International Society of Arboriculture
Arboriculture & Urban Forestry 2019. 45(5):201–210
ARBORICULTURE & URBAN FORESTRY
Scientific Journal of the International Society of Arboriculture

Utilizing a Thermal Time Model to Estimate Safe Times to Transplant *Tilia* Trees

By Tapio Linkosalo, Pilvi Siljamo, Anu Riikonen, Frank M. Chmielewski, and Juha Raisio

Abstract. City trees planted in parks and along streets are typically grown to large size in nurseries before being transplanted to their final growing sites. According to tendering rules within the European Union (EU), any business may compete for public contracts in any EU country, and this applies to purchases of valuable lots of nursery trees. There is however a risk of poor transplanting success if the trees are imported from very distant locations with a different pace of spring development. The aim of this study was to implement a Thermal Time model to predict the spring development of *Tilia* trees to find out in which geographical area the spring development is sufficiently similar to conditions in southern Finland, so that the success of transplantation of the trees is not unduly risked. We used phenological observations collected at the International Phenological Gardens (IPGs) over the whole of Europe, together with ERA-Interim weather data to estimate the model parameters, and then used the same date to predict the onset of leaf unfolding of *Tilia* during the years 1980 to 2015. Producing maps of phenological development of *Tilia*, we concluded that there are no large risks of frost damage if tree import area is limited to northern parts of Baltics or to the west coast of Scandinavia.

Keywords. Leaf Unfolding; Phenology; Thermal Time Model; *Tilia* sp.; Urban Trees.

INTRODUCTION

Small-leaved lime (*Tilia cordata* Mill.) is a broad-leaf species common throughout most of northern Europe and Scandinavia. It is, alongside its hybrid with *T. platyphyllos*, *T.* × *europaea L.*, used widely as an ornamental tree species in cities and lining streets, as it is fast-growing and relatively tolerant of urban conditions (e.g., Säbo et al. 2003). It is a predominant street tree in cities such as Oslo, Gothenburg, and Helsinki (Sjöman et al. 2011). The *Tilia* trees planted in northern Europe are most commonly clones of *Tilia* × *europaea* (formerly known as *Tilia* × *vulgaris* Hayne) (Bühler and Kristoffersen 2009; Pauleit et al. 2002). This hybrid is usually propagated vegetatively by grafting or mound layering, leading to a predominance of relatively few clones (Pauleit et al. 2002; Buhler et al. 2007).

Most commonly, urban trees begin their life in tree nurseries and are transplanted in parks and along streets in increasingly large sizes (Pauleit et al. 2002). Transplanting causes stress for trees, largely believed to be related to difficulties in water uptake resulting from root loss or change of root environment (McKay 1997), and tree losses following transplanting are relatively common. While garden centers sell predominantly containerized tree stock, large trees for landscaping are typically grown in the field and lifted for transport with root balls wrapped in burlap (ball and burlap method) (Eaton et al. 2009). Growing large trees takes several years and thus is a long-term investment for plant nurseries, and predicting the future market for a given tree taxa is difficult. As a result, acquiring trees of desired taxa and size may only be possible by importing nursery trees from distant locations.

Successful transplanting of trees from the nursery to the landscape is affected by tree size and management prior to and after transplanting, but also by the season of the operation and phenological stage of trees (Richardson-Calfree and Harris 2005; Pryor and Watson 2016). This brings about the challenge of successfully synchronizing the digging up, transportation, and planting of trees with differences in climate and the timing of phenological events across large distances. Some aspects of phenology in relation to transplanting trees have been studied, such as the relative timing of shoot and root growth initiation (e.g., Richardson-Calfree and Harris 2005). To our knowledge, however, bud burst or dormant period timing in relation to transport of nursery trees across climatic zones has not been previously studied.

According to EU legislation, when a public purchase of a sufficiently valuable lot of nursery trees is made, all businesses registered within the EU, irrespective of the geographic region or distance to the planting site, have equal right to compete for the tender. For living plant material in springtime, this may be problematic. Within the EU, the thermal growing season starting date varies for over a month from south to north. Nursery trees are most successfully transplanted when they are fully dormant (e.g., Solfjeld and Hansen 2004). If the transplanting of the trees takes place too late in spring, then in the more southerly nurseries, the spring has advanced further, and trees may already start to develop their leaves. When brought to more wintry conditions in the north, they may be exposed to frost damage and drying, with high likelihood of increased transplanting stress and tree losses. On the other hand, if trees are dug up in southerly locations and brought to southern Finland too early in spring, the local soil may still be frozen (Soveri and Varjo 1977; Huttunen and Soveri 1993), preventing tree planting.

Some of the problems related to this seasonal mismatch may be avoided by a period of cold storage, commonly used on smaller plantlets for forestry (McKay 1997; Lindqvist 2001) to match the timing of phenological events with local climate, but for large sized nursery stock, this would accrue considerable, additional costs. Therefore the feasibility of directly transported plant material from various geographical locations needs to be evaluated in the tendering process. Tools are needed to predict the spring development of trees in advance, to define the possible source areas for nursery trees as a function of geographical location and calendar date. The most cost-effective way would be to define the geographical area and time window from where the plant transplantation is possible on an average year with minimal risk of plant damage and poor transplanting success.

