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Calculation of Foliage Mass and Foliage Area

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Introduction

In Finland, the forest canopies are the main source of the volatile organic compounds (VOC). These forests are representative of the boreal ones, and they cover about 80% of the total land area of the territory of Finland. The forests throughout the country are utilised commercially and managed regularly with the consequence that the natural tree species composition is much affected by human interference. Similarly, the management affects substantially the stocking as determined by the age distribution of tree populations. This holds also for the foliage density with the consequence that the foliage density is representing large stand-to-stand variability along with the stocking, the dominant tree species, and the age of tree populations.

In Finland, the forests are mainly the coniferous ones with the dominance of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), these two species covering more than 80% of the total stem wood volume. The rest of the forest resources represents deciduous species, mainly Pendula birch (*Betula pendula*) and Pubescent birch (*Betula pubescens*). The stocking of stem wood varies from 115 m^3 ha^{-1} in southern Finland (between 60^o-64^o N) to 60 m^3 ha^{-1} in northern Finland (between 64^o-70^o N). Only the most northern part of the country falls outside the boreal forest zone with the representation of the ecotone between the boreal and tundra biomes. In these conditions the forest cover is scattered and represents mainly the mountain birch (*Betula pubescens* var *tourtuosa*).

The northward decrease of the stem wood stocking across the country represents the decreasing canopy cover and foliage biomass density, too. At the same time, the dominance of coniferous species increases except the most northern part of the country above the coniferous timber line. The main part of the deciduous forests are located in the southern Finland. However, only seldom pure birch forests are dominating the landscape, and the deciduous trees are mainly growing in mixtures with Scots pine and Norway spruce, whenever the site is fertile enough. Similarly, Scots pine and Norway spruce form mixtures on sites of medium and high fertility. On poor sites, Scots pine is grown in pure stands.

The spatial variability in the forest resources in terms of tree species composition, stocking and foliage density implies that the emissions of the VOC vary throughout the country, and the reliable estimates of the emissions of VOC need a careful analysis of the spatial distribution and properties of foliage in terms of the foliage mass and area and its representation of different tree species. In this context, the seasonality and the duration of the deciduous foliage need a special attention compared to the coniferous species, the foliage of which is more or less constant throughout the year. This implies that coniferous species are capable to emit VOC even outside the period, when deciduous trees are having the foliage. Thus, the tree species composition combined with the prevailing weather conditions are a key to the successful analysis on how a single tree population or larger forest areas with numerous tree populations may emit VOC to the atmosphere (Guenther et al 1993, Lamb et al. 1993, Simpson 1995, Simpson et al. 1995).

This study aims at developing a procedure to calculate the emissions of VOC from a selected tree stand or from a selected forest area as a function of the properties of canopy of tree stands and the prevailing temperature and radiation conditions. Ultimately, this study characterises the forest canopies throughout Finland in terms of the density of mass and area of foliage for the use in VOC calculations over the country.

Material and methods

The permanent sample plots of the Finnish National Forest Inventory were utilised in calculating the density of mass and area of foliage throughout the country (Figure 1). The sample plots form clusters located systematically through the country in such a way that the distance in both the north-south and the east-west direction between the clusters is 16 km in southern Finland (between 60^{o} and 64^{o} latitudes) and 32 km in northern Finland (between 64^{o}. and 70^{o} N). The clusters of plots are compiled by four permanent plots arranged in north-south direction and located 400 m apart. The size of a plot depends on the diameter of trees; i.e. trees with the diameter > 10.5 cm at the breast height are assessed in plots of 0.03 hectare (radius 9.77 m) and trees with the diameter < 10.5 cm in plots of 0.01 hectare (radius 5.64 m) (Metsäntutkimuslaitos 1995). Furthermore, each tree within the circle with radius half that of the plot (4.89 m and 2.82 m) was measured as a sample tree. Only, the sample plots on the upland mineral soils were utilised in this study. In total, 1256 plots (1009 for southern Finland

