SNAP CODE: **1101**
1102
1111
1112

SOURCE ACTIVITY TITLE: **OTHER SOURCES AND SINKS**
Non-managed deciduous forests
Non-managed coniferous forests
Managed deciduous forests
Managed coniferous forests

NOSE CODE: **11.01.04, 11.01.05, 301.01.(06-11), 301.01.(15-17)**
301.02.(04-12), 301.02.(15-16)
301.11.(04-11), 301.11.(15-17)
301.12.(04-12), 301.12.(15-16)

NFR CODE: **5 E**

1 ACTIVITIES INCLUDED

All types of foliar forest emissions will be considered, non-managed and managed, deciduous and coniferous. Forest foliage is primarily a source of VOC, and we distinguish here between isoprene, monoterpenes, and 'other VOC'. Emissions from forest soils are covered in the chapter dealing with activities 110117, 110216, 111117 and 111216. Note that for methane the flux is believed to be from the atmosphere to the forest floor, so in any case a zero emission factor is recommended for this species. Emissions from forest fires are covered in 1103 "Forest and other vegetation fires". Emissions from the forest undergrowth and root system have not yet been included, although may be added at a later stage. Emissions from shrub-like vegetation, maquis, garrique, or other vegetation types are covered in SNAP 1104 "Natural grassland and other vegetation".

2 CONTRIBUTIONS TO TOTAL EMISSIONS

According to CORINAIR-90, forests (deciduous and coniferous) contributed 19% of total European NMVOC emissions, 4.4% of CH_4 emissions, 14.3% of N_2O emissions and 0.8% of NH_3 emissions.

However, as noted below the natural emission estimates for VOC as supplied for CORINAIR-1990 must now be regarded as outdated. Table 2.1 compares the more recent estimate of Simpson et al. (1995) and Guenther et al. (1995) with estimates of anthropogenic emissions.

Table 2.1: Comparison of estimated isoprene, OVOC, and monoterpene emissions from forests with man-made VOC. Units: ktonnes per year

Country	Isoprene	OVOC	Monoterp.	Man-made
				VOC**
Albania	6	9	16	30
Austria	32	78	30	418
Belgium	30	13	7	364
Bulgarian	135	44	41	178
Czechoslov.***	70	95	124	
Denmark	7	7	4	167
Finland	82	354	398	209
France	480	216	215	2393
Germany	121	190	249	3154
Greece	21	35	62	293
Hungary	82	16	23	205
Iceland	0	0	7	6
Ireland	2	6	11	102
Italy	53	89	142	2080
Luxembourg	2	1	0.4	19
Netherlands	8	6	5	424
Norway	29	104	143	266
Poland	63	176	113	802
Portugal	36	61	70	202
Romania	154	83	55	567
Spain	137	248	272	1050
Sweden	108	389	370	528
Switzerland	5	17	30	284
Turkey	213	460	175	
Russia	2006*	3197*	1060-3490[I]	3566
UK	53	27	39	2287
Sum	4000	6000	3700-6100	20000

Notes: All isoprene and OVOC emissions are from Simpson et al., 1995.
All monoterpene emissions (except Russia) are from Guenther et al., 1995, in ktonne carbon. * 1989 estimates were made for whole Soviet Union, however, Russia is expected to account for the majority of emissions. **Man-made emissions are unofficial estimates, generally derived by subtracting estimated Natural and Agricultural emissions from total emissions. *** Former Czechoslovakia
Other references: I - Isidorov, 1992, sum of pine+fir emissions

3 GENERAL

3.1 Description

The subject of emission inventories for emissions from vegetation is still very much in its infancy in Europe, and the design of an inventory procedure should reflect this. Indeed, NMVOC inventories prepared for the CORINAIR 1990 data-base have already been outdated by recent re-evaluations of the emission factors on which these have been based (Guenther et al., 1993, 1995, 1998, Simpson et al., 1995, Seufert et al., 1997). Generally, the mix of emissions varies greatly both in and between vegetation types, and knowledge of this mix is constantly being updated and in some cases completely revised.

*** It is more important at this stage to assemble the land-use information than to estimate the emissions directly. ***

This is especially true for NMVOC as models are almost completely reliant on good land-use databases for their biogenic emissions estimates. Hopefully the procedures suggested here will lead to a Europe-wide database, which will greatly improve emission estimates for model calculations and policy decisions.

Biogenic VOC is also a rather loose term for a wide range of compounds, of which only a few are generally of most interest. Isoprene is generally the compound of most importance for ozone modelling for example, and it is useful to inventory this compound specifically. Emissions of the various terpenes may also be important, although there are great uncertainties associated with their atmospheric behaviour. Similarly, the remaining VOC species ('other VOC', or OVOC) doubtless play some role in atmospheric chemistry problems, but little is known about the chemistry of many components or the quantitative emissions of individual species. Emissions may be large, however.

A review of the sources and chemistry of biogenic VOCs has recently been given by Fehsenfeld et al., 1992. A special-issue Atmospheric Environment dealing with a large number of European measurements has recently been published (Seufert et al., 1997).

Emissions vary greatly from one tree species to another. And as knowledge has increased some species previously classified as non-isoprene emitters have actually now been found to emit isoprene in significant quantities. Conversely, oaks were previously thought to be always high isoprene emitters, whereas now it is recognised that some evergreen oaks emit little isoprene but very high amounts of terpenes (Seufert et al., 1997).

These considerations have been reflected in the new SNAP codes adopted for this chapter, which assign codes to specific types of trees, rather than to "high-isoprene emitters" etc.

Light and temperature controls on emissions

For all types of vegetation, an appropriate system describing the emissions flux on an hourly basis is that of Guenther et al. (1996):

$$\text{Flux } (\mu g\ m^{-2}\ yr^{-1}) = \int \varepsilon \,.\, D \,.\, \gamma \ dt \qquad (1)$$

where ε is the average emission potential ($\mu g\ g^{-1}\ h^{-1}$) for any particular species, "D" is the foliar biomass density (g dry weight foliage m^{-2}), and γ is a unit less environmental correction factor representing the effects of short-term (e.g. hourly) temperature and solar radiation changes on emissions.