The most practical means of predicting the spring development of plants, like the leaf development of *Tilia*, is with modeling. Phenological models have been widely used to forecast phenological events, such as leaf unfolding and onset of pollen season (e.g., Hänninen 1990; Linkosalo et al. 2008; Schaber and Badeck 2003; Chmielewski and Götz 2016). Most models use air temperature as the key driver of phenological development, while there is variation in the mechanism that triggers the development. Most simple models use a plain calendar date which can be interpreted as representing a signal from the changing light environment (e.g., day length) in spring (Linkosalo and Lechowicz 2006), while more complex models also describe the development and release of winter dormancy and its impact on the spring development. Many studies of modeling boreal phenology suggest that the simple models omitting the dormancy phase are at least equal if not better than the more comprehensive ones (Linkosalo et al. 2008).

Since urban *Tilia* trees are usually of clonal origin, it is even more applicable to use phenological modeling, as one can assume that the plants have largely the same response to environmental cues, and therefore the same model with same parameterization should work satisfactorily in a wide geographical area. In this study, we used phenological observations collected throughout Europe and fitted a Thermal Time (TT) model that predicts the timing of leaf unfolding to the data. We then used the model to simulate the leaf unfolding on a temperature data grid covering the whole of northern and central Europe and a time period of 35 years. We used the results to produce maps showing the average and variation of *Tilia* bud development. We utilized the maps to define areas from where the *Tilia* nursery trees can be brought to southern Finland without risking poor transplanting success.

MATERIALS AND METHODS

We used a common Thermal Time model to predict the leaf unfolding dates for northern and central Europe. The model describes the development leading to the occurrence of the phenological event by accumulating a temperature sum, and once this sum exceeds a pre-set threshold, the phenological event is predicted to take place. The model has three parameters: the onset date of temperature sum accumulation, t_0, a critical threshold for effective temperatures, T_{Crit}, and a temperature-sum threshold, S_{Crit}, for the event to take place. The temperature sum, $S(t)$, is accumulated as:

$$S(t) = \int_{t_0}^{t} r(T)dt \cong \sum_{t_0}^{t} r(T)\Delta t \,,$$

where t_0 is the starting date of temperature sum accumulation, Δt is time-step, and $r(T)$ is the rate of temperature sum accumulation:

$$r(T) = \begin{cases} T - T_{Crit} & ,T > T_{Crit} \\ 0 & ,T \leq T_{Crit} \end{cases},$$

where T is the (daily average) temperature and T_{Crit} the critical threshold for effective temperature.

The model predicts the leaf unfolding to take place on the day t when the temperature sum, $S(t)$, exceeds the critical threshold, S_{Crit}.

$$S(t) > S_{Crit}$$

We used phenological data for the leaf unfolding of *Tilia cordata* collected in the International Phenological Gardens throughout Europe for the years 1980 to 2015 (Chmielewski et al. 2013). The International Phenological Gardens are a collection of gardens sharing vegetatively propagated plants of a common origin, thus making a large provenience experiment. The network of gardens was established by F. Schnelle and E. Volkert in 1957. In the year 2015, the network consisted of 80 gardens (Figure 1). Of these, we used *Tilia* data from 78 gardens (Table 1); two were omitted as they did not have observations for the time period of the study.

For fitting the Thermal Time model, we used 2 m temperature data from the ERA-Interim global atmospheric re-analysis (Dee et al. 2011) produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) (http://www.ecmwf.int/). Results of the numerical weather prediction (NWP) models are in grid form, where one grid cell represents average conditions inside the grid cell. The ERA-Interim data covers the period from 1979 and is updated in real time. We used the daily mean temperature values derived from ERA-Interim data (+3h, +6h, +9h, +12h forecast length) as our preliminary analysis indicated that higher time resolution did not improve the results. The best available horizontal resolution is 0.72º (approx. 80 km [49.7 mi]). The ERA-Interim applied the four dimensional variational analysis (4D-Var) using several observation types, e.g., surface observations, satellite data, soundings, etc.

Generally, in NWP models, short forecasts (i.e., 1 to 12 hour forecast lengths) represent the state of the atmosphere, land, and surface conditions well, and ERA-Interim also includes bias correction for the state of the atmosphere (Dee et al 2011). Thus NWP data is a competitive alternative to observational data, especially to get data for multiple locations or in gridded form.

The ERA-grid cells where the IPGs were located were picked for the model parameter fitting. The phenological model was written in an Excel spreadsheet. The model performance was estimated by calculating the Sum of Squared Errors (SSE):

