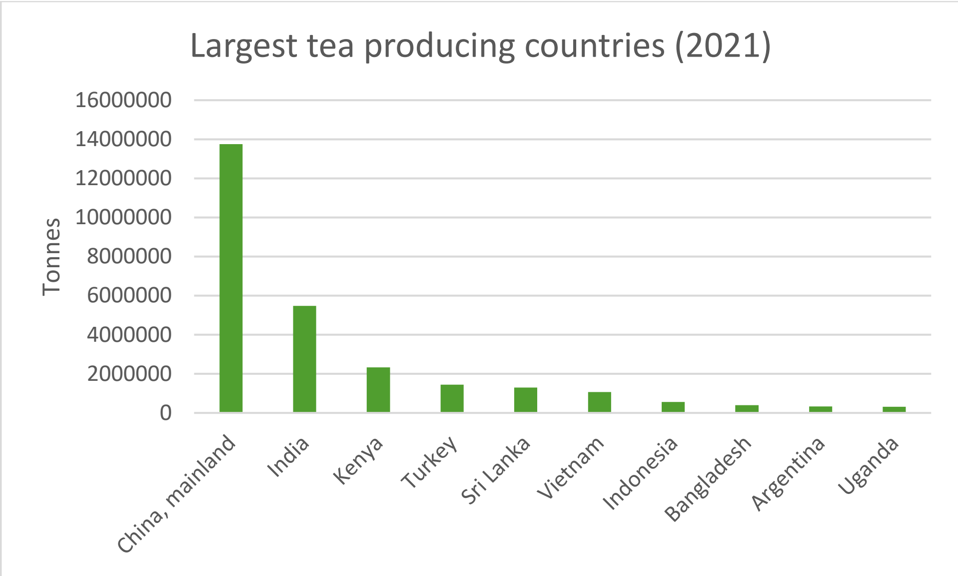

Figure 1.2. Graph over the largest tea producing countries in the world in 2021 (FAO 2023). (CC BY-NC-SA 3.0 IGO)

Whilst both the production and trade of tea are increasing annually, the industry is facing a number of challenges, with climate change, economic sustainability for the producers, and market transparency being three of the main ones (FAO 2022, Han et al. 2018). Being a rainfed crop which is generally cultivated in monocultures, tea is highly dependent on weather and climate conditions. Extreme weather, increasing temperatures and unpredictable rain patterns are all major threats to the resilience of tea farmers and the sustainability of the tea industry as a whole (Ahmed et al. 2018, Han et al. 2018, FAO & IGG 2016).

1.3 Biology of tea from an agronomical perspective

Tea is an evergreen, perennial tree-crop cultivated mainly for its leaves, shown in Figure 1.3. It is a heterogeneous plant with a high degree of plasticity both for biochemical, physiological, and morphological attributes, both for the species as a whole and within different varieties (Banerjee 1992). This is a result of the plant being self-sterile and crossbreeding between varieties being a common occurrence, both naturally as well as a mean of creating hybrids for developing new cultivars (Carr 2018, Chen et al. 2012).

Tea is a long-lived plant with an economical life span of 50–60 years, referring to the time where the plant is considered to produce enough yield to remain in production before being replaced. Under the right conditions tea plants can remain in production for upwards of a hundred years (Carr 2018, De Costa et al. 2007). There are examples of older tea trees still being harvested for their leaves, known as ancient tea trees, with the oldest one said to be 2700 years old (Carr 2018).

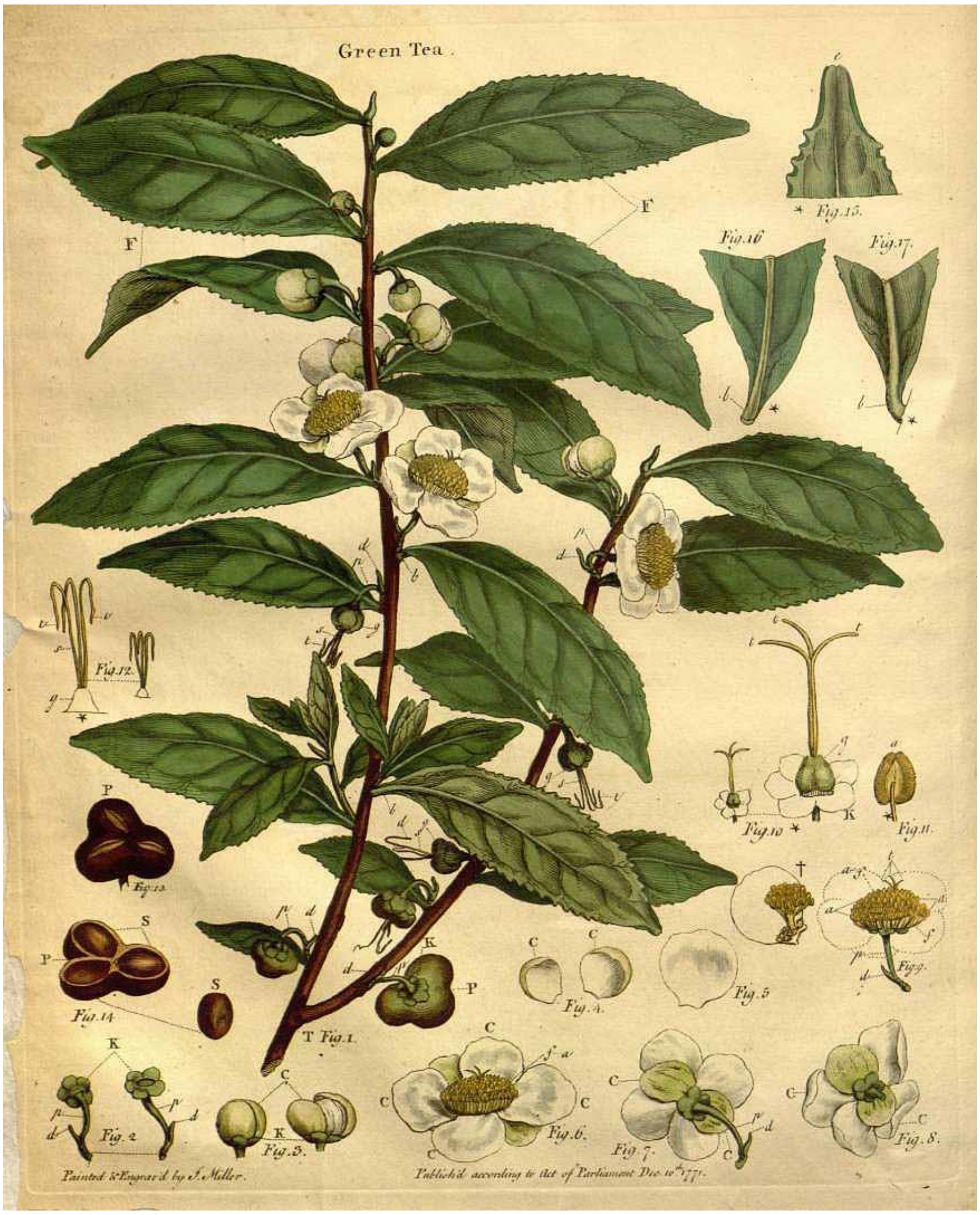

Figure 1.3. Botanical illustration of tea (Lettsom 1799).

1.3.1 Growth pattern

It takes a long time to establish young tea plants and years before the plants are fully matured. Plant maturity depends on growing conditions and is expected to take longer in colder climates as the plant goes dormant during colder months (De Costa et al. 2007). First harvest can be attempted before the plants reaches full maturity, at three to five years of cultivation, but is expected to be lower than yields from mature plants (Carr 2018, Melican 2016, Willson & Clifford 1992).

In nature tea plants grow into either shrubs (var. *sinensis*) or moderately sized trees (var. *assamica*), if allowed to grow without pruning or interruption. Tea grown for commercial production is plucked for leaves regularly, resulting in the apical meristem of each branch constantly being removed and a new shoot emerging from the axillary bud below the plucking point (Chen et al. 2012, De Costa et al. 2007). To ensure a high yield, young tea bushes are pruned horizontally to promote the development of axillary buds for a multi-stemmed plant with a high ratio of terminal buds. Mature bushes are continuously pruned to remain at about 1 m tall for ease of harvest, both for manual hand-plucking and for machine harvest (Carr 2018, Chen et al. 2012, De Costa et al. 2007).

1.3.2 Root system

The root system of a tea plant consists of woody, structural roots, which provide support for the upper parts of the plant and where the plant store starches, and feeder roots, which are used for nutrient and water uptake. The tap root can grow deeper than 5 m into the soil, which protects the plant from drought by being closer to the water table. Contrary to the deep tap root, the majority of the feeder roots can be found in the uppermost area of the soil profile, believed to be a result of tea historically being grown in areas with high water tables and high amounts of precipitation, in certain areas of more than 2000 mm/year (Carr 2018, Willson & Clifford 1992).

Young plants require moist soil which does not inhibit lateral growth to become well-established. The rooting of cuttings produced through vegetative propagation, the most common way to produce new tea plants, are dependent on multiple factors such as the age and health of the mother plant, the age of the growth and what part of the plant the cutting originated from. Rooting hormones can be used to accelerate the root growth to some extent, but it does not ensure that bad cuttings root more easily (Chen et al. 2012, Willson & Clifford 1992).

1.3.3 Leaves

The main focus of harvest in tea cultivation are fresh shoots, usually picked as two leaves and a bud. The leaves can be harvested multiple times during the growing season, with the first occurring during early spring and the last during late autumn. New shoots can emerge from the plant at any point during the growing season, which mean that any single tea bush can have growths of multiple different ages, making the harvest process more difficult. The replacement cycle for new shoots depends on air temperature but is approximated at 42 days in shoot growth studies done in India (Carr 2018, Chen et al. 2012, Willson & Clifford 1992).