Guenther et al. (1991, 1993) showed that, to a very good approximation, the short-term (hourly) variations in emissions of isoprene could be described by the product of a light dependent factor, C_L and a temperature dependant factor, C_T. Thus, the so-called ISOG algorithm:

$\gamma_{iso} = C_L \cdot C_T$ (2, ISOG)

The light factor, C_L is given by:

$$C_{L_{iso}} = \frac{\alpha c_{L1} L}{\sqrt{1+\alpha^2 L^2}} \quad (3)$$

where α (= 0.0027) and c_{L1} (= 1.066) are empirical constants, and L is the PAR flux (µmol photons (400-700nm) m^{-2} s^{-1}). Temperature dependence $C_{T_{iso}}$ is described by:

$$C_{Tiso} = \frac{\exp(C_{T1}(T - T_S)/RT_S T)}{1+\exp(C_{T2}(T - T_M)/RT_S T)} \quad (4)$$

where R is the gas constant (= 8.314 J K^{-1} mol^{-1}), and c_{T1} (= 95000 J mol^{-1}), c_{T2} (= 230000 J mol^{-1}), and T_M (= 314 K) are empirical coefficients based upon measurements of three plant species: eucalyptus, aspen, and velvet bean, but which seem to be valid for a variety of different plant species (Guenther et al. 1993, Guenther 1997). T_S (= 303 K) is the standard temperature.

The environmental correction factor for monoterpene emissions from most plants are parameterised using the following equation (Guenther et al. 1993):

$\gamma_{mts} = \exp(ß \bullet (T\text{-}T_S))$ (5a, MTS)

where ß (= 0.09 K^{-1}) is an empirical coefficient based on non-linear regression analysis of numerous measurements present in the literature. This type of emission is associated with vaporisation of terpenes from stores within the plant tissue, and this algorithm is referred to here as MTS.

Recently it was shown that some evergreen oaks, and also Norway spruce, show a light-dependency of monoterpene emissions. At least for *Q. ilex* this dependency seems to be well described by the Guenther isoprene algorithms (Kesselmeier et al., 1996, Seufert et al., 1997). Denoting this behaviour by MTL, we have:

$\gamma_{mtl} = \gamma_{iso}$ (5b, MTL)

These emission algorithms represent our current knowledge of terpenoid emission by plants. These algorithms will likely need to be revised in the future, when a better biological understanding of the biosynthesis and emission of terpenoids is available, since there remains an uncertainty in the resulting emission estimates that is about a factor of 3 or more. This variation is mainly due to the (1) differences in the emissions from branch to branch and from tree to tree, (2) variation with season, (3) nutrient condition of the plant, (4) stress and (5) experimental errors. Suggestions for improved algorithms have been made by Schuh et al.

(1997) and Schnitzler et al. (1997), but the generality of these suggestions need further testing before we can recommend a change from the basic Guenther algorithms.

The relationship between environmental conditions and emission of OVOC is even less understood than isoprene and monoterpenes. Emissions of some of these compounds, including a group of C_6 unsaturates, are strongly influenced by external factors other than light and temperature, such as plant wounding by microbes, insects or mechanical stress. Given the lack of other information regarding the factors controlling oxygenated hydrocarbon emission, the use of equation (5) for parameterisation of oxygenated hydrocarbon emission is recommended (Guenther et al, 1994, Geron et al., 1994, König et al. 1995). i.e.:

$$\gamma_{ovoc} = \gamma_{mts} \qquad (6)$$

These light and temperature dependencies are illustrated in Figures 3.1 and 3.2.

Figure 3.1: Temperature dependency of isoprene (ISOG) and of terpene stores (MTS) emissions.

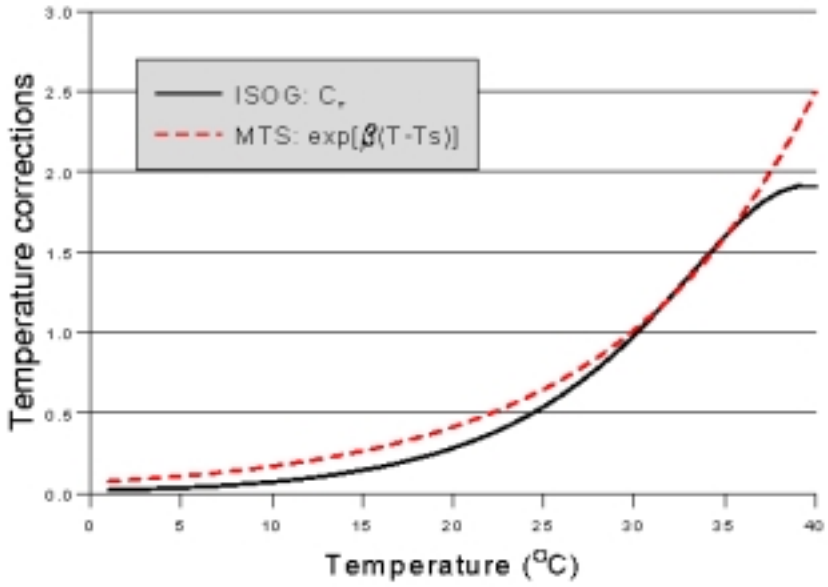
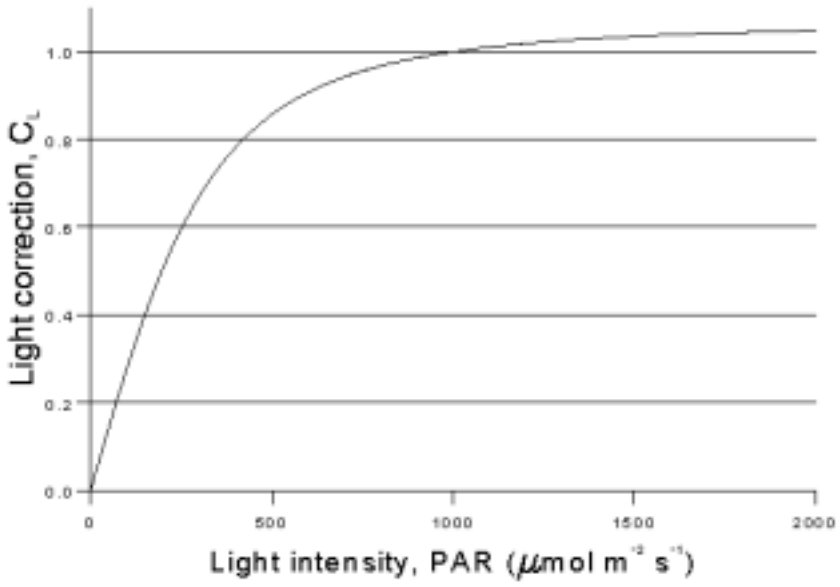