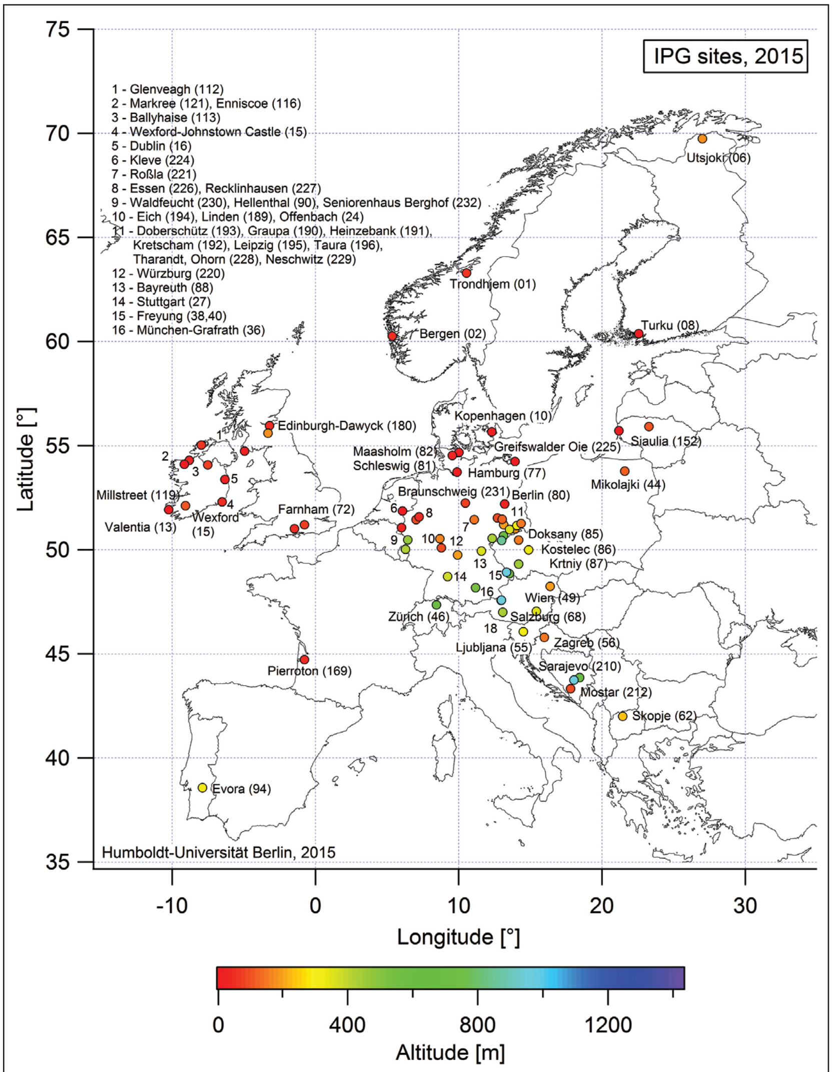

Figure 1. A map of the International Phenological Gardens (IPGs) in Europe in the year 2015. Map courtesy of Humbold University of Berlin.

Table 1. Sites, locations, and years of the phenological data collected at the International Phenological Gardens (IPGs).

IPG	Country	Station	Latitude	Longitude	Elevation	Number of observations
1	N	Trondhjem-Stjordal-KVITHAMAR	63.30	10.53	70	24
5	SE	Stockholm-BOGESUND	59.37	18.50	50	10
13	IRL	Kerry-Valentia Observatory	51.93	-10.25	14	41
14	IRL	CO-Wexford-J.F. KENNEDY ARB.	52.33	-6.63	80	33
15	IRL	Wexford-Johnstown Castle	52.30	-6.52	60	34
16	IRL	Dublin-National Botanic Gardens	53.38	-6.33	30	23
17	GB	London-Farnham-HEADLY PARK	51.08	-0.88	84	7
18	BE	GENT-MELLE	50.98	3.80	15	13
19	BE	Bastogne-MICHAMPS	50.00	5.73	500	15
20	D	MÜNSTER	51.97	7.63	60	13
21	D	Hamburg-SCHMALENBECK	53.67	10.27	50	13
22	D	Hamburg-WULFSDORF	53.65	10.20	46	39
23	D	Hannov.-MÜNDEN-STEINBERG	51.33	9.67	500	10
24	D	Offenbach	50.10	8.78	99	39
25	D	Wiesbaden-GEISENHEIM	49.98	7.97	118	21
26	D	TRIER	49.75	6.67	265	31
27	D	Stuttgart-Hohenheim	48.72	9.22	380	46
28	D	Stuttgart-WEILIMDORF	48.82	9.12	330	11
29	D	Kaiserstuhl-BLANKENHORNSBERG	48.05	7.60	285	36
30	D	Kaiserstuhl-LILIENTAL	48.07	7.68	265	37
31	D	FREIBURG-STADT	48.00	7.80	270	40
32	D	Freiburg-ESCHBACH	48.02	7.98	500	36
33	D	Freiburg-SCHAUINSLAND	47.92	7.90	1210	20
35	D	DONAUESCHINGEN	47.95	8.52	680	35
36	D	München-Grafrath	48.18	11.17	540	45
37	D	Freising-WEIHENSTEPHAN	48.40	11.73	460	22
38	D	Freyung-Schönbrunn	48.85	13.52	737	26
39	D	Freyung-KLINGENBRUNN	48.92	13.32	756	30
40	D	Freyung-Waldhäuser	48.93	13.33	956	35
42	D	Tharandt-Hartha	50.98	13.54	360	46
45	PT	PORTO	41.25	8.50	30	0
46	CH	Zürich-Birmensdorf	47.36	8.44	600	42
48	AT	Innsbruck-RINN	47.25	11.50	900	20
50	AT	Wien-OBERSIEBENBRUNN	48.25	16.72	150	23
52	SK	LVU-Banska Stiavnica-Kysihybel	48.45	18.93	540	22
53	HU	Budapest-GÖDÖLLÖ	47.60	19.35	220	16
54	HU	Debreczin-PÜSPÖKLADANY	47.33	21.13	90	7
55	SLO	Ljubljana	46.07	14.50	310	45
56	HR	Zagreb-Krizevci	45.80	15.97	146	36
57	RS	SOMBOR	45.78	19.12	90	18
58	BA	Sarajevo-IVAN SEDLO	43.86	18.43	1000	17
60	RS	BAR	42.08	19.08	5	18
61	RS	Beograd-SMEDEREVSKA-PALANKA	44.37	20.95	121	18
62	MAK	Skopje	42.00	21.43	240	39
69	D	WAGENINGEN	51.98	5.67	25	5
72	GB	London-Farnham-Alice Holt	51.20	-0.78	80	9
77	D	Hamburg-QUICKBORN	53.73	9.88	13	16
78	D	Berchtesgaden-Kühroint	47.57	12.95	1430	8
79	D	Berchtesgaden-Schapach	47.58	12.97	950	10
80	D	Berlin-Thyrow	52.20	13.20	42	17
81	D	Schleswig	54.53	9.55	36	4
83	D	DEUSELBACH	49.77	7.05	480	6
85	CZ	Praha-Doksany	50.47	14.17	158	15
86	CZ	Praha-Kostelec	50.00	14.87	345	14