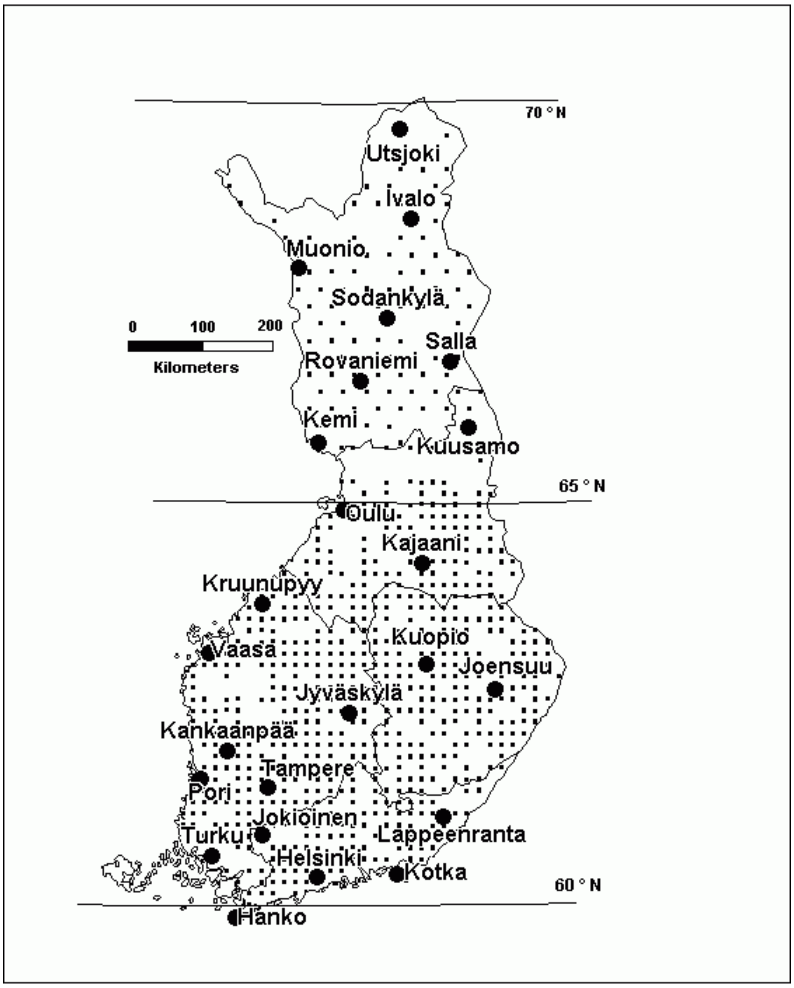

Figure 1. *Location of the permanent sample plots of the National Forest Inventory and the weather stations used in the study.*

and 247 for northern Finland) were used for the estimation of the foliage mass and area in this study.

The description of each tree on the plot includes the diameter and species of each tree taller than 1.3 m. Furthermore, sample trees representing the tree population on the plot were selected based on the relascope sampling in such a way, that sample trees covered the diameter distribution with the emphasis on the trees representing the most frequent diameter classes. The description of the sample trees includes the diameter at the breast height, tree height and the height of the crown bottom. Based on these factors, the foliage mass and area for the samples trees were calculated. Thereafter, the foliage mass and area of the sample trees were generalised for the sample plot and further over the area represented by the plot. Finally,

Table 1. *Parameter values of Equation (1) for different tree species.*

Tree species	α_1	β_1	γ_1
Scots pine	-3.7983	7.7681	7.0000
Norway spruce	-1.9602	7.8171	12.0000
Birches	-3.9823	8.0580	8.0000

the plotwise estimates of the foliage mass and foliage area were generalised over selected regions including the whole country.

In calculating the foliage mass (M, kg) of the sample trees, the allometric Equation (1) presented by Marklund (1987, 1988) was utilised, i.e.

$$M = e^{\alpha_1 + \beta_1 \left(\frac{d_{1.3}}{d_{1.3} + \gamma_1} \right)} \quad (1)$$

where $d_{1.3}$ is the breast height diameter [cm] and α_1, β_1 and γ_1 are the parameters with the species-specific values presented in Table 1. The values for Scots pine and Norway spruce are those presented by Marklund (1987, 1988).