Figure 3.2: Light dependency for emissions of compounds, which are emitted as they are synthesised (e.g. isoprene)



Calculation of annual emissions then requires in principal both temperature and radiation data over the whole year with appropriate spatial resolution. However, many simplifications are possible and the simpler methodology (section 4) proposes a seasonal approach. The use of equations 1-6 above is covered in the detailed methodology (section 5).

3.2 Definitions

Some relevant terms are:

Forest - for the purposes of this guidebook the definition of forest should be as inclusive as possible. In theory all trees should be included, although in practice other definitions of forest may be included in statistical definitions, e.g.:

UNECE/FAO Forest means land with tree crown cover of more than about 20% of the area, with trees usually growing to more than about 7 m in height and able to produce wood. This includes both closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground and open forest formations with a continuos grass layer in which tree synusia cover at least 10% of the ground.

Branch-level - refers to emissions or measurements where the ambient radiation and temperature is an average over a whole branch, including both sun leaves and shade leaves.

Leaf-level - data refer to data appropriate to a single leaf. Leaf-level emission potentials are on average 1.75 times higher than branch-level rates because the latter are mores shaded (Guenther et al., 1994). Emission potentials in this chapter are only given as branch level. (U.S. papers tend to give leaf-level, which requires modelling the shading within a forest canopy)

Coniferous - all trees classified botanically as *Gymnospermae*, generally referred to as softwoods or needle-leafed species.

Non-coniferous - all trees classified botanically as *Angiospermae*, generally referred to as hardwood or **broad-leaved** species. Note that such species can be other deciduous or evergreen.

Deciduous - all plants that shed leaves, usually in the autumn.

DW - dry weight of plants (used for emission rates), as opposed to fresh weight.

Foliar Biomass densities - as used here give the mass of foliage per unit projected ground area, and must not be confused with total biomass densities which have the same units (g m^{-2}) but include wood mass.

OVOC - Other volatile organic compound. Any non-methane VOC species other than isoprene or monoterpenes emitted by vegetation, including oxygenated VOC but also non-oxygenated.

PAR - photosynthetically active radiation, typically about 45-50% of total global radiation, covering the wavelength range 400-700nm.

3.3 Techniques

3.4 Emissions

Biogenic emissions consist of a wide variety of species. Attention has mainly focused on isoprene and the class of monoterpene compounds (alpha-pinene, beta-pinene, limonene, etc.). The remaining 'other' VOC (OVOC) species consist of a large number of species including hydrocarbons and oxygenated compounds (alcohols, aldehydes, etc.), and have proven difficult to quantify in atmospheric samples. See section 9.

3.5 Controls

'Control measures' is not usually an applicable concept for forest emissions. However, it can be mentioned that much of the current forest cover in Europe is artificial, in the sense that the selection of species has been decided by human intervention. Thus, Sitka forest plantations in the U.K. represent an emissions increase over the coniferous forest, which they replaced, so control in terms of species selection could be envisaged. Such action to reduce 'natural' emissions has so far only been undertaken in California as far we are aware!

4 SIMPLER METHODOLOGY

All methodologies for calculating biogenic emissions essentially involve multiplying an emissions factor for a type of vegetation by a statistic giving the amount of vegetation in the country or grid square. Two major alternatives for this are (1) to perform these calculations at a genera or preferably species specific level (requiring for example separate statistics for Norway spruce, Douglas fir, etc.), or (2) to perform the calculations for different ecosystem types. In this latter method, each ecosystem is assumed to consist of a number of species, and the assigned emission rates attempt to give the average emissions from this category.

The rest of this chapter follows a species orientated method (1) approach as far as possible. The main justification for this is that the recent European measurements have differed sufficiently from their American counterparts on an ecosystem basis that where possible detailed species measurements should form the basis of the database. Of course, data still does not exist for many vegetation types in Europe, in which case some ecosystem-assumptions are necessary anyway. These will be based as far as possible on knowledge of European species.

As noted in section 3, an appropriate system describing the emissions flux on an hourly basis is that of Guenther et al. (1996):

$$\text{Flux } (\mu g\ m^{-2}\ yr^{-1}) = \int \varepsilon \,.\, D \,.\, \gamma \ dt \qquad (1)$$

where ε is the average emission potential (μg g^{-1} h^{-1}) for any particular species, "D" is the foliar biomass density (g dry weight foliage m^{-2}), and γ is a unitless environmental correction factor representing the effects of short-term (e.g. hourly) temperature and solar radiation changes on emissions. For isoprene emissions, and light-activated terpene emissions (so far only quantified for two forest species, *Picea abies* and *Quercus ilex*), γ is a function of light and temperature, and is denoted γ-iso. Terpene and OVOC emissions from most vegetation types are simply dependent on temperature, in which case γ is temperature-only dependant, and denoted γ-mt.

The simplified methodology consists of modifying equation (1) to be a seasonal rather than an hourly calculation.

$$F = \varepsilon \,.\, D \,.\, \Gamma \qquad (7)$$

Where Γ represents the integrated value of γ over the growing season of the vegetation concerned.