Table 1. (continued)

IPG	Country	Station	Latitude	Longitude	Elevation	Number of observations
87	CZ	Brno-Krtiny	49.32	14.17	457	11
88	D	Bayreuth	49.94	11.57	360	5
90	D	Hellenthal/Eifel	50.48	6.43	470	3
94	P	Evora	38.57	-7.90	309	0
112	IRL	Glenveagh National Park Church Hill	55.03	-7.97	65	8
118	IRL	Aarmagh Observatory	54.35	6.65	64	7
119	IRL	Millstreet Country Park	52.12	-9.08	116	7
152	LT	Botanical Garden Siauliai University	55.92	23.27	117	9
169	F	Pierroton	44.73	-0.78	58	7
180	GB	RBG Edinburgh-Dawyck	55.60	-3.32	180	6
182	GB	Edinburgh-Inverleih	55.97	-3.21	50	7
190	D	Graupa	51.00	13.92	180	11
191	D	Heinzebank	50.68	13.12	610	10
192	D	Kretscham-Rothensehma	50.45	12.98	850	9
193	D	Doberschütz (NW-Sachsen)	51.53	12.70	99	10
194	D	Eich (Vogtland)	50.55	12.33	444	5
195	D	Leipzig	51.20	13.13	198	9
196	D	Taura (N-Sachsen)	51.47	13.02	124	10
210	BA	Sarajevo	43.86	18.43	630	3
211	BA	Sarajevo-Ivan Sedlo	43.75	18.04	967	3
212	BA	Mostar	43.33	17.80	99	3
221	D	Roßla	51.45	11.07	155	6
224	D	Kleve	51.87	6.07	9	4
225	D	Greifswalder Oie	54.24	13.92	3	5
228	D	Ohorn	51.17	14.05	305	5
231	D	Braunschweig	52.25	10.45	81	4

$$SSE = \sum \left(x_{ij} - z_{ij}\right)^2 ,$$

where x_{ij} is the observed and z_{ij} is the predicted leaf unfolding date on year i and station j. We calculated the model in a large matrix of varying parameter values (Table 2) and picked the parameter combination that resulted in the minimum of SSE values. We also divided the data in two halves, odd and even years, estimated the minimum SSE for both halves, and then used the parameter estimation from one half to calculate the model SSE on the other. When this independent SSE is compared to the SSE that results from fitting the model to the specific data set, the increase in the SSE value indicates how data-dependent the model parameter values are (Wallach and Kofinet 1987).

Table 2. Parameter and SSE values for the Thermal Time model.

		Parameters of calculation matrix				Model optimum		
		Min	Max	Step	Number	All	Odd years	Even years
Starting date	DOY	80	120	1	41	97	82	98
Temperature sum threshold	degree-day	100	300	5	41	175	295	210
Critical temperature threshold	° C	-5	5	0.25	41	-2	-2.5	-3.5
Total parameter combinations					68921			
SSE, all	degree-day^2					185,318	196,881	188,079
SSE, odd years	degree-day^2					86,523	80,785	96,698
SSE, even years	degree-day^2					98,795	116,096	91,381
Increase in SSE	%						13.1	20.1

We also calculated the Root Mean Squared Error (RMSE) of the model fit to compare our results to previous studies:

$$RMSE = \sqrt{\frac{SSE}{n}}$$

where n is the number of individual leaf unfolding observations (921 for all the data).

For the estimation of leaf unfolding dates over central and northern Europe, ERA-data for the years 1980 to 2015 were used, from 41°N to 65°N latitude and 10°W to 35°E longitude, with 1.125° (approx. 100 km [62 mi]) grid size.

RESULTS

The resulting Thermal Time model was used to simulate the leaf unfolding of *Tilia* over the examined geographical area for the years 1980 to 2015. The pattern of the leaf unfolding dates show a delay when going from south to north, while there is little variation in the times in the west to east direction. The north to south variation is as expected and corresponds with real phenological observations. Somewhat surprisingly, there was little variation in the west to east direction, where we expected to see the transition from maritime to continental climate impact the bud burst phenology, a phenomenon seen for the leaf unfolding of birch (Siljamo et al. 2013). The largest simulated difference of average bud burst dates within the examined area and timeframe was about 45 days, and largest difference to southern Finland, about 15 days earlier and 30 days later (Figure 2A). For the early years (Figure 2B) the geographical variation of bud burst was less than average (Figure 2A), but for the late years (Figure 2C), the difference between northern Italy and southern Finland could be 20 to 25 days.