The foliage mass was further converted to the foliage area by utilising the values of the specific foliage area (area of foliage per mass unit (SLA), $m^2\ kg^{-1}$) presented by Kull and Niinemets (1993), Niinemets and Kull (1995) and Ross et al. (1986) for different species (Table 2).

Calculation of the seasonality of foliage of deciduous species

Equation (1) gives the maximum values of the foliage mass and the consequent maximum values of foliage area. However, Equation (1) excludes the seasonality of the foliage (built-up of foliage in the spring and senescence of foliage in the autumn) which characterises the deciduous canopies. In other words, Equation (1) gives the foliage mass for deciduous trees, but it does not allocate it over the growing season with no indication of the seasonal duration of the foliage. In the case of the coniferous species, these problems do not exist but Equation (1) is giving a sufficient estimate for the foliage regardless of the phase of the growing season.

Table 2. *Values of the specific foliage area for different species.*

Species	SLA, m^2 kg^{-1}
Scots pine	5.54
Norway spruce	5.65
Birches	18.46

The calculation of the springtime built-up of the foliage is based on the effective temperature sum (ETS, d.d.); i.e. the sum of the daily mean temperatures $(T_d, {}^oC)$, which exceeded the threshold temperature $(T_b, {}^oC)$.

$$ETS = \sum_{d=1}^{n}(T_d - T_b), \qquad \text{if} \qquad T_d \geq T_b \tag{2}$$

where n is the number of days for which $T_d \geq T_b$ and $T_b = 5^\circ$ C.

In southern Finland, the built-up of foliage (budburst) is assumed to occur whenever the value of ETS exceeds the value 36 d.d. (i.e. a = 36). Similarly, the built-up of foliage is completed (the mass of foliage has the maximum value indicted by Equation (1)) whenever the value of ETS exceeds the value 865 d.d. (Raulo and Leikola 1974). The values of a and b used for northern Finland were a = 36 d.d. and b = 600 d.d. (Kellomäki and Kolström 1994). The percentage share (SH_{up}, %) of the maximum foliage during the built-up phase is calculated as

$$SH_{up} = \sum_{d=1}^{n}\frac{\log\left(\left(\frac{(ETS-a)}{b-a}\right)\times 100\right)}{2}, \tag{3}$$

where n is the number of days from the moment with ETS > 0 d.d. to the moment when b is having the given values.

The calculation of the senescence of foliage is also based on the calculation of ETS, but now the calculation is done backwards. In other words, the percentage share (SH_{down}) of foliage

***Table 3**. Dominance of different tree species, % of the area of forest land.*

Region	**% of total number of stands**							
	Pine	*Spruce*	*Pendula birch*	*Pubescent birch*	*Aspen*	*Alder*	*Other decid.*	*Treeless*
Whole country	49.2	37.02	2.5	6.9	1.4	1.4	0.1	1.6
Southern Finland	45.3	41.13	3.0	6.1	1.4	1.7	0.1	1.4
Northern Finland	65.2	20.24	0.4	10.1	1.2	0.4	0.0	2.4

present in the canopy is reduced along with reducing ETS until no foliage is present in the canopy, i.e.

$$SH_{down} = 100 - \sum_{d=1}^{n} \frac{1}{C}\left(T_b - T_d\right), \qquad \text{if} \quad T_d \le T_b \qquad (4)$$

where C is a correction [^{o}C] factor, $T_b = 10^{\circ}\mathrm{C}$ and n is the number of days from the moment of the initiation of senescence to the moment when no foliage is present in the canopy.

Results

Tree species composition and age structure of forests

Through the country, Scots pine dominates about a half (49%) of the tree populations (Table 3). The dominance of Norway spruce (37%) and deciduous species (14%) is much less. The dominance of Scots pine is especially pronounced in northern Finland, where Scots pine is the dominant in 65% of the forested area. Norway spruce has an equal occurrence regardless of the region. In northern Finland Pubescent birch is more frequent than in southern Finland, but the dominance of deciduous tree species is quite equal regardless of the region.