The leaves that are left on the plant are called maintenance foliage and remain on the plant all year round. To ensure that the plant continue to produce new shoots without suffering from reduced photosynthesis, the maintenance foliage need to be as effective as possible in capturing the light that the plant receives. This means that the maintenance layer needs to be high enough on the plant to not be shaded by new growth, and that new leaves needs to be added to the layer throughout the plant's life as the leaves age and grow less efficient in their photosynthesis (Willson & Clifford 1992).

1.3.4 Tea breeding

In modern cultivation around half of the tea grown around the world were created using vegetative propagation, this to ensure genetic uniformity. Due to tea being a perennial crop that will remain in production for up to a hundred years, it is necessary that the plant material hold a high quality. Tea grown from seed does not breed true and create highly heterogenous seedlings, resulting in plants with varying quality and characteristics (Chen et al. 2012, Willson & Clifford 1992).

There are more than 500 cultivars of tea currently being grown in tea plantations around the world. The most common method of creating new cultivars is by crossing two clonal parents. Other methods include the use of mutant seedlings, polyploidy, and creating hybrids by crossing with landraces or wild tea species with the large gene bank that they hold.. The development of new cultivars take a long time when compared to annual crops, as tea is a woody perennial, and should instead be compared to breeding of trees (Carr 2018, Chen et al. 2012, Willson & Clifford 1992).

Current goals in tea breeding include creating cultivars that grow well under changing environmental and diversifying the genetic material used in breeding. Climate change is a major difficulty facing tea growers around the world with changing weather patterns and more extreme weather events. A variety in genetic material will be necessary to develop plants that can thrive in future conditions and to ensure that there are varieties and cultivars that cater to the needs of both growers and consumers (Chen et al. 2012).

1.3.5 Crop requirements for tea cultivation

The majority of tea worldwide is produced in tropical to subtropical regions, areas with warm, wet summers and cool, dry winters (Carr, 2018). Heat and droughts are the most common difficulties in production areas during summer and autumn, whilst sudden frost and freezing damage are the most common during winter, early spring, and late autumn (FAO & CAAS 2021, Li et al. 2018).

Most tea varieties have their optimum productivity with air temperatures ranging between 18–25°C, which decreases when temperatures fall below 13°C or rise above 30°C (Bhagat et al. 2010, De Costa et al. 2007, FAO & CAAS 2021, Shoubo 1989). Most varieties can withstand negative temperatures between -3°C and -16°C, with the small-leaved China-type (including hybrids) being more cold-hardy when compared to other varieties. The buds and young leaves are especially vulnerable to frost and freezing damage, risking wilting and dying if temperatures fall below 1–2°C (Shoubo 1989, Chen et al. 2012, Zhang et al. 2020).

Tea plants require a high amount of precipitation, evenly distributed throughout the year (Bhagat et al. 2010, Eden 1965). Annual rainfall of 1000–1400 mm, monthly precipitation of 100–150 mm/month, and a relative humidity of 80% being the optimum (Eden 1965, FAO & CAAS 2021, Shoubo 1989). If the humidity falls below 50% or the monthly precipitation is below 50 mm/month, for several consecutive months, the shoot growth and bud development is inhibited, resulting in a reduced harvest (Eden 1965, Shoubo 1989).

Climate graphs displaying average monthly temperatures and precipitation of famous tea growing regions can be found in Figure 1.4. Graphs displaying the climate in examples of colder tea growing regions in Europe and Tibet, as well as for the location of Swedish tea farm, can be found in Appendix 1 (Figure 5.1 and Figure 5.2).

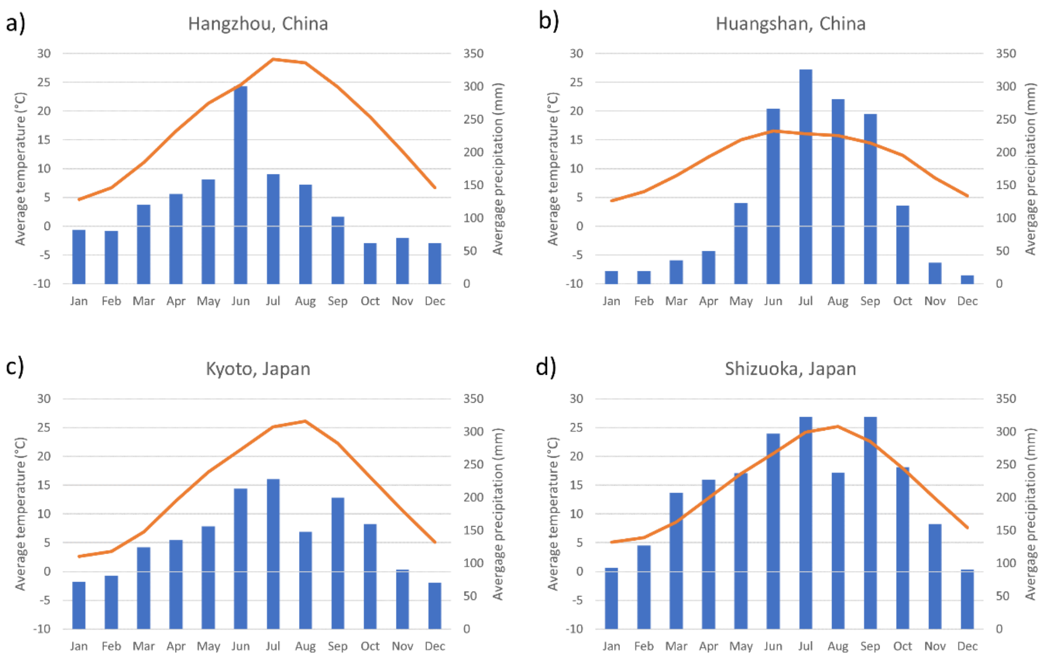

Figure 1.4. Climate graphs displaying the average monthly temperature and precipitation for four famous tea growing regions in China and Japan for the period 1991-2021. a) Hangzhou in China, b) Huangshan in China, c) Kyoto in Japan, d) Shizuoka in Japan. Data retrieved from Climate-Data..org (2023).

As a general rule, tea can be grown in most types of soil. The critical elements being a pH ranging from 4.5–6.5, with pH below 4.0 and above 7.0 impacting both plant development and the nutrient uptake of the plant (Chen et al. 2012, De Costa et al. 2007), and the soil being well-drained, but not prone to drying out (Carr 2018, Willson & Clifford 1992). Tea soils generally range from less than 1% of organic matter, in more tropical regions, to more than 30%, in peat based soils (Willson & Clifford 1992). As a general rule, tea grow well in soils with a high content of organic matter, as it retains moisture and aid in water infiltration, improves the soil texture, as well as store and supply nutrients. Covering the soil by adding organic matter in the form of mulching (straw, bark, manure, etc.) provide protection for the plants, by insulating the soil and keeping the temperature more even. This is especially important during winter where it can reduce cold stress for the roots. Covering the soil also aid in keeping the water in the soil from evaporating, reducing the need for watering (Ahmed et al. 2018, Carr 2018, De Costa et al. 2007, Shoubo 1989, Willson & Clifford 1992).

1.4 Purpose and research questions

Evaluation of cultivation conditions for tea has been done for many tea-growing regions of the world, but there is a gap in research when it comes to novel regions such as Europe and regions where tea cultivation has not previously been attempted.

The purpose of this study was to evaluate the possibilities of growing tea, *Camellia sinensis*, in Sweden, focusing on climatic crop requirements for tea found in previous studies done on tea cultivation and literature about the subject of growing tea. The study also aimed to have interviews with Swedish tea growers to confirm the findings in the theoretical study.

The key research questions being whether or not it is possible to grow tea in Sweden, and if so, where in the country cultivation would be most suitable.

1.4.1 Delimitations

The study was limited to evaluating the China-type variety of the tea plant, *Camellia sinensis* var. *sinensis*, due to the other varieties (var. *assamica*, var. *dehungensis*, and var. *pubilimba*), not being suited for cultivation in regions with colder climates according to the research read in the literature study.

The climatic crop requirements that were the focus in this study was temperature and precipitation. Other factors that are important to tea cultivation, such as soil quality (pH, texture and drainability) and topography are described in the text, but not included in the final land suitability evaluation. This was due to the climatic requirements being deemed more important for the baseline possibilities of tea cultivation in Sweden.

2. Material and Methods

The methodological approach taken in this study was a mixed methodology where initial steps were decided upon using a literature study to find climatic crop requirements for tea based on data from previous studies and weather data from tea farms around the world. The main structure of this study was inspired mainly by two papers describing more developed land suitability evaluation for tea done in China (Li et al. 2012) and India (Rahaman & Aruchamy 2022), as well as the *Guidelines for land-use planning* by FAO (1993).

To confirm if the results of the theoretical land evaluation were realistic and to compare the results with the reality of tea growing in Sweden, interviews with tea growers in Sweden were conducted.

2.1 Literature study

The literature used in the study were in the form of books and scientific articles, mainly found using web-based search engines such as Primo, Google Scholar and Scopus. Further reading was found by reviewing references found in the literature.

The main sources for foundational information about the biology and cultivation of the tea plant, were the *books Advances in Tea Agronomy* by M.K.V. Carr (2018), *Tea: Cultivation to Consumption* by K.C. Willson & M.N. Clifford (1992), a research paper by Shoubo (1989), and a report by the FAO & IGG (2016).