The minimum SSE value when utilizing all the data was achieved with the following parameter combination: t_0: 97 (Apr-7), T_{Crit} -2 °C, S_{Crit} 175 degree-days (Table 2). The RMSE-value for all the data was 14.2 days. As is typical for the TT models (e.g., Linkosalo et al. 2000), the parameters showed a considerable amount of inter-dependency, resulting in a range of parameter combinations reaching almost similar model SSE values (Figure 3).

We split the data into two halves, odd and even years, and the parameter combinations resulting with the minimum SSE for each half did not vary much (Table 2). The increase in the SSE value, when using

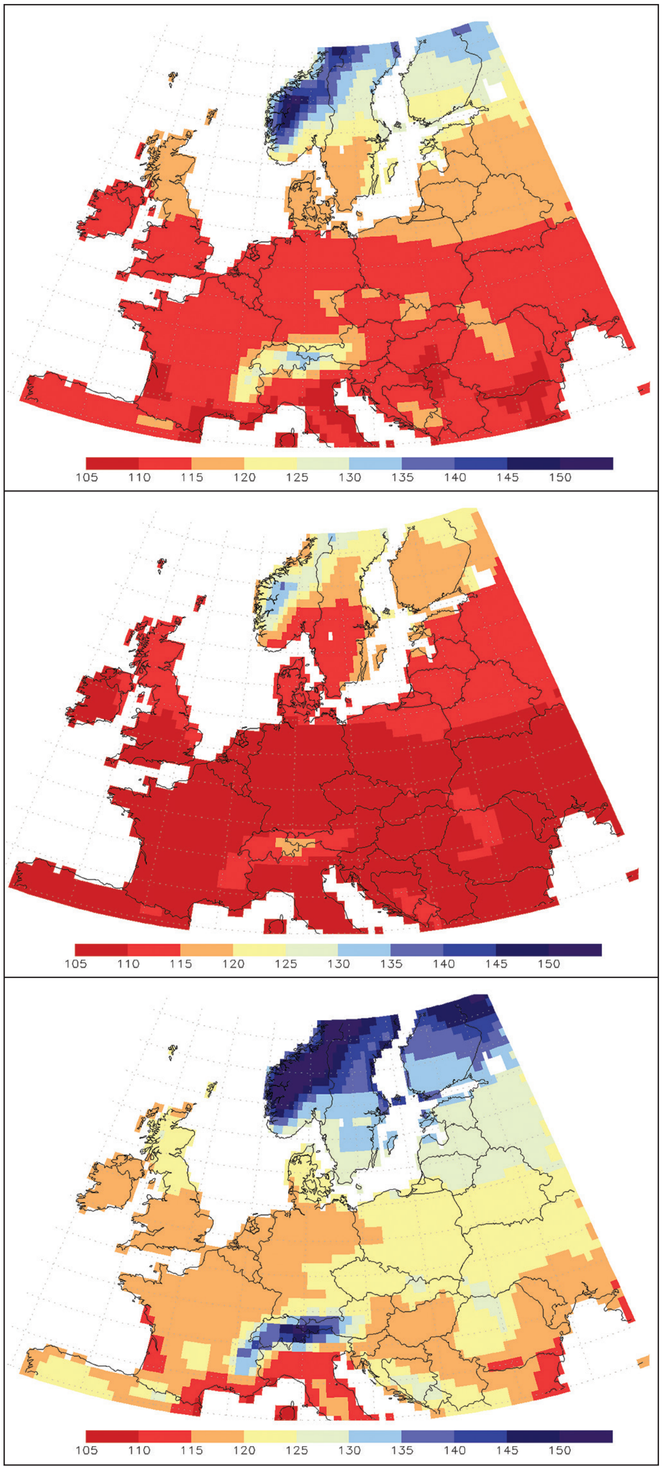

Figure 2. The simulated bud burst dates for Central and Northern Europe. The subplots show the average (A), first (B), and last (C) bud burst dates for the period of 1980 to 2015. The grid cells for the calculation are 1.125 degrees squared, and the temperature data is derived from the ERA-model.

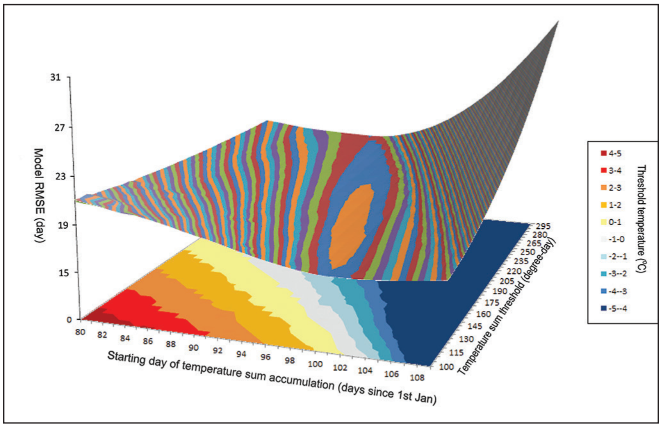

Figure 3. The model SSE values (Z-axis) as the function of model parameters. X-axis shows the starting date (DOY) and Y-axis the temperature sum threshold. For each pair of the latter two, the critical temperature threshold giving the smallest SSE value was picked, and this temperature threshold is shown on the a contour map on the floor of the graph.

parameters estimated from the other half of the data, was 13 and 20%. The value is somewhat larger than when using phenological models for the flowering of birch (Linkosalo et al. 2008). All in all the increase in SSE in this study is quite small, indicating that the model with this parameterization can be safely extrapolated.