A half of the tree populations represents populations of single tree species and a half of mixtures of variable composition of different tree species (Table 4). Scots pine is more frequent to grow in pure stands than other species, especially in northern Finland. The share of pure birch stands is 2-3%. The increased share of pure birch in northern Finland stands indicates the increase of water-logged soils with preference of Pubescent birch the dominance of mountain birch in the areas above the coniferous timber line.

The age structure of the forests is quite the same throughout the country; i.e. the share of the young stands (age < 40 years), middle-aged stands (age < 80 years) and mature stands (age >

Table 4. *Share of pure stands of different tree species and mixed stands, % of the number of stands.*

Region	% of total number of stands					
	Total, pure	*Pine, pure*	*Spruce, pure*	*Birch, pure*	*Mixed*	*Treeless*
Whole country	48.6	30.3	16.4	2.0	49.8	1.6
Southern Finland	48.5	27.7	18.9	1.8	50.2	1.4
Northern Finland	49.4	40.5	6.1	2.8	48.2	2.4

Table 5. *Age structure of forests, % of age classes (years) of the number of stands.*

Region	No trees	Age class, years							
		<20	*21-40*	*41-60*	*61-80*	*81-100*	*101-120*	*121-140*	*>141*
Whole country	1.6	18.7	20.5	12.1	15.6	12.1	8.2	3.9	7.3
Southern Finland	1.4	18.8	23.4	13.4	16.5	13.0	8.7	2.3	2.4
Northern Finland	2.4	18.4	8.6	6.1	11.8	8.1	5.9	10.3	28.2

Table 6. *Density of foliage mass for pure stands of different tree species and mixed stands, g m* $^{-2}$.

Region	Density of foliage mass, g m $^{-2}$			
	Pine, pure	*Spruce, pure*	*Birch, pure*	*Mixed*
Whole country	284	1120	128	752
Southern Finland	306	1145	132	784
Northern Finland	223	802	117	595

80 years) is one third in each case (Table 5). This pattern holds both for southern Finland and for northern Finland equally.

Density and seasonality of foliage mass

Over the country, the mean density of foliage mass was about 280 g m^{-2} for pure Scots pine, 1100 g m $^{-2}$ for pure Norway spruce, 130 g m^{-2} for pure birch and 750 g m^{-2} for tree species mixtures (Table 6). The same values are slightly higher for southern Finland but substantially smaller (25-40%) for northern Finland regardless of tree species.

The density of foliage mass increases along with increasing stand age from 60 g m^{-2} at the age class < 20 years up to 500 g m^{-2} at the age class 81-100 years (Table 7). Thereafter the density of foliage mass deceases along with increasing stand age down to 300 g m^{-2}. The same pattern holds for both southern Finland and northern Finland, but the culmination may

***Table** 7. Density of foliage mass per stand age classes, g m $^{-2}$.*

Region	**Age class, years**							
	<20	*21-40*	*41-60*	*61-80*	*81-100*	*101-120*	*121-140*	*>140*
Whole country	60	220	454	427	503	433	307	372
Southern Finland	68	230	482	463	545	460	381	571
Northern Finland	29	105	186	215	218	262	236	302

occur later in northern Finland than in southern Finland. Nevertheless, the density of foliage mass in the North was only a half of that in southern Finland regardless of the age class.

Over the country, the density of foliage in the youngest stands (age < 20 years) is fairly same for Scots pine and Norway spruce (70-80 g m^{-2}), but substantially less for birch (20 g m^{-2}) (Table 8). Thereafter the density of foliage mass stabilises for Scots pine at the level of 200-290 g m^{-2} with the largest value at the age class of 81-100 years. The same pattern holds for Norway spruce, but now the density of foliage mass varies within the range 350-950 g m^{-2}, the largest value representing the age class of 81-100 years. In maturing birch stands, the density of foliage mass varies from 60 g m $^{-2}$ to 90 g m^{-2}, the largest value representing the age class of 101-120 years.