Using meteorological data from the EMEP MSC-W models the integrated values, Γ-iso and Γ-mts, have been calculated for both 6 monthly (May-October) and 12 monthly growing seasons, as averages over each country. These have been calculated from hourly γ values, and thus have units of hours. The Γ values are tabulated in Table 4.1. With this simplified methodology we could estimate for example the isoprene emissions from 1 km^2 of deciduous oak (e.g. *Q. robur*) as simply:

Emission = Area x ε . D . Γ-iso
= 10^6 (m^2) x 60 (μg g^{-1} h^{-1}) x 320 (g m^{-2}) x Γ-iso (h)

For Austria, for example, Table 4.1 gives Γ-iso for 6-months as 452, therefore we have:

Emission = 10^6 (m^2) x 60 (μg g^{-1} h^{-1}) x 320 (g m^{-2}) x 452 (h) = 8.67 tonne km^{-2}

Table 4.1: Country average values of integrated environmental correction factors, Γ-iso and Γ-mts for 6 and 12 month growing seasons (unit= hours).

	Γ-mts = Γ-ovoc		Γ-iso	
	6-month	12-month	6-month	12-month
Albania	745	976	563	719
Austria	588	734	452	540
Belarus	753	895	581	684
Belgium	739	969	580	712
Bosnia Herz.	709	893	561	686
Bulgaria	824	1029	620	755
Croatia	883	1121	667	815
Czech Republic	712	885	533	633
Denmark	518	704	373	485
Estonia	565	669	422	491
Finland	458	523	339	379
France	840	1107	669	829
Germany	698	890	525	632
Greece	1076	1440	816	1057
Hungary	966	1188	730	874
Ireland	467	713	337	478
Italy	904	1208	711	902
Latvia	636	757	486	572
Lithuania	675	813	516	613
Luxembourg	786	1003	620	745
Macedonia,F.Y.R.	631	783	492	597
Moldova, Rep. of	858	1040	649	771
Netherlands	676	901	513	643
Norway	327	397	240	284
Poland	736	912	558	669
Portugal	1015	1388	853	1093
Romania	783	964	587	706
Russia, Fed.	808	917	637	717
Slovakia	797	977	607	724
Slovenia	745	940	562	682
Spain	982	1301	806	1004
Sweden	423	508	315	368
Switzerland	465	580	368	432
Turkey	976	1263	783	983
United Kingdom	493	720	358	492
Ukraine	856	1023	656	771
Yugoslavia	752	937	557	674

5 DETAILED STATE OF THE ART METHODOLOGY

The detailed methodology still relies on the basic equations (1-6) given above, but allows for the use of better input information and a more refined calculation if local meteorological data are available. We give details for calculations at either a monthly or hourly resolution.

5.1 Monthly calculation

For the monthly calculation we make the following assumptions for the integration of the ISOG-type emissions:

1. The light-intensity variation given by equation 2 can be replaced by a simple step-function, where $C_L = 1$ during most of the day and zero otherwise.
2. The calculation of the temperature correction (Eqns. 4,5) need not be done every hour, but instead may be approximated by a monthly average daytime temperature.
3. Ambient temperature and light-intensity provide a reasonable approximation to leaf-level light and temperature.

Approximation (1) is generally rather good, as light levels quickly reach 1000 μmol m^{-2} s^{-1} during the morning hours in most locations, even with moderate cloud cover. (200 μmol m^{-2} s^{-1} is set as the cut-off for defining daylength as this corresponds to approx. $C_L = 0.5$). Approximation (2) introduces larger errors, but only of order 20% or so, which is much less than the uncertainties in the emission potentials. Approximation (3) has been tested by Simpson et al.(1995) and shown to introduce only moderate uncertainties for European conditions, again much less than those of the emission potentials.

The number of light-hours per day corresponding to the above definition can be calculated as a simple function of latitude and month:

Table 5.1: Number of light-hours* per day (N_L) as a function of latitude and month.

Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
80	0.0	0.0	0.0	13.1	24.0	24.0	24.0	15.2	6.1	0.0	0.0	0.0
78	0.0	0.0	4.4	12.9	20.5	24.0	24.0	14.6	7.2	0.0	0.0	0.0
76	0.0	0.0	5.8	12.7	18.6	24.0	20.2	14.1	7.9	0.0	0.0	0.0
74	0.0	0.0	6.8	12.6	17.5	20.9	18.6	13.8	8.5	0.0	0.0	0.0
72	0.0	0.0	7.4	12.5	16.7	19.1	17.6	13.6	8.9	0.0	0.0	0.0
70	0.0	0.0	7.9	12.4	16.1	18.0	16.8	13.4	9.2	2.5	0.0	0.0
68	0.0	1.6	8.4	12.3	15.6	17.2	16.2	13.2	9.4	4.2	0.0	0.0
66	0.0	3.6	8.7	12.2	15.2	16.6	15.8	13.0	9.6	5.2	0.0	0.0
64	0.0	4.7	8.9	12.2	14.9	16.1	15.4	12.9	9.8	5.9	0.0	0.0
62	0.0	5.4	9.1	12.1	14.6	15.7	15.0	12.8	9.9	6.4	1.5	0.0
60	2.4	6.1	9.4	12.1	14.3	15.4	14.7	12.7	10.1	6.9	3.3	0.0
58	3.7	6.6	9.5	12.0	14.1	15.0	14.4	12.6	10.2	7.3	4.3	2.2
56	4.6	7.0	9.7	12.0	13.9	14.7	14.2	12.5	10.3	7.7	5.1	3.5
54	5.3	7.3	9.8	11.9	13.7	14.5	14.0	12.4	10.4	7.9	5.7	4.4
52	5.8	7.7	9.9	11.9	13.5	14.2	13.8	12.3	10.4	8.2	6.2	5.1
50	6.3	7.9	10.0	11.9	13.4	14.0	13.6	12.2	10.5	8.4	6.6	5.7
48	6.7	8.2	10.1	11.8	13.2	13.8	13.4	12.2	10.6	8.6	7.0	6.2
46	7.1	8.4	10.2	11.8	13.1	13.6	13.3	12.1	10.6	8.8	7.3	6.6
44	7.4	8.6	10.2	11.8	12.9	13.5	13.1	12.1	10.6	9.0	7.6	6.9
42	7.7	8.8	10.3	11.7	12.8	13.3	13.0	12.0	10.7	9.1	7.9	7.3
40	7.9	9.0	10.4	11.7	12.7	13.1	12.9	11.9	10.7	9.3	8.1	7.6
38	8.2	9.1	10.4	11.6	12.6	13.0	12.8	11.9	10.8	9.4	8.4	7.8
36	8.4	9.3	10.5	11.6	12.5	12.9	12.6	11.8	10.8	9.6	8.6	8.1