The RMSE value of 14.2 days was considerably larger than the values achieved when fitting a TT model to phenological data for the flowering of birch (Siljamo et al. 2013), and also larger than for models fitted to data from a more restricted area, where values of even below 2 days have been reported (e.g., Linkosalo et al 2008). We fitted the model also to a smaller geographical area (Germany), but found that the model RMSE value was only slightly reduced, so it seems that the large geographical area used in this study is not the reason for the rather large RMSE value of the model. We also checked the model prediction residuals against geographical variables, but found no significant correlations (results not shown).

DISCUSSION

Our results showed that bud development of *Tilia* in central and northern Europe starts in early April and at a low critical temperature threshold, which suggests that, after the bud development start date (t_0), moving the *Tilia* trees from southerly nurseries to southern Finland may prove problematic. The plants would have already progressed in their bud development and may be vulnerable to frost damages in the colder conditions of Finland. Our results indicate that since the plants should be transported in full rest state, this is best done before April to avoid the possibility that bud development has started in the nursery trees.

However, that would mean planting trees in winter conditions: ground frost melts on average, depending on site conditions, in mid-April to mid-May in southern Finland (Huttunen and Soveri 1993). Severe night frosts, which may cause damage to buds at advanced stages of development, are also frequent, as the average daily temperature in March is still below freezing in the area (Pirinen et al. 2012) with average daily minimums in the range of -4 to -6° C (21 to 25° F) . Thus transplanting before April would be very unpractical, and lifting trees in the southern nurseries before April to transplant a month or two later would require considerable cold storage capacity. The increased cost and responsibility for arranging storage and possible loss of stock quality during storage (e.g., Lindqvist 2001) would need to be dealt with within the commercial chain.

The critical temperature threshold (T_{crit}) for our model, -2° C (28° F), was much lower than is typically seen on Thermal Time models predicting the onset of spring events, such as leaf unfolding and onset of flowering (Pirinen et al. 2012). Combined with the modeled starting date of temperature sum accumulation (t_0) in early April, this emphasizes the role of the starting date in determining the date of leaf unfolding. The starting date parameter (t_0) most likely reflects a feature in the light environment of the plant, such as meeting a critical day or night length. In our model, after the starting date is met, the bud development proceeds even on the coldest days, while development of course is faster on warmer days. Interestingly, the resulting starting date of early April falls close to spring equinox, the date when the day length is the same all over the globe. The model parameterization suggests an interpretation of *Tilia* bud development, that once the critical day length is met, the bud development rather rapidly proceeds towards the leaf unfolding. In other words, day length is an important factor defining the leafing date.

In contrast to our finding of critical temperature threshold (T_{crit}) of -2° C (28° F) for most phenological models of boreal and temperate trees, the typical range for the critical temperature parameter is between 2° and 5° C (36° and 41° F)(e.g., Linkosalo et al. 2008). For these plants, the bud development may be considerably delayed due to cold weather, even after the critical day length is met. This in turn brings more variation to the date of leaf unfolding. Thus our model results indicate that *Tilia* leaf unfolding phenology is more strongly driven by day length and shows less inter-annual variation in leaf unfolding dates than other boreal broad-leaf species.

The model RMSE value, indicating the difference between model and observations, was larger than is common for TT models (Schaber and Badeck 2003; Linkosalo et al. 2008), but the RMSE did not show any trends on latitude or longitude (results not shown). There was a slight trend on altitude, such that the higher elevation gardens show higher values of RMSE. This is most likely due to higher elevations having also steeper slopes, a feature which has a considerable impact on local temperature conditions. As the ERA-Interim weather data is smoothed in a grid instead of local observations adjacent to the phenological gardens, the temperature data is unlikely to precisely match the geographical properties of the terrain adjacent to the higher elevation gardens.

We conclude that the safe source area for importing plants to southern Finland within the reasonable planting season would be limited to the areas where the bud development in an average year would be only slightly ahead of the development state in southern Finland. This would include the northernmost parts of the Baltics, as well as the west coast of Scandinavia. Additionally, areas where bud development lags behind from local conditions would also be acceptable plant sources for spring plantings, such as the rest of Scandinavia, excluding the more southerly Skåne and Denmark. In transporting trees from more distant locations, there is the risk that spring development of the trees has started while the conditions in southern Finland are still wintry.

It seems likely that a risk of phenological mismatch is also applicable to autumn plantings. Although spring planting is often preferred, autumn planting is also common and considered fairly well suited for *Tilia* (Solfjeld and Hansen 2004). Transplanting trees too early in the autumn is known to give inferior results (Solfjeld and Hansen 2004), but late fall transplanting increases the risk of drying and cold injury (Richardson-Calfee and Harris 2005). This indicates that phenology is potentially equally important in autumn transplantation. However, modeling autumn phenology is not as accurate as that of spring events, so experimental work may be needed to figure out the limits of transporting plants for autumn transplanting.