The overall pattern as regards the density of foliage mass in relation to different age classes holds for southern Finland and northern Finland equally, but the performance of the absolute levels are species specific. For Scots pine, the density of foliage in the North is 80-90% of that in southern Finland, but for Norway spruce only 30-40%. In the case of birch, the density of foliage mass in northern Finland is 80-90% compared to southern Finland, except for the oldest stands, where the density of foliage mass in northern Finland exceeds that in southern Finland.

The initiation of the built-up of birch foliage occurred in the most southmost part of the country (Helsinki, 60^{o} N) nearly two months earlier than in the northernmost part of the country (Utsjoki, 70^{o} N). On the other hand, the senescence of the birch foliage canopy initiated in the Helsinki area about a month later than in the Utsjoki area with the consequence that in the Helsinki area the period with any canopy cover was three months longer than in the Utsjoki area. Thus, throughout the country the seasonality of the deciduous canopies may have a substantial effect on the temporal variability of the total canopy cover.

***Table 8**. Density of foliage mass (g m $^{-2}$) per tree species in different age classes.*

Region	**Age class, years**							
	<20	*21-40*	*41-60*	*61-80*	*81-100*	*100-120*	*121-140*	*>141*
Pine								
Whole Country	71	261	233	285	290	289	276	250
Southern Finland	85	272	230	289	297	286	274	298
Northern Finland	21	141	247	272	260	304	277	235
Spruce								
Whole Country	80	342	943	833	956	807	719	804
Southern Finland	87	360	968	861	982	849	887	1018
Northern Finland	44	113	271	312	470	400	500	686
Birch								
Whole Country	19	61	67	69	67	93	46	55
Southern Finland	18	62	69	70	72	91	29	64
Northern Finland	26	53	46	64	44	104	57	53

Spatial distribution of density of foliage mass and area over the country

The spatial distribution of density of foliage of Scots pine indicates, that the density only seldom exceeds the value of 600 g m^{-2} even in southern Finland (Figure 2). More characteristically, the density of foliage mass falls within the range 200-400 g m^{-2}, but no special geographical pattern is recognisable. In southern Finland, the smallest values for Scots pine are indicating mainly the dominance of Norway spruce or in some cases fresh clear-cut area or dominance of young stands. In northern Finland, the characteristic values of density of foliage mass represent the values smaller than 200 g m^{-2} indicating the low stocking due to the large-scale utilisation of forests in 1950s and 1960s with consequent dominance of seedling stands and young stands. In these conditions, the foliage mass density of Norway spruce may locally exceed 500 g m^{-2} indicating the existence of old-growth Norway spruce stands. In northern Finland, the density of foliage mass of Norway spruce, however, remains generally less than 200 g m^{-2}. The mass density of foliage for birches is generally less than 200 g m^{-2} throughout the country, and only sporadically the density exceeds this values, mainly in southern Finland.

The foliage area index for Scots pine exceeds seldom the value of 1-2 m^{2} m^{-2} (Figure 3). Characteristically, the higher values represent regions with high dominance of Scots pine as in the region with sandy soils in south-eastern Finland or in the regions representing the inland sites in central Finland or the lake Inari basin in the northernmost Finland. For Norway