Search terms used when using search engines were “tea” and “*Camellia sinensis*”. These words were combined with relevant search terms related to the subject of the study, such as “cultivation”, “crop requirements”, “temperature”, “climate”, “environment”, etc. and were connected using Boolean Operators to narrow down the search results. New search terms were found using keywords mentioned in other literature.

The literature used were mainly peer-reviewed research papers and books, as well as publications made by organizations such as FAO and WMO, to ensure that the information was reliable.

2.2 Study area

Arable land in Sweden is mainly centred around the middle to southern regions of the country, due to the northern regions having a growing season that is too short (SMHI 2021). The study therefore focused on the regions of Sweden where agriculture is the most prevalent. The counties with the largest area of cultivated land being Skåne, Västra Götland, Östergötland, Kalmar, Uppsala and Gotland (SCB 2023).

2.3 Selection of evaluation factors

This study uses a simplified model of land evaluation for crops inspired by FAO (1976), where evaluation factors were decided upon after a literature review. Due to tea mainly being grown in regions that range for tropical to subtropical, and the premises of this study was whether or not tea could be cultivated in Sweden, the focus of the land evaluation would be the climatic requirements of the tea plant.

The climatic crop requirements were decided upon amongst those most frequently mentioned in literature reviewing the meteorological aspects of tea cultivation, with more weight given to literature about tea cultivation in colder regions of China, Japan, South Korea, and the Himalayas. Criteria decided upon mainly focused on negative temperatures and precipitation amounts, as regions where these criteria would be fulfilled appeared to be the most difficult to find in Sweden.

The sub-criteria connected to temperature were minimum temperature, relative frequency of temperatures below -13°C (between October and April), probability of temperatures below -13°C for ten or more consecutive days, and annual accumulated temperature. In regard to precipitation, the sub-criteria were annual accumulated precipitation and probability of precipitation below 50 mm for three or more consecutive months. Thresholds for each criterion were divided into four classes: *highly suitable*, *moderately suitable*, *marginally suitable*, and *unsuitable*, after reviewing values found in literature and comparing those with weather data from tea gardens around the world. These thresholds can be found in Table 2.1.

Table 2.1. Climatic crop suitability criteria (or crop requirements) for tea cultivation.

	Classes			
	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Minimum temperature	> -13°C	-16°C to -13°C	-20°C to -16°C	< -20°C
Relative frequency of temperatures < -13°C (Oct–Apr)	< 5%	5 – 10%	10 – 20%	> 20%
Probability of year with 10 or more consecutive days of temperatures ≤ -10°C	< 10%	10 – 20%	20 – 30%	> 30%
Annual accumulated temperature (T_{base} = 5°C)	> 1800 degree days	1500 – 1800 degree days	1200 – 1500 degree days	< 1200 degree days
Annual accumulated precipitation	> 1000 mm	700 – 1000 mm	500 – 700 mm	< 500 mm
Probability of year with three or more consecutive months of precipitation < 50 mm/month	< 20%	20 – 30%	30 – 40%	> 40%

2.3.1 Explanation of criteria

Minimum temperature

The majority of tea growing regions have much milder winters than what most regions of Sweden experience every year. It was therefore deemed important to find the absolute minimum temperature that tea can survive .

In Appendix 2 (Table 5.1), a range of minimum temperatures for *Camellia sinensis* var. *sinensis* can be found listed. These temperatures were divided into the four suitability classes found in Table 2.1.

The average annual minimum temperature for each point was calculated by finding the yearly minimum temperature for each year in the dataset. The yearly minimum temperatures were added together, and the sum was divided by the total number of years, creating an average annual minimum temperature to compare with suitability classes.

Relative frequency of temperatures below -13°C (October through April)

In a similar study done in China (Li et al. 2012), the frequency of temperatures below -13°C was used as a criterion determining regions where tea cultivation was suitable. The relative frequency reveals how often during the period of October through April, the temperature drops below -13°C. The ranges for relative frequency were decided after comparing temperature graphs of colder tea growing regions during winter months (Climate-Data.org 2023) with temperatures described in literature.

To calculate the relative frequency of temperature dropping below -13°C, days with minimum temperature below -13°C during October-April, were counted for the entire time period. The sum was divided by total number of days in the period October–April, between the years 1979–2018. The resulting relative frequency was then compared to the suitability classes.

Probability of year with 10 or more consecutive days of temperatures equal to or below -10°C

In tea cultivation, spring is one of the most important periods of the entire year, due to the high value of the first harvest of spring tea. A delay in the spring harvest has a detrimental effect on the economic situation for tea farmers in regions where this occurs. In relation to this, during the literature study, it was frequently mentioned that consecutive days of negative temperatures play a large role in this as it can delay the harvest season and reduce the yields (Hwang & Kim 2014, Zheng et al. 1990).

This criterion was used as a complement to minimum temperature and relative frequency of temperatures below -13°C, as tea can survive temperatures down to at least -10°C for several consecutive days without being injured to such a degree that it kills the plants. The suitability ranges were decided by the same method described for previous criteria.

To calculate the probability of the criteria being fulfilled, the years with instances of ten or more days of temperatures equal to or below -10°C occurring at least once, were then added together, and divided by the total number of years, resulting in the probability of the criteria occurring, which was then compared to the suitability classes.

Annual accumulated temperature

Accumulated temperature (AT), or growing degree days (GDD), is a common method used for estimating plant growth as well as approximating when certain stages of the plant's life cycle are expected to be reached, such as when they produce fruit. It is a method suitable for evaluating plant growth for tea, as it can be related to the speed of which the dormant plants develop new buds during spring (Omae & Takeda 2003).

Regarding tea, the annual accumulated temperature (AAT) is most commonly used, but due to uncertainty in methods used to calculate AAT for values listed in Appendix 2 (Table 5.2), a separate method of evaluating the Swedish conditions regarding this criterion was used. As there are a number of locations in Scotland where tea is cultivated and produced into a finished product, it was decided that the Scottish values for AAT would be used as a base instead (Tea Scotland 2021). The AAT for the regions where the farms were located ranged from 775–2200 degree days, with most farms being located in regions where the AAT ranged from 1200–1800 degree days (Ray 2008, Barnett 2006). The method of calculation described in (1), where $T_{mean} \geq 5°C$ and $T_{base} = 5°C$.

The resulting values were divided into four classes, found in Table 2.1, according to the number of tea farms there were within each range.

$$AAT = \sum(T_{mean} - T_{base}) \qquad (1)$$

Annual accumulated precipitation

In the major tea producing regions, the precipitation ranges from 1000–2000 mm/year (Eden 1965, FAO & CAAS 2021, Shoubo 1989). It was therefore necessary to compare the actual annual accumulated precipitation to the lowest annual accumulated precipitation for tea cultivation, values listed in Appendix 2 (Table 5.3).

The value that was compared to the suitability classes was the average of the annual accumulated precipitation for each point.

Probability of year with three or more consecutive months of precipitation below 50 mm/month

The risk of drought damaging the tea plant was frequently mentioned in literature and it was deemed necessary to account for this in addition to the annual accumulated precipitation. In literature, several consecutive months of precipitation below 50 mm/month was regarded as drought (Eden 1965, Chen et al. 2012, Zhao et al. 2016). Three or more months was decided as the length of time to consider the conditions to be “in drought”, after comparing precipitation charts for different tea growing regions found in Carr (2018).

To calculate the probability of the criteria being fulfilled, the years with instances of three or more months of precipitation below 50 mm/month occurring at least once, were then added together. The sum was then divided by the total number of years, resulting in the probability of the criteria occurring, which was then compared to the suitability classes.

2.4 Datasets and processing

The meteorological data used in this study was a dataset of daily surface meteorological data from the Copernicus Climate Change Service (Boogaard et al. 2020). The dataset described the daily temperature and precipitation for 2904 points in southern Sweden. The World Meteorological Organization (WMO) recommend using at least 30-year periods of reference (WMO 2017), as such data from the years 1979–2018 were used. The geographical locations of the points were projected on a regular latitude-longitude grid with a resolution of 0.1° x 0.1° (Boogaard et al. 2020), presented in Figure 2.1. There were some overlaps for rain data, where certain points used the same data. This results in an unsymmetrical grid for maps using rain data as an input.

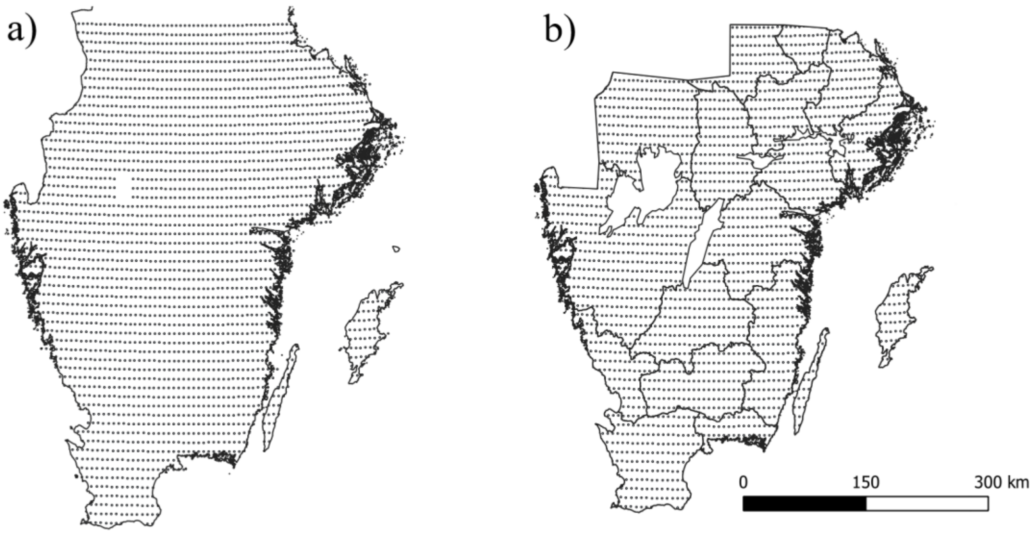

Figure 2.1. Geographical locations of data points: a) before layers with study area, lakes and province borders were added, b) map with layers added used to display final results.