LITERATURE CITED

Bühler, O., P. Kristoffersen, and S.U. Larsen. 2007. Growth of street trees in Copenhagen with emphasis on the effect of different establishment concepts. Arboriculture & Urban Forestry 33(5):330–337.

Chmielewski, F.M., S. Heider, S. Moryson, and E. Bruns. 2013. International Phenological Observation Networks: Concept of IPG and GPM. In *Phenology: An Integrative Environmental Science* (pp. 137–153). Springer Netherlands.

Chmielewski, F.M., and K.P. Götz. 2016. Performance of models for the beginning of sweet cherry blossom under current and changed climate conditions. Agricultural and Forest Meteorology. 218–219:85–91.

Dee, D.P., S.M. Uppala, A.J. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, M.A. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, A.C.M. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, C. Delsol, R. Dragani, M. Fuentes, A.J. Geer, L. Haimberger, S.B. Healy, H. Hersbach, E.V. Hólm, L. Isaksen, P. Kållberg, M. Köhler, M. Matricardi, A.P. McNally, B.M. Monge-Sanz, J.J. Morcrette, B.K. Park, C. Peubey, P. de Rosnay, C. Tavolato, J.N. Thépaut, and F. Vitart. 2011. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Q.J.R. Meteorol. Soc. 137:553–597.

Eaton, G.K., and B.L. Appleton. 2009. Getting Started in the Nursery Business: Nursery Production Options. Virginia cooperative extension publication. 430-050.

Hänninen, H. 1990. Modeling bud dormancy release in trees from cool and temperate regions. Acta For. Fenn. 213:1–47.

Huttunen, L., and J. Soveri. 1993. *Luonnontilaisen roudan alueellinen ja ajallinen vaihtelu Suomessa*. (In Finnish). Vesi- ja ympäristöhallinnon julkaisuja - Sarja A 139. <https://helda.helsinki.fi/handle/10138/156324>

Lindqvist, H. 2001. Effect of different lifting dates and different lengths of cold storage on plant vitality of silver birch and common oak. Scientia Horticulturae 88(2):147–161.

Linkosalo, T., T.R. Carter, R. Häkkinen, and P. Hari. 2000. Predicting spring phenology and frost damage risk of *Betula* sp. under climatic warming: a comparison of two models. Tree Physiology 20:1175–1182.

Linkosalo, T., and M.J. Lechowicz. 2006. Twilight far-red treatment advances leaf bud-burst of silver birch (*Betula pendula*). Tree Physiology 26:1249–1256.

Linkosalo, T., H.K. Lappalainen, and P. Hari. 2008. A comparison of phenological models of leaf bud burst and flowering of boreal trees using independent observations. Tree Physiology 28:1873–1882

McKay, H.M. 1997. A review of the effect of stresses between lifting and planting on nursery stock quality and performance. New Forests 13(1–3):369–399.

Pauleit, S., N. Jones, G. Garcia-Martin, J.L. Garcia-Valdecantos, L.M. Rivière, and T.B. Randrup. 2002. Tree establishment practice in towns and cities–Results from a European survey. Urban Forestry and Urban Greening 1(2):83–96.

Pirinen, P., S. Simola, J. Aalto, J.P. Kaukoranta, P. Karlsson, and R. Ruuhela. 2012. Tilastoja Suomen Ilmastosta 1981–2010 (Climatological statistics of Finland 1981–2010, In Finnish). Finnish Meteorological Institute Reports, Helsinki. <https://helda.helsinki.fi/handle/10138/35880>

Pryor, M., and G. Watson. 2016. Mature tree transplanting: Science supports best management practice. Arboricultural Journal 38(1):2–27.

Richardson-Calfee, L.E., and J.R. Harris. 2005. A review of the effects of transplant timing on landscape establishment of field-grown deciduous trees in temperate climates. HortTechnology 15(1):132–135.

Sæbø, A., T. Benedikz, and T.B. Randrup. 2003. Selection of trees for urban forestry in the Nordic countries. Urban Forestry and Urban Greening 2(2): 101–114.

Schaber J., and F.W. Badeck. 2003. Physiology-based phenology models for forest tree species in Germany. International Journal of Biometeorology 47:193–201.

Siljamo, P., M. Sofiev, E. Filatova, L. Grewling, S. Jäger, E. Khoreva, T. Linkosalo, S. Ortega Jimenez, H. Ranta, A. Rantio-Lehtimäki, A. Svetlov, L. Veriankaite, E. Yakovleva, and J. Kukkonen. 2013. A numerical model of birch pollen emission and dispersion in the atmosphere. Model evaluation and sensitivity analysis. International Journal of Biometeorology 57:125–136.

Sjöman, H., J. Östberg, and O. Bühler. 2012. Diversity and distribution of the urban tree population in ten major Nordic cities. Urban Forestry and Urban Greening 11(1):31–39.

Solfjeld, I., and O.B. Hansen. 2004. Post-transplant growth of five deciduous Nordic tree species as affected by transplanting date and root pruning. Urban Forestry and Urban Greening 2(3):129–137.

Soveri, J., and M. Varjo. 1977. *Roudan muodostumisesta ja esiintymisestä Suomessa vuosina 1955-1975*. Vesihallitus. (In Finnish)

Wallach, D., and B. Goffinet. 1987. Mean squared error of prediction in models for studying ecological and agronomic systems. Biometrics 43:561–573.