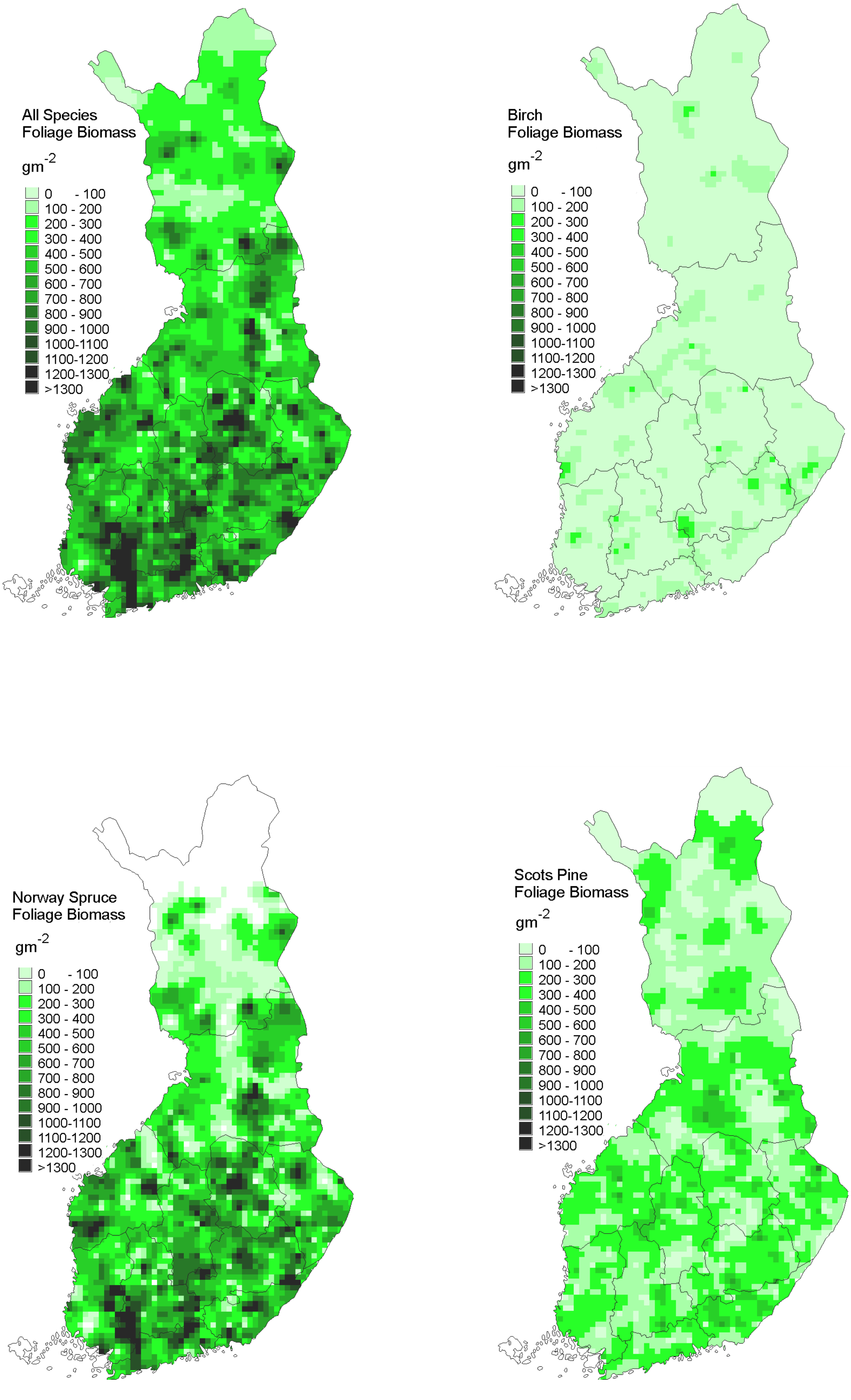

Figure 2. *Spatial distribution of density of foliage mass of different tree species.*