The data from each point was processed using R (in RStudio, see Appendix 2) to calculate values corresponding to each crop suitability criteria mentioned in 2.4 (Posit Team 2023).

2.4.1 GIS mapping

The data from the pre-processing in RStudio, were combined with the longitude and latitude for each data point and then used to create grided layers with QGIS displayed in Figure 2.1. To estimate values between points, spatial interpolation was used and in the case of this study Inverse Distance Weighted interpolation (IDW) was chosen as the most suitable method. Using this method, data points are weighted against each other to estimate the value of an unknown point. Depending on the distance between the unknown point and the data points, a weighting coefficient control to what degree each data point influence the value of the unknown point. IDW-interpolation was used to ensure that the minimum and maximum values remained the same throughout the process (QGIS.org 2023).

The quality of the interpolation for this method decrease if the data points are unevenly distributed, which was not an issue with the grid used for the data points. Minimum and maximum values can only occur on the data points and not in the interpolated surface, occasionally causing peaks and valleys to appear around data points. In this study, averages were used for all criteria, the minimum and maximum values used needed to be actual data, and ranges of values were used to evaluate the results. Disadvantages and aim for the study in mind, IDW-interpolation was decided to be the most suitable method of interpolation to use.

Six sets of maps were created – one for each criterion. Similarly, two maps for the land suitability evaluation, using the multiple-criteria evaluation mentioned in 2.4.2, were created for the final analysis. The maps were finalized by adding layers showing lakes, provinces and trimming the northernmost areas. These areas are not displayed in the final result figures, but the values are included in the text.

2.4.2 Multiple-criteria evaluation

To evaluate the land suitability according to the multiple criteria decided upon in 2.4, a point system for the different classes was created. Each class was assigned a sum of points: *highly suitable* = 3p, *moderately suitable* = 2p, *marginally suitable* = 1p, and *unsuitable* = 0p.

These points were then added together, and the final sum was evaluated according to the percentage of the total sum of points (6 criteria x 3p = 18p). These percentages were then assigned to different classes: *highly suitable* ≥ 75%, *moderately suitable* 50–75%, *marginally suitable* 25–50%, and *unsuitable* < 25%.

2.5 Interviews

Tea has been grown in Sweden since 2016, not including Carl von Linnaeus failed attempts during the 18th century, when a smaller tea plantation was started on Gotland. After this, more attempts at tea farming been initiated.

As there have been attempts to grow tea in Sweden, it was deemed important to include these growers' experiences in this study to connect the theoretical evaluation with practical experience. Interviews with four tea growers were therefore carried out (interview questions found in Appendix 3). The questions for the interviews were inspired by Melican (2016).

The interviews were summarized, and the most important parts related to the study can be found in 3.2.

3. Results

3.1 Land suitability evaluation

3.1.1 Precipitation

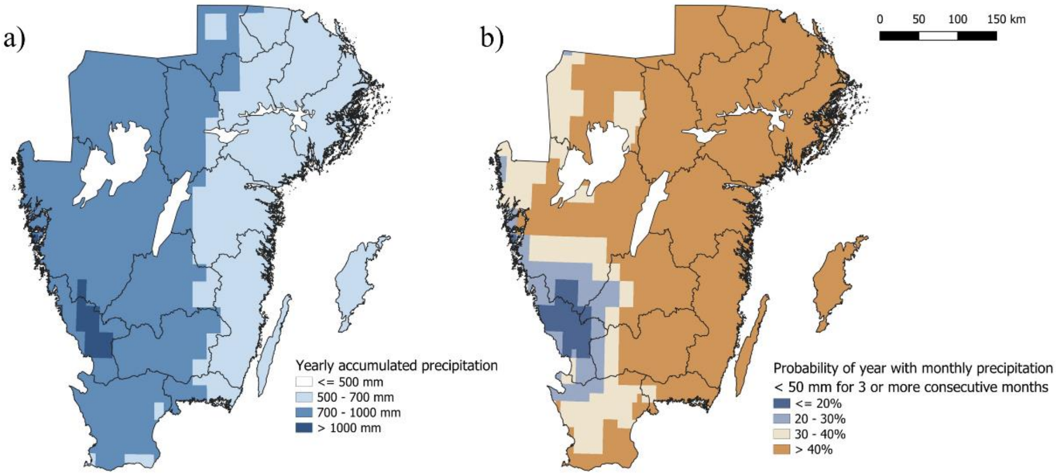

Figure 3.1. Land suitability layers based on climatic crop requirements related to precipitation for tea: (a) average yearly accumulated precipitation, (b) probability of year with monthly precipitation below 50 mm for three or more consecutive months.

The western regions of Sweden received both the highest annual accumulated precipitation and had the lowest probability of having a year with three or more consecutive months with precipitation below 50 mm/month, presented in Figure 3.1. (a-b). The regions overlap in terms of both criteria to a high degree.

Highly suitable regions. 49 of 2904 (1.7%) locations were classed as highly suitable in regard to annual accumulated precipitation, and 35 of 2904 (1.2%) in regard to the probability of a year with precipitation below 50 mm/month for three or more consecutive months.

Moderately suitable regions. 1748 of 2904 (60.2%) locations were classed as moderately suitable in regard to annual accumulated precipitation, and 196 of 2904

(6.7%) in regard to the probability of a year with precipitation below 50 mm/month for three or more consecutive months.

Marginally suitable regions. 1107 of 2904 (38.1%) locations were classed as marginally suitable in regard to annual accumulated precipitation, and 370 of 2904 (12.7%) in regard to the probability of a year with precipitation below 50 mm/month for three or more consecutive months.

Unsuitable regions. 0 of 2904 (0.0%) locations were classed as unsuitable in regard to annual accumulated precipitation, and 2303 of 2904 (79.3%) in regard to the probability of a year with precipitation below 50 mm/month for three or more consecutive months.

3.1.2 Temperature

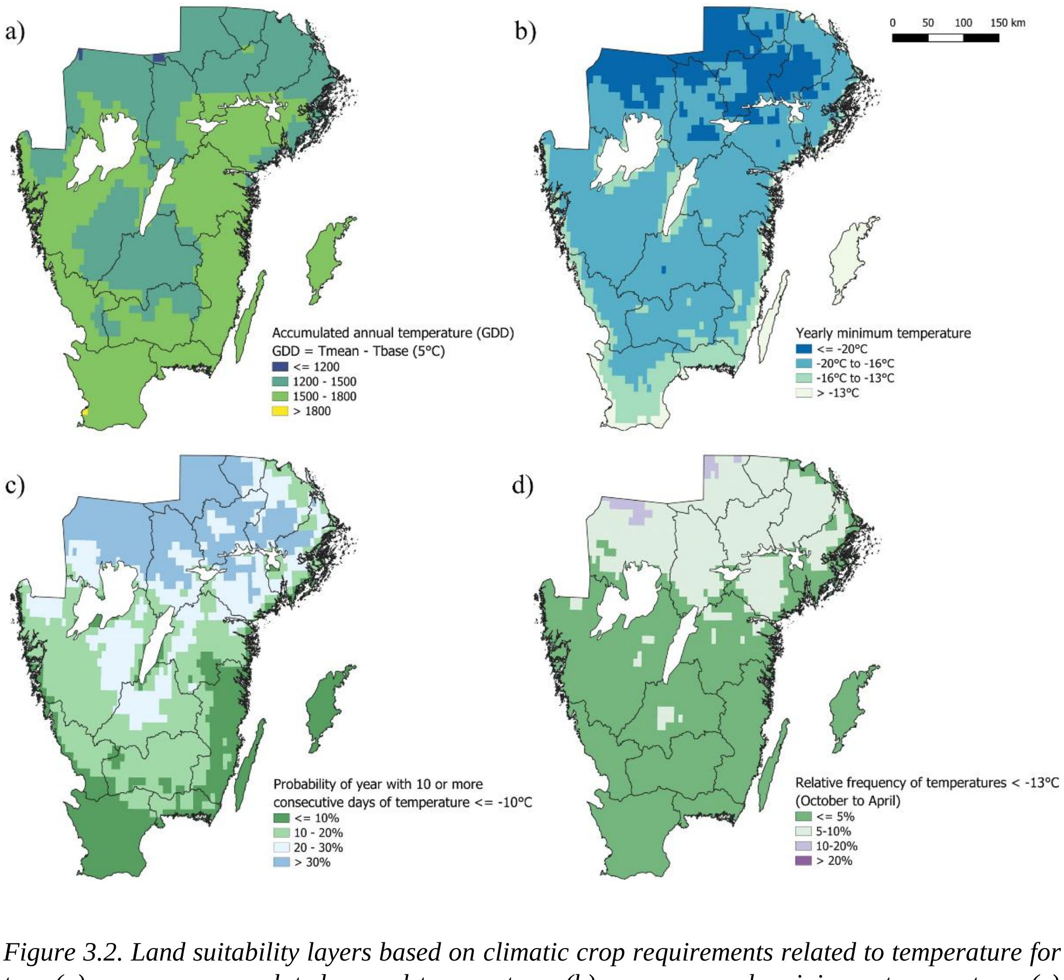

Figure 3.2. Land suitability layers based on climatic crop requirements related to temperature for tea: (a) average accumulated annual temperature, (b) average yearly minimum temperature, (c) relative frequency of temperatures below -13°C, (d) probability of year with 10 or more consecutive days of temperatures equal to or below -10°C.