Notes: Day-lengths (in hours) calculated for the 15th of each month from Latitudes 80 degrees N to 36 degrees N. *Period of light-hours defined for PAR>200 μmol m^{-2} s^{-1}.

If we let mm1 and mm2 be the start and end of the growing season for a particular vegetation type , N_d (mm) be the number of days per month, N_L (mm) be the number of light-hours per day (Table 5.1), and T_{mm} be the monthly mean temperature, for month "mm", yearly emissions can be evaluated with:

$$\text{Emis(isoprene)} = \sum_{mm=mm1}^{mm2} A.D.\gamma_{iso}(T_{mm}).N_d(mm).N_L(mm)$$

Emissions of terpenes from species displaying MTL behaviour are also described by this equation.

For the yearly emissions of species displaying the MTS-type behaviour there is no light-dependency, and we perform the calculation for 24 hours per day:

$$\text{Emis(monoterpenes)} = \sum_{mm=mm1}^{mm2} A.D.\gamma_{mt}(T_{mm}).N_d(mm).24$$

Similarly,

$$\text{Emis(OVOC)} = \sum_{mm=mm1}^{mm2} A.D.\gamma_{ovoc}(T_{mm}).N_d(mm).24$$

5.2 Hourly calculation

If desired, and appropriate meteorological data are available, the environmental correction factors (γ) may be evaluated on an hourly basis using local surface temperature and sunlight conditions. The algorithms, temperature and light corrections, C_T and C_L , are as given in Equations 1-7 above.

Refinements:

Age distribution of forest

Isidorov et al. (1993) have pointed out that a land-use data-base built up with knowledge of not only the area but also the age distribution within each region can give a better description of the biomass densities. This approach requires more data but helps to eliminate a potentially large area of uncertainty.

Seasonal variation

Foliar density varies markedly over the year, and this can be straightforwardly incorporated into the above calculations if data are available through the use of seasonal-dependent foliar biomass density.

Altitude temperature correction

Atmospheric temperature generally decreases with height at a rate of ca. 6 degrees C per km. Thus, data obtained from a meteorological station at a given height may be corrected to temperatures in another location (e.g. on a mountainside) before applying any of the detailed methodologies.

6 RELEVANT ACTIVITY STATISTICS

Vegetation coverage in terms of the vegetation types discussed in section 8 is required, together with foliar biomass estimates (D), and estimates of growing seasons. Commercial forestry at least is usually well documented. Other wooded land is a common category where definitions are more problematic.

For a good inventory it is actually most important to specify the correct foliar biomass density to accompany any given area of vegetation. This is because "area" is an ill-defined quantity in many instances, e.g. 1 km^2 of wooded area may include very dense forest with an average foliar biomass density of, say, 1400 g m^{-2}, or it may contain scattered trees with only 100g m^{-2}.

The new SNAP codes have been designed to encourage the use of data for each tree species separately for at least the most common trees. Very nice examples of this type of compilation are provided by Andreani-Aksoyoglu and Keller (1995) for Switzerland, and Ortiz and Dory (1990) for Spain, the latter tabulating area coverage and mean biomass factors for all 50 level III territorial units.

Categories such as mixed forest should be avoided as this gives no information on species content. If species-specific data are not available, then genus-level data should be used. Only as a last resort should more general categories be supplied.

As pointed out by Veldt (1989) common vegetation names are often confusing, and care should be taken to provide Latin names of species as well as common names of all species. Translations of some common tree species names are included in Table 14.1, taken from EC (1996).

Foliar Biomass densities

For the simpler methodology, seasonal average foliar biomass densities may be used. Default values are suggested below, and in section 8. These suggestions appear to fit quite well a wide range of measurements, but the variability of Mediterranean vegetation may cause some problems. For example, Ortiz & Dory (1990) mention a land-use class, Monte hueco, which consists of a mixture of species, with biomass densities as low as 100 g m^{-2}. For coniferous forests, Veldt suggests densities of 700-1400 g m^{-2} for different species < 60 deg N latitude, whereas Ortiz and Dory use 400 g m^{-2}. Even further north, variations are great. Andreani-Aksoyoglu and Keller, 1995, quote a biomass factor for oak species of 530 g m^{-2}. Some variations are systematic; Isidorov et al. (1993) points out that foliar biomass as a proportion of total tree biomass increases in harsher conditions, and with age.

*** Therefore, it is STRONGLY RECOMMENDED that foliar biomass densities appropriate to the local vegetation are used. These may well be a factor of 2 or three different to the default values. ***

Table 6.1: Default foliar biomass densities (adapted from Veldt, 1989)

Land Use Type		Foliar Biomass Density, D ($g\ m^{-2}$)
Broadleaf:		
Deciduous Oaks		320
Birch (*Betula*)		320
Poplar, aspen (*Populus*)		320
Default deciduous broadleaved		300
Evergreen broadleaved		500
Conifers		
Norway spruce (*Picea abies*)	> 60° N lat.	800
	55-60° N lat.	1400
	< 55° N lat.	1600
Sitka spruce (*Picea sitchensis*)		1400
Other spruce		1400
Scots pine (*Pinus sylvestris*)	> 60° N lat.	500
	< 60° N lat.	700
Other *Pinus ssp*.		700
(Fir) *Abies ssp*.		1400
Douglas Fir (*Pseutotsuga menziessi*)		1000
Larch (*Larix*)		300
Other coniferous		1000

Comment on Satellite data

Satellites provide a spatially comprehensive method of mapping vegetation with very high-resolution. Use of such data is encouraged, but a strong warning should be issued that ground-validation is essential if biogenic emissions are to be estimated. The apparent beauty and detail of a satellite image should not be mistaken for accuracy! Satellite data are easily mis-interpreted (wrong species, problems with non-dominant vegetation, etc.) and even in the United States where biogenic emission inventories are very advanced, discrepancies of up to a factor of 5 are still found between satellite-derived isoprene emissions and ground-based determinations (Lamb et al., 1997).