Tapio Linkosalo (corresponding author)
Natural Resources Institute Finland (Luke)
Latokartanonkaari 9
FI-00790 Helsinki, Finland
tapio.linkosalo@iki.fi

Pilvi Siljamo
Finnish Meteorological Institute
Helsinki, Finland

Anu Riikonen
University of Helsinki
Helsinki, Finland

Frank M. Chmielewski
Humbold University
Berlin, Germany

Juha Raisio
Urban Environment Division
City of Helsinki
Helsinki, Finland

Résumé. Les arbres plantés dans les villes sont, en règle générale, cultivés en pépinière jusqu'à l'atteinte d'une dimension appréciable avant d'être transplantés sur leur emplacement définitif dans les parcs et le long des rues. Selon les règles d'adjudication en vigueur dans l'Union européenne (UE), toute entreprise peut soumissionner pour des contrats (marchés) publics dans tout pays de l'UE, et ces règles s'appliquent à l'acquisition de lots significatifs d'arbres de pépinières. Il existe cependant un risque pour une plantation infructueuse si les arbres proviennent de pépinières très éloignées avec un rythme distinct de développement printanier. L'objectif de cette étude était d'implanter un modèle de temps thermique afin de prédire le développement printanier de *Tilia* en vue de découvrir la zone géographique où le développement printanier était similaire aux conditions rencontrées dans le sud de la Finlande, de manière à ce que le succès de la transplantation d'arbres ne pose pas indûment un risque. Les observations phénologiques colligées par International Phenological Gardens (IPGs) couvrant toute l'Europe furent utilisées en lien avec les données météorologiques ERA-Interim afin d'estimer les paramètres du modèle puis utiliser les relevés des années 1980 à 2015 afin de prédire le déclenchement du débourrement des feuilles de *Tilia*. En produisant des cartes sur le développement phénologique du *Tilia*, l'absence de risques élevés de dommages causés par le gel fut établie si la zone d'importation des arbres était limitée aux portions situées au nord des états baltes ou à la côte ouest de la Scandinavie.

Zusammenfassung. Straßenbäume, die in Parkanlagen und Straßen gepflanzt werden, sind typischerweise in den Baumschulen vor der Verpflanzung an ihren finalen Standort zu großen Stärken herangezogen worden. In Übereinstimmung mit den europäischen Ausschreibungsregeln, kann sich jeder in jedem europäischen Land bei öffentlichen Ausschreibungen mitbewerben. Das betrifft auch den Erwerb von wertvollen Mengen an Baumschulware. Dennoch besteht ein Risiko von geringem Anwachserfolg, wenn die Bäume von sehr weit entfernten Standorten mit einem unterschiedlichen Entwicklungsstart im Frühjahr importiert werden. Das Ziel dieser Studie war die Implementierung eines thermalen Zeitmodells zur Vorhersage des Entwicklungsstarts von *Tilia*-Bäumen im Frühjahr, um herauszufinden, in welcher geographischen Gegend die Frühjahrsentwicklung ähnlich den Bedingungen in Südfinnland ist, so dass das Risiko des Verpflanzungserfolgs nicht übermäßig strapaziert wird. Wir verwendeten zusammen mit ERA-Interim Wetterdaten phänologische Beobachtungen, die in den Internationalen Phänologischen Gärten (IPGs) überall in Europa gesammelt wurden, um die Modellparameter zu bestimmen. Dann wurden die gleichen Daten zur Vorhersage des Blattschiebens von Linden während der Jahre 1980 bis 2015 verwendet. Nachdem wir Karten mit der phänologischen Entwicklung von Linden erstellt hatten, konnten wir daraus schließen, dass es kein großes Frostrisiko gibt, wenn der Baumimport auf das nördliche Baltikum oder bis zur Westküste von Skandinavien begrenzt bleibt.

Resumen. Los árboles plantados en parques y a lo largo de las calles generalmente crecen hasta ser de gran tamaño en viveros antes de ser trasplantados a sus sitios finales de crecimiento. De acuerdo con las normas de licitación dentro de la Unión Europea (UE), cualquier empresa puede competir por los contratos públicos en cualquier país de la UE y esto se aplica a las compras de lotes valiosos de árboles de viveros. Sin embargo, existe el riesgo de un éxito de trasplante deficiente si los árboles se importan desde lugares muy lejanos con un ritmo diferente de desarrollo en primavera. El objetivo de este estudio fue implementar un modelo de Tiempo Térmico para predecir el desarrollo de los árboles de *Tilia* y averiguar en qué área geográfica ese desarrollo es lo suficientemente similar a las condiciones en el sur de Finlandia, de modo que el éxito del trasplante de árboles no sea un riesgo indebido. Utilizamos las observaciones fenológicas recopiladas en los Jardines Fenológicos Internacionales (IPG) en toda Europa, junto con los datos meteorológicos de ERA-Interim para estimar los parámetros del modelo y luego utilizamos la misma fecha para predecir el inicio del despliegue de la hoja de *Tilia* durante los años de 1980 a 2015. Al producir mapas del desarrollo fenológico de *Tilia*, llegamos a la conclusión de que no hay grandes riesgos de daños por heladas si el área de importación de árboles se limita a las partes del norte de los países bálticos o a la costa oeste de Escandinavia.