The coastal areas and the southernmost parts of Sweden had the highest annual accumulated temperature, warmer yearly minimum temperatures, and the lowest relative frequency of temperatures below -13°C and the probability of continuous negative temperatures below -10°C, presented in Figure 3.2. (a-d).

Highly suitable regions. 3 of 2904 (0.1%) locations were classed as highly suitable in regard to annual accumulated temperature, 323 of 2904 (11.1%) in regard to yearly minimum temperature, 1805 of 2904 (62.2%) in regard to the relative frequency of temperatures below -13°C, and 599 of 2904 (20.6%) in regard to the probability of temperatures equal to or below -10°C for ten or more consecutive days.

Moderately suitable regions. 1443 of 2904 (49.7%) locations were classed as moderately suitable in regard to annual accumulated temperature, 389 of 2904 (13.4%) in regard to yearly minimum temperature, 891 of 2904 (30.7%) in regard to the relative frequency of temperatures below -13°C, and 865 of 2904 (29.8%) in regard to the probability of temperatures equal to or below -10°C for ten or more consecutive days.

Marginally suitable regions. 1297 of 2904 (44.7%) locations were classed as marginally suitable in regard to annual accumulated temperature, 1553 of 2904 (53.5%) in regard to yearly minimum temperature, 208 of 2904 (7.2%) in regard to the relative frequency of temperatures below -13°C, and 580 of 2904 (20.0%) in regard to the probability of temperatures equal to or below -10°C for ten or more consecutive days.

Unsuitable regions. 161 of 2904 (5.5%) locations were classed as unsuitable in regard to annual accumulated temperature, 639 of 2904 (22.0%) in regard to yearly minimum temperature, 0 of 2904 (0.0%) in regard to the relative frequency of temperatures below -13°C, and 860 of 2904 (29.6%) in regard to the probability of temperatures equal to or below -10°C for ten or more consecutive days.

3.1.3 Land suitability for tea cultivation

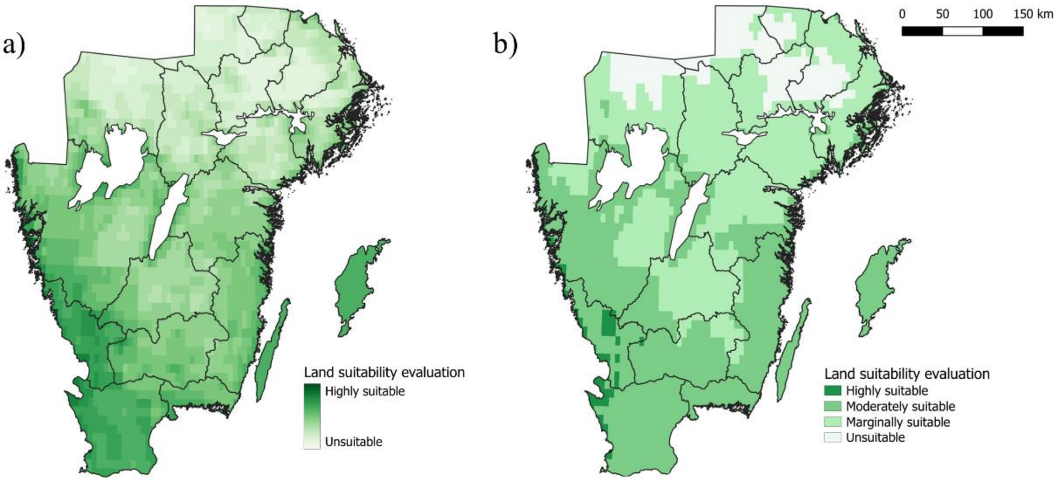

Figure 3.3. Land suitability evaluation for tea cultivation based on point system described in 2.4.2. (a) suitability gradient from unsuitable to highly suitable, (b) zoning for the four suitability classes.

In Figure 3.3, (a) displays the range of the point system, with point sums ranging from 3p to 17p, (b) presents the suitability classes after dividing the point sums in (a) into the four ranges (< 25%, 25–50%, 50–75%, and > 75%).

Highly suitable regions. 78 of 2904 (2.7%) locations were classed as highly suitable for tea cultivation. These regions were located on the West Coast of Sweden, stretching a short distance inland.

Moderately suitable regions. 1073 of 2904 (36.9%) were classed as moderately suitable for tea cultivation. These regions were located along the coastline, spreading further inland, around the lakes Värnen and Vättern, and includes the islands in the Baltic Sea.

Marginally suitable regions. 1115 of 2904 (38.4%) were classed as marginally suitable for tea cultivation. These regions were located on the South Swedish highlands and north of Vättern and Värnen).

Unsuitable regions. 638 of 2904 (22.0%) were classed as unsuitable for tea cultivation. These regions were all located north of the lake Mälaren.

3.2 Synthesis of interviews with Swedish tea growers

The tea farms included in the study were started in 2016 with 500 plants (Gotland), in 2018 with 300 plants (Gränna), in 2019 with 30 plants (Svenshögen), and in 2023 with 10.000–15.000 seeds planted (Kristianstad), with locations of the farms displayed in Figure 3.4.

The plant material first used in Gotland, Gränna and Svenshögen, was all imported from the Netherlands in the form of young plants (*Camellia sinensis* var. *sinensis*, unknown cultivar). There has been a need to continue importing new plants, as attempts to grow from seeds have been unsuccessful and attempts to grow from cuttings have been only partly successful as they tend to have poor root growth and survivability when being transplanted into larger pots/open field. In 2022, Gotland had the first seeds produced by their tea plants.

The plant material used in Kristianstad was in the form of seeds, imported from Nepal, which are being grown in a cold greenhouse (85-90% successfully sprouted). Freshly produced seeds were used, as tea seeds need to be fresh to sprout successfully.

Methods of soil preparation used included adding acidic soil, sand, peat, and manure to lower the pH, as well as improve drainage and soil texture. All of the farms use irrigation to some extent, from manual watering to drip irrigation.

The areas where the tea farms are located displayed in Figure 3.4 are all located in areas that are classed as moderately suitable according to the classification system used in this study. A range of different cultivation methods has been used and are currently being used, from growing in greenhouses, open-field cultivation (including garden and hügelkultur) and being planted in or near forests (coniferous and mixed forest). The results of the different cultivation methods vary from year to year, depending on weather conditions. The survival rate of the plants ranges from 0–100%, with cold (and wet) winters and wide temperature differences between day and night during spring being mentioned as difficulties. The plants that survive the winters with the leaves green and attached to the plant, generally lose their leaves in early spring, making the plants appear dead, but they sprout new leaves as the temperature start to rise (Figure 3.5).

Figure 3.4. Locations of Swedish tea farms. In the order of west to east: Svenshögen, Gränna and Gotland. The southernmost point being Kristianstad.

Protective measures that have been used include fence against animals, as well as polytunnels, cover (fabric) and heating coils in the ground to protect against frost and low temperatures. There have also been attempts to move plants inside a greenhouse during winter for a few months and then transplanting them back into the soil outside during spring, to avoid the coldest temperatures during winter. The protective measures have been successful to varying degrees, with moving plants to a greenhouse during the winter or growing them there permanently being the most successful. The need for fencing was described as both unnecessary and necessary by different farmers, as experiences with wildlife differs.

Finding locations with the correct microclimate, where the plants are protected against intense sunlight, cold temperatures and wind, as well as a location with a soil that does not dry out too quickly, were also mentioned as prerequisites for successful tea cultivation. The conditions in Sweden were described as not optimal in general by growers, and as such, the importance of finding locations that fit as many of the requirements as possible is necessary.

All of the farms (except Kristianstad) have managed to produce and process tea leaves into small batches of finished product, either from leaves plucked with the purpose of producing tea or from branches and leaves left after pruning.

Figure 3.5. New spring leaves growing on tea plant in Gränna, 2023-05-05.

3.2.1 Reflections and concerns from growers

The growers all believe that tea cultivation has a future in Sweden, but that there is too little information about how to do it successfully under Swedish conditions. As a result of this, all of the growers have felt the need to employ different cultivation methods and protective measure to find the most successful way of growing tea in the conditions that exists in the area where they are located. Several growers mentioned the need of a network between growers (and with experts) that could share their experiences and knowledge, creating a support for both existing and prospecting growers.

The major concerns regarding tea cultivation mentioned by growers were the cold temperatures during winter and wide temperature differences between night and day during spring, believed to play a part in the plants losing their leaves. Other concerns mentioned were the sun intensity during summer, the need for a good microclimate, and the issue of water (the need of irrigation and the sustainability of growing a plant generally found in areas with a precipitation of more than 1500 mm/year).

4. Discussion

4.1 Growing tea in Sweden

The result of the land suitability evaluation and the synthesis of the interviews with Swedish tea growers, both indicate that it is possible to grow tea in Sweden, especially in regions around the West coast and north-western Skåne, where there are high amounts of precipitation, and the climate is milder with the risk of low temperatures being less when compared to further inland. According to the tea growers that were interviewed for the study, growing tea in greenhouses can be done quite easily. However, as the focus of this study was whether or not tea could survive the Swedish climatic conditions, it was not considered as a relevant method of growing tea for this study.

The conditions are not optimal for large scale tea cultivation, but with the right plant material, small scale production should be possible according to this study. If tea is introduced as a speciality crop in Sweden, it could be an option for farmers looking for a long-lived, perennial crop, where tea could be an alternative to nut and fruit trees in agroforestry.

There are challenges to solve before tea can become a valid alternative and further research needs to be conducted to find suitable varieties or cultivars, as well as suitable cultivation methods for the local conditions. There is little to no knowledge regarding tea cultivation in the country, and every grower will need to start their tea growing on a trial-and-error basis.