7 POINT SOURCE CRITERIA

No point sources

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Emission potentials (ε) are required separately for isoprene, monoterpenes and OVOC. Further, for monoterpenes two classes of behaviour are distinguished. For most trees emissions are temperature-only dependant, controlled by the γ-mts environmental factor (equation 5a). For evergreen oaks the MTL algorithm is used (eqn. 5b).

Emission potentials for a wide variety of species have recently been compiled by Guenther et al. (1994, 1997), Geron et al.(1994) for American woodlands, and by Steinbrecher (1997) and Seufert et al. (1997) for European species. Very little reliable experimental data on the emissions of OVOCs is available, and consequently Guenther et al. (1994) recommended the use of a uniform emission rate of 1.5 $\mu g\ g^{-1}\ h^{-1}$ for all tree species, recognising that this was a first order approximation to a ten-fold range (0.5-5 $\mu g\ g^{-1}\ h^{-1}$). The data of König et al.(1995) fall within this range, and so until further European data are available then 1.5 $\mu g\ g^{-1}\ h^{-1}$ also seems a reasonable choice for preliminary, first-order, estimates of OVOC emissions in Europe.

The emission potentials are given in Table 8.1.

Table 8.1: Standard emission potentials (μg g^{-1} h^{-1} at 30 deg. C and PAR=1000 μmol m^{-2} s^{-1}) for European trees.

Isoprene and monoterpene emission potentials are taken from Guenther et al., 1994, 1997, or Geron et al., 1994, except where European measurements can provide a basis, as indicated by additional refs. For terpenes ε-mtl denote emissions controlled by light and temperature (using γ-mtl), whereas ε-mts denote emissions controlled by temperature only. All isoprene rates are branch-level, often derived from leaf-level U.S. estimates by division by 1.75.

		Type	Foliar	Iso.	Terpenes		O-VOC	Additional Refs.	
Common name	Latin name		biomass	ε-iso	ε-mtl	ε-mts	ε-ovoc	Iso.	Terp.
(example)			density, D						
			g m^{-2}						
Fir	*Abies*	e	1400	0	0	3	1.5		
Maple/Sycamore*:	*Acer*	d	320	0	0	3	1.5	S93	S93
Common Alder	*Alnus*	d	320	0	0	1.5	1.5	S93	S93
Birch	*Betula*	d	320	0	0	0.2	1.5	K	P,K
Hornbeam	*Carpinus*	d	320	0	0	0.65	1.5	K	K
Cedar	*Cedrus*	e	700	0	0	1.5	1.5		
Orange	*Citrus sp.*	d	320	0	0	1.5	1.5		
Italian cypress	*Cupressus*	d	700	0	0	0.65	1.5		
Blue gum	*Eucalyptus sp.*	e	400	20	0	3	1.5	Str97b	H
European beech	*Fagus*	d	320	0	0	0.65	1.5	P,S93,K, Sh	K,Sh
Ash	*Fraxinus*	d	320	0	0	0	1.5	S93	S93
Walnut	*Juglans*	d	320	0	0	3	1.5		
Common juniper	*Juniperus*	e	700	0	0	0.65	1.5	O	O
European larch	*Larix*	d,c	300	0	0	1.5	1.5	S93	S93
Olive	*Olea*	e	200	0	0	0	1.5		
Date palm	*Phoenix*			20	0	0	1.5		
Spruce	*Picea sp.*	e	Varies	1	1.5	1.5	1.5	As P.abies	
Norway spruce	*Picea abies*	e	Varies	1	1.5	1.5	1.5	S94,Ke;	J,Ke, S94,LP
	Picea omorika	e	Varies	10	0	0.65	1.5		
Blue spruce	*Picea pungens*	e	Varies	1	0	0.65	1.5		
Sitka spruce	*Picea sitchensis*	e	Varies	6	0	3	1.5	Str96,97b,Sm	
Pines:	*Pinus sp.*	e	700	0	0	3	1.5		-
Aleppo pine	*Pinus halepensis*	e	700	0	0	0.65	1.5		H
Umbrella pine	*Pinus pinea*	e	700	0	0	6	1.5	Ks,Std,Str97a,Sf	
Maritime pine	*Pinus pinaster*	e	700	0	0	0.2	1.5		Si
Scots pine	*Pinus sylvestris*	e	Varies	0	0	1.5	1.5		J
Pistachio	*Pistacia sp.*			0	0	3	1.5	H,Ha	H,Ha
Americ. sycamore*	*Platanus*	d	320	34	0	0	1.5		
Poplar	*Populus*	d	320	60	0	0	1.5	H	
Cherry#4	*Prunus*	d	300	0	0	0	1.5		
Douglas Fir	*Pseudotsuga*	e	1000	0	0	1.5	1.5		D