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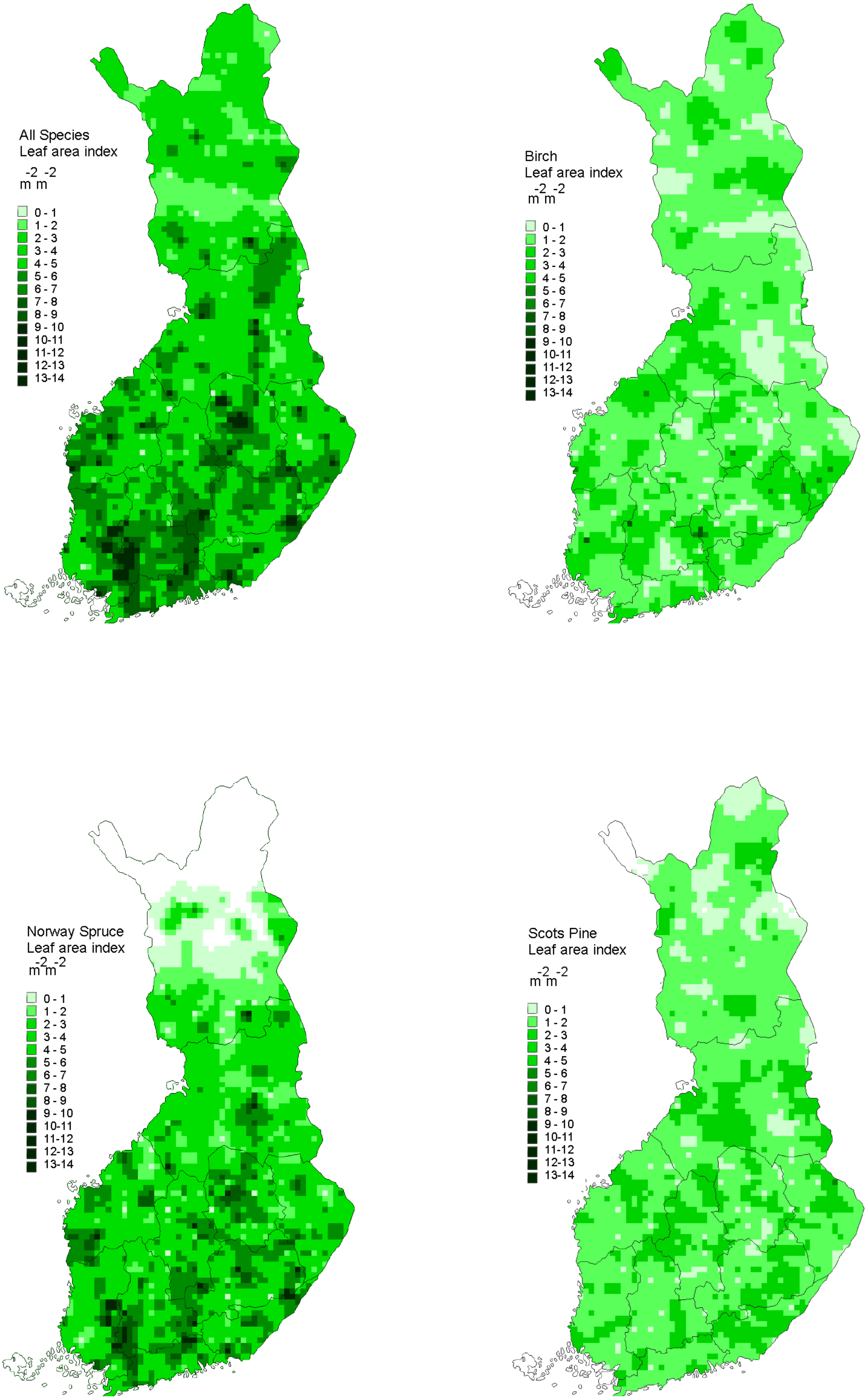

Figure 3*. Spatial distribution of foliage area index of different tree species.*

spruce, the values of foliage area index fall mainly within the range of 4-6 $m^2 m^{-2}$. The highest values occur, for example, in the regions representing the inland in southern Finland or in central Finland with the high dominance of Norway spruce on fertile sites. These areas are also characterised by large dominance of mature tree stands compared to other regions in southern and central Finland. To some extent, the foliage area distributions for birches follow that of Norway spruce, i.e. the birches are having the main dominance of fertile sites as Norway spruce is doing, too. Furthermore, the foliage index for birches is having the largest values in the regions, where the shifting cultivation was an important form of land use still in the early 1900s as in the eastern central Finland. The foliage area index for birches falls mainly within the range of 2–4 $m^2 m^{-2}$. The foliage area for all the tree species falls within the range of 2 – 4 $m^2 m^{-2}$ through the country except an area cross the northern Finland, where the foliage area is less than 2 $m^2 m^{-2}$. The maximum values of the foliage area index over all the tree species are more than 10 $m^2 m^{-2}$. These areas represent the dominance of mature Norway spruce stands.

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