4.2 Crop requirements

The primary source of difficulties in this study were finding a consensus in literature, as to what the limits were for growing tea and to find first-hand sources for the information. Due to there being several varieties and hundreds of cultivars of the plant, that are all grown in different regions of the world, it was difficult to connect values for the criteria with what kind of tea plant the literature referred to. Primary focus was therefore placed on research conducted in China, Japan and South Korea, where the major varieties of tea being cultivated are *Camellia sinensis* var. *sinensis* and hybrids of different varieties.

Most literature regarding the extreme lowest temperature to grow tea in often referred to temperatures that would kill buds and new shoots, but failed to mention what temperatures would kill the plant itself (Kimura et al. 2021, Nakano 2002). To showcase this, the values found for extreme lowest temperature ranges from -30°C to +10°C, which is an extremely wide range (Appendix 2 – Table 5.1). The literature where these particular values come from does not mention what variety they are referring to, but the latter is assumed to be var. *assamica*. Similarly, literature regarding precipitation most often mention the optimum amounts for tea cultivation, not mentioning the lowest amount for survivability. The most difficult aspect concerning precipitation are primarily the wide differences in the amount of precipitation required for cultivation to be possible. Connected to this the fact that literature sometimes mention very low annual precipitation (i.e. 500 mm/year), but that irrigation is necessary yet fail to mention to what degree the plants need to be watered (Carr 2018, Willson & Clifford 1992).

It was also difficult to relate the values found for precipitation to the climate in Sweden. Areas where tea is traditionally being grown is warmer, resulting in the evapotranspiration being higher and the plants requiring more water. It is therefore difficult to say what amount of precipitation is necessary for tea grown in Swedish conditions as the average temperature is lower for most parts of the country, and as a general, the annual precipitation is also lower.

It is a fact that there are tea farms currently operating in Europe in climatic conditions that are much more similar to Sweden compared to the conditions in traditional tea growing regions (Bolton 2022, Tea Grown in Europe Association

2022, Tea Scotland 2021). Finding regions in Sweden with conditions similar to these tea growing regions could give a clearer view of what the limits of tea cultivation is compared to looking at the regions of the world where conditions are closer to optimal.

4.3 Sustainability and ethical aspects

Before introducing tea as an alternative crop, both the sustainability and ethical aspects need to be considered. Tea is a crop that require large amounts of water in the regions where it is traditionally grown, but these are also regions that receive high amounts of annual precipitation (Carr 2018, Willson & Clifford 1992, Shoubo 1989). Contrary, the regions of Sweden with the highest amount of precipitation would still be considered having a low amount when compared to that of traditional tea growing regions. If shown that the water requirement of tea grown in Sweden is so substantial that irrigation is necessary, regardless of where in the country the crop is grown, consideration need to be taken before deciding to start up a tea farm. Water availability connected to farming is already an issue in some parts of the country and the economical aspect of having to invest in irrigation systems need to be considered (Jordbruksverket 2022).

The economical sustainability for potential farmers has many aspects to it. New tea farms need to invest both money and time in either seeds or young plants, with the first potential earnings years in the future. That is if the plants survive and can be harvested. The crop is labour-intensive during harvest and if grown on a larger scale, will require either investing in mechanized harvesting equipment or hiring workers for manual picking. Investing in post-harvest processing equipment or sharing equipment between several farmers to lessen the expense would also be necessary, as tea leaves need to be processed relatively soon after being harvested (Carr 2018, Willson & Clifford 1992).

From a social perspective, tea cultivation in Sweden could increase the interest in the commodity that is tea. Most Swedes buy their tea in form of tea bags, which is vastly different from speciality tea grown around the world. The traditions, knowledge and labour that comes with creating high-quality tea is unknown to most people. If a greater understanding could be created from growing tea locally, more people could also begin to look into where the tea that they buy come from and whom it is produced by.

4.4 Future studies

Tea cultivation in Europe and more specifically in Sweden is a relatively new concept, which also mean that it is a new area of research with a wide array of subjects to explore.

There is a need for more extensive suitability studies that include more factors to base the land suitability evaluation on, for example factors related to soil (such as pH, texture and structure, water availability, etc.), and a wider array of climatic requirements (such as humidity, light conditions, frequency of extreme weather events, etc.). It is also necessary to include availability as well as cost of harvest and post-harvest processing. These aspects all need to be included in the evaluation (FAO 1976, FAO 1993).

To further investigate the possibilities of tea cultivation in Sweden, different types of cultivars need to be grown to evaluate their suitability, preferably in different regions of the country as the climate vary greatly. If possible, cultivars from several different countries should be included in the experiment to find the most suitable candidates. Seed-grown plants compared to imported young plants would be preferred both from an economic, environmental and a quantitative perspective. Saplings compared to seeds are more expensive, come with a higher risk of importing pests, and requires more fuel in transportation when considering size and quantity. The time required to grow seeds into well-sized plants take longer, but the aspect of acclimatization would be included in this timeframe. In growing seeds, larger quantities of individual plants could be grown and with the heterogeneous nature of seedlings, the chance of individual plants displaying a higher survivability in Swedish conditions would be higher.

Tea produced in Europe and in Sweden would not be able to compete in quantity with large tea producing countries, but possibly in quality with novel terroirs. Plants grown in conditions that cause stress, such as cold climates, higher altitudes, and shade, could create compounds that improve taste, which is true to some extent in tea (Willson & Clifford 1992; Wickremasinghe 1974, Shao et al. 2021). The difference in the growing season, when comparing conditions in Sweden and to that of traditional tea growing areas, also need to be explored in how it effects the plant. The growing days during summer are considerably longer, with more hours of sunlight compared to more southern latitudes and the opposite during winter (Climate-Data.org 2023). The growing season is shorter, but more intensive, and the effect on the amount of yield needs to be explored.

In traditional tea growing regions, the economic life expectancy of a tea plant is up to a hundred years (Carr 2018, De Costa et al. 2007), but it is unknown if the same is true for conditions that are less than optimal. When connected to the slow start that is to be expected when growing tea in colder climates, and the fact that first harvest will be delayed when compared to plants grown in optimal conditions, there need to be evidence that prove that the investment is worth it in the end.

4.4.1 Climate change

The datasets used for the land evaluation process were, as mentioned in 2.3, of the periods 1979–2018. This makes the evaluation dated due to the changing climate. The data from the points will most likely be vastly different in the future and this makes the result of this study unreliable in the sense of both a warmer climate, change in precipitation and with an increase of extreme weather (SMHI n.d.). More extensive land suitability evaluations should therefore include predictions of what the climate will be for the regions included in the evaluation. This will be especially important when considering the long period of time that tea plants can remain productive.

5. Conclusion

This study was conducted to answer the questions of whether or not it is possible to grow tea in Sweden in regard to climatic conditions, and if so where in the country it would be the most suitable. The result of the land suitability evaluation showed that it is possible and that the West coast would be particularly suitable, with high annual precipitation and a milder, coastal climate.

In interviews with Swedish tea growers, the general consensus was that tea cultivation does have a future in the country, but that measure to protect the plants from the harsher climate is necessary, with extremely cold temperatures, wide temperature differences during spring and the need for irrigation being mentioned as stand-out challenges.

As a conclusion, Carl Linnaeus was right in his beliefs that tea could be grown in Sweden, all that it took was a few centuries of research and development of agricultural practises and technologies, but the idea of being self-sufficient was an overstatement to say the least.

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Appendix 1

Graphs displaying the average temperature and precipitation per month for two examples of colder tea growing regions in Europe and Tibet, as well as the locations in Sweden where tea is currently being grown.

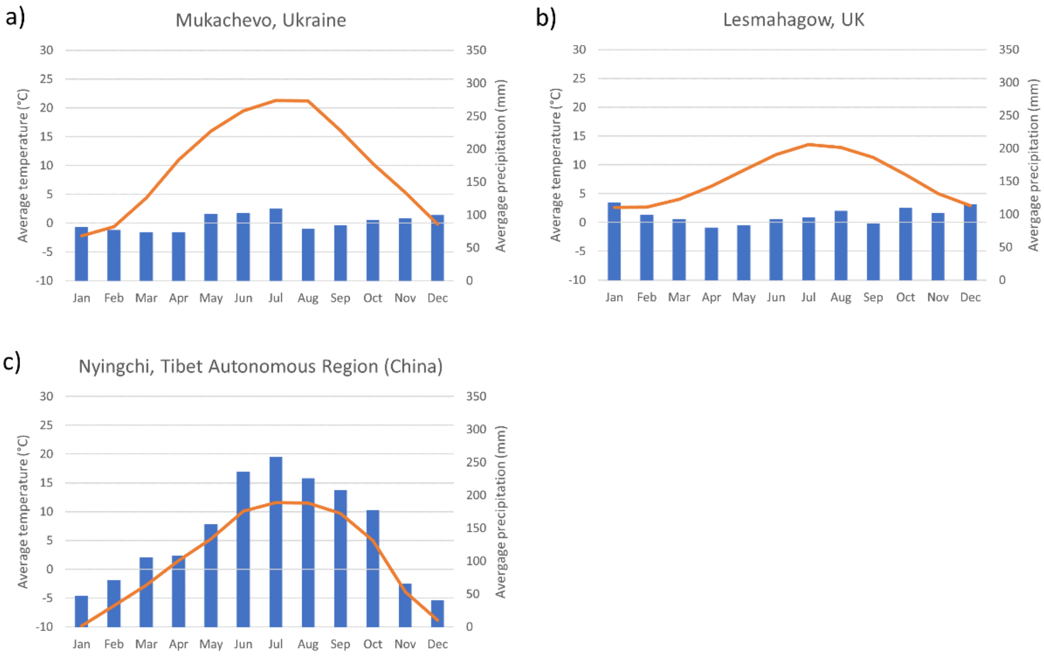

Figure 5.1. Climate graphs displaying the average monthly temperature and precipitation for three colder tea growing regions in Europe and Tibet for the period 1991-2021. a) Zhornyna Experimental Tea Plantation in Ukraine, b) Scottish Tea House in the United Kingdom, c) Yigong Tea Plantation in Tibet (China). Data retrieved from Climate-Data.org (2023).