Oaks:	-			-	-	-		-;	-
Default deciduous Oak#1	-	d	320	60	0	0.2	1.5	Sf	Sf
Default evergreen Oak#2	-	e	500	0	20	0	1.5	Sf	Sf,
Turkey oak	*Quercus cerris*	d	320	0	0	1	1.5	S97	S97
Kermes/Holly oak	*Quercus coccifera*	e	500	0	20	0	1.5	SH	SH
Hungarian oak	*Quercus frainetto*	d	320	100	0	0.2	1.5	S97,Sf,	Sf
Holm oak	*Quercus ilex*	e	500	0	20	0	1.5	Be,Ks96,Str97,Sf	
Sessile oak	*Qercus petraea*	d	320	60	0	0.2	1.5	K,S97,Str97b,Sf	
Downy oak	*Quercus pubescens*	d	320	60	0	0.2	1.5	S97	S97
European oak#3	*Quercus robur*	d	320	60	0	0.2	1.5	S93,I	S93
Cork oak	*Quercus suber*	e	500	0	0	0.2	1.5	Sf	Sf
Locust	*Robinia pseudoacacia*	d	320	10	0	-	1.5		
Willow	*Salix*	d	150	34	0	0.2	1.5	O	S93
Saw-palmetto	*Serenoa*	d	320	10	0	0	1.5		
Lime tree/Basswood	*Tilia*	d	320	0	0	0	1.5		
Elm	*Ulmus*	d	320	0	0	0.2	1.5		

Notes:
Type gives evergreen (e),deciduous (d), or (d,c) for *Larix* deciduous coniferous
#1 e.g. *Q. rubra, Q.faginea, Q.lusitanica.*
#2 e.g. *Q.rotundifolia, Q.callipiprinos,Q.ithhaburiensis, Q.coccifera*
#3 also known as English oak, Pendunculate oak
#4 includes almond,apricot, blackthorn (sloe), peach.
* Sycamore = *Acer pseudoplatanus*, not to be confused with the American sycamore, *Platanus occidentalis*

Refs:
Be Bertin et al, 1997; D Duyzer, 1993; H Hewitt, C.N. and Owen, S., pers.comm.; I Isidorov et al., 1985; J Janson, 1993; K Koenig et al., 1995; Ks96,97 Kesselmeier et al., 1996, 1997; LP Lindskog and Potter, 1995; Ha Hanson et al., 1997; O Owen et al., 1997; P Puxbaum, 1997; Sh Schuh et al., 1997; Si Simon et al., 1994; Sf Seufert et al., 1997; Sm Simpson et al., 1995; Std Staudt et al., 1997; S94 Steinbrecher, R., 1994; S93,97 Steinbrecher et al., 1993, 1997; Str96,97a,97b Street et al., 1996,1997a,1997b.

9 SPECIES PROFILES

Emission (γ) potentials have been given separately for isoprene, terpenes, and OVOC, and this division represents the most important level of speciation. However, there are many species represented within the class of terpenes and OVOC covering a wide range of chemical behaviour. This section attempts some guidance as to likely breakdowns among the monoterpene and OVOC classes.

Monoterpenes

Although many types of monoterpenes exist, most plants emit only 2-3 major species, with the reactive α-pinene often dominating emissions from species such as Norway spruce and Scots pine (Janson, 1993). The ratio of one compound to another is very variable, both with season and temperature, so it is very difficult to specify the speciation in a quantitative way

(Janson, 1993). In order to illustrate the major compounds, Table 9.1 compares the ratios of several monoterpenes to α-pinene obtained from several studies. Table 9.2 groups a number of species in order of their relative frequency of emission.

Table 9.1: Relative composition of hydrocarbon-mix emitted by vegetation as reported by different authors, adapted from Duyzer (1993). Numbers in % are given relative to α-pinene (α-pinene is 100%)

	Veldt:91	Janson:93	Janson:93	Steinb.'93	Simon:93	Duyzer:93
	Average of several pines	Scots pine	Norway spruce	Norway spruce	Maritime pine	Douglas fir
β-pinene	40	33	5	17	105	40-100
3-carene	30	111	6-800		50	30-80
Limonene	26	61	5-15	13	44	20-60

Table 9.2: Examples of monoterpenes emitted by vegetation into the atmosphere (Zimmerman, 1979; Isidorov, 1985, as given by Guenther et al., 1994).

Major	**Frequent**	**Occasional**
Δ^3 - Carene	αThujene	αFenchene
d-Limonene	Tricyclene	β-Fenchene
Myrcene	Terpinolene	δ-Fenchene
α-pinene	α-Terpinene	ε-Fenchene
β-pinene	β-Terpinene	Bornylene
Sabinene	γ-Terpinene	Alloocimene
Camphene	p-Cymene	Methyl chavicol
1,8-Cineole	α-Phellandrene	p-Cymen-8-ol
β-Phellandrene	trans-Ocimene	Linalool
	cis-Ocimene	2-Methyl-6-methylene-1,7-octadiene-3-one
	2-Carene	Pinocarvone
		Verbenone
		Fenchone
		Thujone
		Camphor

OVOC

The identification and quantification of OVOC emissions from plants has proven one of the most difficult problems in evaluating total biogenic emissions. OVOC consists of a wide variety of compounds, many of which have been difficult to measure. Examples are alcohols, ketones, esters, ethers, aldehydes, alkenes and alkanes. Useful reviews can be found in Puxbaum (1997), Bode et al. (1997), Guenther et al. (1994) and Kotzias et al. (1997). The most extensive quantitative European data-set appears to be that of König et al. (1995), otherwise some screening studies are also available (Hewitt and Street, 1992, Steinbrecher, 1994, Isidorov, 1992, Goldstein et al., 1996, Arey et al., 1991a,b).

10 UNCERTAINTY ESTIMATES

None of the biogenic emission inventories used in Europe can be compared in terms of complexity or accuracy with those generated in the U.S.. All European methodologies have been severely limited by the availability of data on a European scale. Several key items are either missing or known to only a limited extent, necessitating some rather arbitrary choices.

Assessment of the uncertainties inherent in calculations of biogenic VOC emissions in Europe is rather difficult. As a starting point, estimates of the uncertainty of even recent U.S. inventories have suggested up to a factor of 3 for isoprene (Guenther et al., 1994). Further, even though much progress has been made in emission potentials and algorithms (Guenther et al., 1993, 1997, Seufert et al., 1997), awareness has grown of the large uncertainties associated with specifying land-cover for particular species. Even in the U.S., where land-use databases exist over the whole country in consistent format, uncertainties associated with specifying forest coverage are still significant (Guenther et al., 1994). In Europe such uncertainties are very much greater because such coherent land-use data sets have not yet become available.