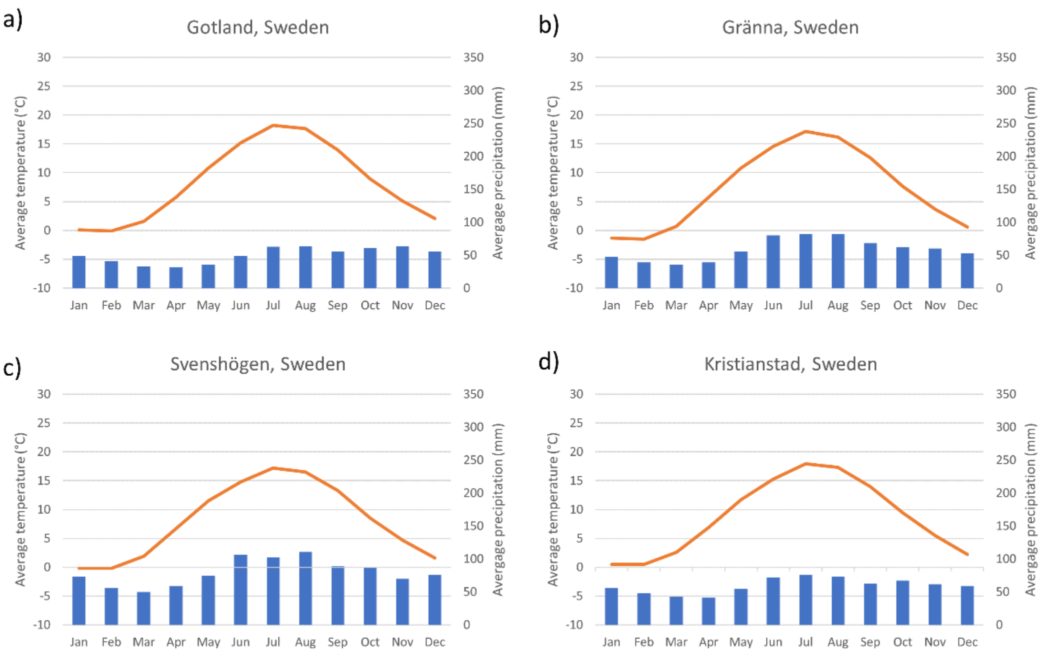

Figure 5.2. Climate graphs displaying the average monthly temperature and precipitation for the four tea farms in Sweden for the period 1991-2021. a) Gotland, b) Gränna c) Svenshögen, d) Kristianstad. Data retrieved from Climate-Data.org (2023).

Appendix 2

Tables with listing values found in literature regarding crop requirements for tea cultivation (*Camellia sinensis* var. *sinensis*). Listed values represent the most extreme values unless otherwise described.

Table 5.1 Minimum temperature.

Description of value	Temperature	Source
Absolute T_{min} (tea growth possible)	-20°C	Shoubo (1989)
Absolute T_{min} (economic culture optimum)	-13°C	Shoubo (1989)
LT_{50} (for buds)	-15°C	Nakano (2002)
100% dead buds	-18°C	Nakano (2002)
T_{min} (from actual tea garden in South Korea)	-17.4°C	Hwang & Kim (2014)
Absolute T_{min}	-16°C	Zheng et al. (1990)
T_{min} (in South Korean tea growing areas)	-17°C	Jeong & Park (2012)
Absolute T_{min}	-20°C	Han et al. (2018)
T_{min}	-13°C	Li et al. (2012)
Absolute T_{min}	-30°C	Willson (1992)
T_{min}	-15°C	Chen et al. (2012)
T_{min}	-10°C	Zhao et al. (2016)
T_{min}	-14°C	Zou (2015)

Table 5.2. Annual accumulated temperature.

Description of value	Thermal units	Source
Active accumulated temperature of mean daily temperature ≥ 10°C	3000	Shoubo (1989)
Annual accumulated temperature (≥ 10°C)	3000	Han et al. (2018)
Accumulated temperature (≥ 0°C)	3000	Zhao et al. (2016)
Annual accumulated temperature (≥ 10°C)	4000	Zou (2015)
Annual accumulated temperature	3000	Zheng et al. (1990)

Table 5.3. Annual accumulated precipitation.

Description of value	Annual precipitation (mm)	Source
Minimum annual precipitation	800	Zheng et al. (1990)
Mean annual precipitation	750	Shoubo (1989)
Annual precipitation	500	Han et al. (2018)
Mean annual precipitation	800	FAO & CAAS (2021)
Mean annual precipitation	900	Carr (2018)
Mean annual precipitation	900	Zhao et al. (2016)

Appendix 3

Script (from RStudio) used to evaluate the climatic crop requirements for tea. The meteorological data used as input was the dataset from C3S (Boogaard et al., 2020). The script for evaluating climatic crop criteria for Sweden can be found in Figure 5.1 and the script land suitability evaluation in Figure 5.2.

```
# Climate data import and using the work directory (second one is for laptop)
setwd("C:/Users/Lovisa/Documents/Kandidatarbete/R-Tea project/Climate_data/")
setwd("C:/Users/lowwi/Documents/Kandidat/RStudio-Tea project/Climate_data/")

# Empty result files to us in QGIS
station_number <- sprintf('%04d', 1:2904)
results <- data.frame("STATION"=paste(station_number, "ERA5", sep=""),
                      "AAT"=NA, "ABS.TMIN"=NA, "RF.NEG.13"=NA,
                      "NEG.10FOR10"=NA, "RAIN.YEAR"=NA, "RAIN.MONTH"=NA)

# Empty result file for the point score for land suitability evaluation
# 3 points for most suitable, down to 0 points for unsuitable
LSE <- data.frame("STATION"=paste(station_number, "ERA5", sep=""),
                  "AAT"=NA, "ABS.TMIN"=NA, "RF.NEG.13"=NA,
                  "NEG.10FOR10"=NA, "RAIN.YEAR"=NA, "RAIN.MONTH"=NA, "SUM"=NA)

# Creates a character vector with climate data file names for the for-loop
files <- data.frame(FILENAME=paste(station_number,"ERA5.WTH",sep=""))

# Julian date string to simplify, including leap years
j_date <- seq(as.Date("1979-01-01"), as.Date("2018-12-31"), 1)

# Counter for the big loop
i = 1

#----------- Start of the loop -------------------------------------------------

for (i in 1:nrow(files)) {

  # Combine and order the station weather data with Julian date in a data frame,
  # adding column names and removing irrelevant data.
  weather_data <- read.table(files[i,1], header = FALSE, skip = 5)
  colnames(weather_data) <- c("DATE","JULIAN","TMAX","TMIN","RAIN")
  weather_data$TMEAN <- rowMeans(cbind(weather_data$TMAX, weather_data$TMIN))
  weather_data$JULIAN <- j_date
  weather_data <- weather_data[,c("DATE","JULIAN","TMAX","TMIN","TMEAN","RAIN")]

  # Smaller data frames for criteria relating to temperature
  Tmin10 <- weather_data[,c("JULIAN","TMIN")]
  Tmin13 = Tmin10
  Tmin13$MONTH <- format(as.Date(j_date),"%m")

#------------- AV. ACCUMULATED TEMP. TO COMPARE WITH SCOTLAND ------------------

# Average of accumulated temperatures with base 5 degrees C.
  mean_temp <- weather_data[,c("JULIAN","TMEAN")]
  mean_temp$DAY.DEGREES <- ifelse(mean_temp$TMEAN < 5, 0, mean_temp$TMEAN - 5)
  aat = aggregate(list("ACC.TEMP"=mean_temp$DAY.DEGREES),by=list(
                  DATES=cut(as.POSIXct(mean_temp$JULIAN),"year")),sum)

# Average of acc.temp and add to result file
  results[i,2] <- sum(aat[2])/40
```

```
#------------------------- AVERAGE ABSOLUTE TMIN -------------------------------

# Sort data into years, find minimum value
  yearly_Tmin = aggregate(list("TMIN"=weather_data$TMIN),by=list(DATES=cut(
                as.POSIXct(weather_data$JULIAN),"year")),min)

# Sum Tmin for each year and get the average, add to result file.
  results[i,3] <- sum(yearly_Tmin[2])/40

#-------------------- PROBABILITY OF YEAR WITH TEMP < -13C ---------------------

# Number of days in Oct-Apr (Jan=31, Feb=28/29, Mar=31, Apr=30,
# Oct=31, Nov=30, Dec=31) for the 40 year period
  days <- (31*40)+(28*30)+(29*10)+(31*40)+(30*40)+(31*40)+(30*40)+(31*40)

# Check each entry if < -13 (1 if yes, 0 if no)

  Tmin13$limit <- Tmin13$TMIN < (-13)
  Tmin13 <- replace(Tmin13, Tmin13==FALSE, 0)

# Counting number of occurrences between October and April
  Tmin13$octapr <- Tmin13$limit==1 & (Tmin13$MONTH <=04 | Tmin13$MONTH >=10)
  Tmin13 <- replace(Tmin13, Tmin13==FALSE, 0)
  Tmin13_occ <- sum(Tmin13[5])

# Calculate relative frequency over total number of days
# and add result to results file
  results[i,4] <- sum(Tmin13_occ/days)

#---------------- PROBABILITY OF YEAR WITH 10+ DAYS OF <= -10C -----------------

# Check each entry if <= -10 (1 if yes, 0 if no)
  Tmin10$limit <- Tmin10$TMIN <= (-10)
  Tmin10 <- replace(Tmin10, Tmin10==FALSE, 0)
  Tmin10$count <- NA
  Tmin10$reoccur <- NA

# Count for how many consecutive days temperatures are <= -10
# (including multiples of 10)
  count <- 0
  q = 0

  for (q in 1:nrow(Tmin10)) {

    if (Tmin10[[q,3]] == 1) {
      count <- count + 1
      Tmin10[q,4] <- count

      if (count %% 10 == 0) {
        Tmin10[q,5] <- 1
      } else {
        Tmin10[q,5] <- 0
      }

    } else {
      count <- 0
      Tmin10[q,4] <- 0
      Tmin10[q,5] <- 0
    }
  }

# Count total occurrences, occurrences per year and relative frequency/year
  Tmin_10_tot <- sum(Tmin10[5])
  Tmin_10_yearly = aggregate(list("REOCCUR"=Tmin10$reoccur),by=list(
                   DATES=cut(as.POSIXct(Tmin10$JULIAN),"year")),sum)

# Probability of a year with criteria occurring (1 if it happens, 0 if not)
  Tmin_10_yearly$PROBABILITY <- ifelse(Tmin_10_yearly$REOCCUR>=1,1,0)

# Add result to results file
  results[i,5] <- sum(Tmin_10_yearly[3]/40)

#---------------------- AVERAGE YEARLY PRECIPITATION ---------------------------

# Yearly average of precipitation
  yearly_rain <- data.frame("DATE"=weather_data[1], "JULIAN"=weather_data[2],
                           "RAIN"=weather_data[6])
  yearly_rain = aggregate(list(RAIN=weather_data$RAIN),by=list(DATES=cut(
                          as.POSIXct(weather_data$JULIAN),"year")),sum)

# Add result to results file
  results[i,6] <- sum(yearly_rain[2])/40

#---------------- PROBABILITY OF YEAR WITH 3+ CON. MONTHS OF < 50 --------------

# Sum of precipitation per month
```

```
  monthly_rain <- data.frame("DATE"=weather_data[1], "JULIAN"=weather_data[2],
                             "RAIN"=weather_data[6])
  monthly_rain = aggregate(list(RAIN=monthly_rain$RAIN),by=list(DATES=cut(
                           as.POSIXct(monthly_rain$JULIAN),"month")),sum)

# Check if monthly_rain < 50 (1 if yes, 0 if no)
# Replace FALSE with NA (to ignore entries in next step)
  monthly_rain$limit <- monthly_rain$RAIN < (50)
  monthly_rain <- replace(monthly_rain, monthly_rain==FALSE, 0)
  monthly_rain$count <- NA
  monthly_rain$reoccur <- NA

# Loop for counting how many consecutive days temperatures are <= -10
# (including multiples of 10).
  count <- 0
  q = 1

  for (q in 1:nrow(monthly_rain)) {

    if (monthly_rain[[q,3]] == 1) {
      count <- count + 1
      monthly_rain[q,4] <- count

      if (count >= 3) {
        monthly_rain[q,5] <- 1

        if (monthly_rain[(q-1),5] == 1) {
          monthly_rain[(q-1),5] <- 0
        }
      } else {
        monthly_rain[q,5] <- 0
      }
    } else {
      count <- 0
      monthly_rain[q,4] <- 0
      monthly_rain[q,5] <- 0
    }
    q = q + 1
  }

# Probability of a year with criteria occurring (1 if it happens, 0 if not)
  yearly_50_prob = aggregate(list("Total.occ"=monthly_rain$reoccur),by=list(
                   DATES=cut(as.POSIXct(monthly_rain$DATES),"year")),sum)
  yearly_50_prob$PROBABILITY <- ifelse(yearly_50_prob$Total.occ>=1,1,0)

# Add result to result files
  results[i,7] <- sum(yearly_50_prob[3])/40


#-------------------------- For next run of the loop -------------------------

  i = i + 1
}
```

Figure 5.3. Script for evaluating climatic crop criteria in RStudio (Posit Team, 2023).

```
#------------------------- LAND SUITABILITY EVALUATION -------------------------

g = 1

for (g in 1:nrow(results)) {

# LSE for AAT -------------------------------------------------------------------

  if (results[g,2] >= 1800) {
    LSE[g,2] <- 3

  } else if (results[g,2] >= 1500) {
    LSE[g,2] <- 2

  } else if (results[g,2] >= 1200) {
    LSE[g,2] <- 1

  } else {
    LSE[g,2] <- 0
  }

# LSE for absolute minimum temp. ------------------------------------------------

  if (results[g,3] > (-13)) {
    LSE[g,3] <- 3

  } else if (results[g,3] > (-16)) {
    LSE[g,3] <- 2

  } else if (results[g,3] > (-20)) {
    LSE[g,3] <- 1

  } else {
    LSE[g,3] <- 0
  }

# LSE for RF of temp below -13 (oct-apr) ----------------------------------------

  if (results[g,4] < (0.05)) {
    LSE[g,4] <- 3

  } else if (results[g,4] < (0.1)) {
    LSE[g,4] <- 2

  } else if (results[g,4] < (0.2)) {
    LSE[g,4] <- 1

  } else {
    LSE[g,4] <- 0
  }

# LSE for probability of year with 10+ days of -10 or below --------------------
  if (results[g,5] < (0.1)) {
    LSE[g,5] <- 3

  } else if (results[g,5] < (0.2)) {
    LSE[g,5] <- 2

  } else if (results[g,5] < (0.3)) {
    LSE[g,5] <- 1

  } else {
    LSE[g,5] <- 0
  }

# LSE for yearly precipitation -------------------------------------------------
  if (results[g,6] > 1000) {
    LSE[g,6] <- 3

  } else if (results[g,6] > 700) {
    LSE[g,6] <- 2

  } else if (results[g,6] > 500) {
    LSE[g,6] <- 1

  } else {
    LSE[g,6] <- 0
  }

# LSE for monthly rain ----------------------------------------------------------
  if (results[g,7] < (0.2)) {
    LSE[g,7] <- 3

  } else if (results[g,7] < (0.3)) {
    LSE[g,7] <- 2

  } else if (results[g,7] < (0.4)) {
    LSE[g,7] <- 1

  } else {
    LSE[g,7] <- 0
  }

# Total point sum ---------------------------------------------------------------
  LSE[g,8] <- sum(LSE[g,2:7])

  g = g + 1
}
```

Figure 5.4. Script for land suitability evaluation in RStudio (Posit Team, 2023).

Appendix 4

Interview questions regarding the experience of tea cultivation in Sweden, in Swedish (used during interviews) and English.

Bakgrund till odlingen

1. Vilket år började du/ni odla te, *Camellia sinensis*?
2. Vart kom sortmaterialet ifrån och hur valdes det ut? (Kultivar om känd?)
3. Hur mycket te har du/ni planterat och/eller hur många sticklingar/fröer förbereds just nu till den egna odlingen?
    a. Antal plantor?
    b. Areal?
    c. Antal fröer/sticklingar?
4. Hur drivs unga plantor/fröer upp? I växthus (uppvärmt eller inte), polytunnel, friland?
5. Hur valde du/ni ut marken där teodlingen placerades?
6. Hur bearbetades marken innan plantorna placerades ut?
7. Använder du/ni er av bevattning?
8. Gör du/ni något speciellt för att skydda plantorna mot kyla/frost/djur/osv.?
9. Är odlingen ekologisk eller konventionell?
10. Var ligger odlingen (närmaste stad)?
11. Har det kunnat tas någon skörd från plantorna?
    a. Efter hur många år?
    b. Hur många skördar per år?
    c. Snittskörd (kg/år)?
12. Processades skörden till färdigt te? Om ja, hur och till vilken typ av te?
13. Övrigt?

Utmaningar och framtid

14. Vad anser du/ni vara de största utmaningarna för teodling i Sverige?
15. Anser du/ni att teodling har en framtid i Sverige utifrån egen erfarenhet?
16. Vad skulle du/ni föreslå är intressanta områden för framtida forskning på området?
17. Övrigt?

Background information

1. What year did you start growing tea, *Camellia sinensis*?
2. Where does the plant material come from and how was it chosen? (Cultivar if known?)
3. How many plants do you have and/or how many seedlings/seeds are being prepared at the moment for your own tea farm?
    a. Number of plants?
    b. Areal?
    c. Number of seeds/propagations?
4. How are the young plants being nurtured? In a greenhouse (heated or not), polytunnel, open-field cultivation?
5. How did you choose the spot where the tea farm is located?
6. How was the soil prepared before the plants were planted outside?
7. Do you use irrigation?
8. Do you take any measure to protect the plants from freezing temperatures/frost/animals/etc.?
9. Is the farm organic or conventional?
10. Where is the farm located (nearest city/town)?
11. Have you been able harvest the plants?
    a. After how many years?
    b. How many harvests per year?
    c. Average yield (kg/year)?
12. Was the harvest processed into tea? If yes, how, and what type of tea?
13. Other thoughts?

Challenges and the future

14. What do you believe to be the biggest challenges for tea cultivation in Sweden?
15. Do you believe that tea cultivation has a future in Sweden based on your own experiences?
16. What do you believe would be interesting areas for future research regarding the subject of tea cultivation in Sweden?
17. Other thoughts?