We discuss some of the important factors contributing to the total uncertainty of the European emission estimates below.

Emission potentials

Even with large campaigns such as BEMA (Seufert et al., 1997) emission factors for European species are very few, and taken from a very limited set of conditions and samples. Genus-level potentials derived in the U.S. are often not appropriate for Europe because the species mix within a genus is often very different. It is clear that many more measurements are required before emissions in Europe can be described with any confidence, but meanwhile the first positive steps that can be taken are to collect good land-use data as a basis for any inventory.

Land-use data

The focus of most forest statistics appears to be the area of productive, coniferous forest, rather than the categories of most interest for biogenic inventories. Even for the coniferous forest category definitions vary greatly; 1 km^2 of coniferous forest appears to mean that 50% of the stem-volume is coniferous in Finland and Norway, 70% in Sweden, 80% in Ireland, and 100% in the U.K. (UN ECE, 1985). Whichever definition is used, the aim should be to get the best description of foliar biomass for the area and tree species concerned.

Biomass data

Although the biomass data given in the simpler methodology can be used as default values if no other information is available, factor of two uncertainties can easily be introduced. Clearly the best solution is for each country to specify biomass densities appropriate to local conditions.

OVOC emissions

Guenther et al. (1993) noted that the recommended emission rate of 1.5 μg g^{-1} h^{-1} is associated with a 10-fold range (0.5 - 5 μg g^{-1} h^{-1}) in possible emissions, and that even this may underestimate some emissions.

Final remarks

It has been recognised that the minimum level of uncertainty in global biogenic emission estimates is a factor of 3 (Guenther et al., 1995), but this is likely to represent a lower limit for the accuracy of European emission estimates. Further, this figure relates to estimates of annual emissions. Uncertainties for episodic calculations must obviously be substantially greater.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The emission factors and knowledge of land-use within each region are certainly the weakest aspects. The emission factors can only be improved with more measurements. The land-use problem is primarily one of data collection, as presumably forestry and agricultural Institutes hold quite detailed data for most countries. Collection of this land-use data is of the greatest priority.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Follows from land-use and climate data.

13 TEMPORAL DISAGGREGATION CRITERIA

The details of hourly calculations are given in section 5, detailed methodology.

It is worth noting that annual emissions of biogenic emissions give only a limited insight into the importance of these compounds. For assessing their impacts on photochemical ozone formation it is the biogenic emissions during the warmest and sunniest days, which are of interest. In practice therefore, photochemical oxidant models all calculate their own biogenic emission rates internally using short period temperature, radiation data in conjunction with land-use data.

14 ADDITIONAL COMMENTS

Recent developments and re-evaluations of previous methodologies have resulted in significant changes in the emission factors, which should be used in inventorying biogenic VOC emissions. This chapter has presented information on the new emission factors for a range of species derived from the latest American and European evaluations. In addition, much progress has been made in developing algorithms to describe the emission-temperature-sunlight relationships for isoprene, monoterpenes and other VOC. Still, these algorithms will certainly be changed in the future as knowledge of the underlying processes improves. Suggestions for modifications to include long-term (seasonal changes) to the emission potentials, or other improvements have been presented by Guenther (1997), Schnitzler et al., 1997, and Schuh et al. (1997), although more work is needed to evaluate these algorithms before they can be recommended for the Guidebook.

Canopy models

It is possible to apply complex `canopy' approaches in which forest canopy models are used to estimates levels of temperature and radiation at different heights within a canopy (e.g. Pierce and Waldruff, 1991, Lamb et al., 1993), and such an approach was tested in Simpson et al. (1995). Canopy approaches should be used together with 'leaf-level' emission factors, as opposed to the 'branch-level' factors given in section 8. However, the difference in emissions estimates between a canopy model and simple use of branch-levels estimates is relatively small (up to 20%). Given the much larger uncertainties in the emission potentials, uncertainties introduced by the forest-canopy model itself (e.g. in temperature profiles within the canopy), and the lack of evaluation of such models in European conditions, we do not recommend applying such a model for European emissions at this stage.

The emission factors given in section 8 are therefore exclusively for use where emission-canopy models are not used.

It should be noted that this section still presents a simpler methodology for calculating emissions than can be found in Guenther et al., 1995. We make no attempt to account for factors such as net primary production, leaf-area index, or vegetation index. No canopy radiative model is used. Such factors might improve the accuracy of the estimates somewhat, but until the basic emission factors for European vegetation are more firmly established too much sophistication in the inventory procedure seems unnecessary. Groups having the data and resources to implement such methods are referred to Guenther et al., 1994, Guenther et al., 1995 or Geron et al., 1994.

Table 14.1: Generic names of tree species in different European languages

Botanical Name	French	German	Greek	Italian
Fagus sylvatica	Hêtre	Rotbuche	Οξνα δασικη	Faggio
Quercus petraea	Chêne rouvre	Traubeneiche	Δρνς αποδισκο	Rovere
Quercus robur	Chêne pédonculé	Stieleiche	Δρνς ποδισκοφορος	Farnia
Quercus ilex	Chêne vert	Steineche	Αρια	Leccio
Quercus suber	Chêne liège	Korkeiche	Φελλοδρνς	Sughera
Pinus sylvestris	Pin sylvestre	Gemeine Kiefer	Δασικ πενκη	Pino silvestre
Pinus nigra	Pin noir	Schwarzkiefer	Μανη πενκη	Pino nero
Pinus pinaster	Pin maritime	Seestrandkiefer	Οαλασσια πενκη	Pino marittimo
Pinus halepensis	Pin d'Alep	Aleppokiefer	Χαλεπιος πενκη	Pino d'Aleppo
Picea abies	Epicéa commun	Rotfichte	Ερνθρελατη νψηλη	Abete rosso
Picea sitchensis	Epicéa de Sitka	Sitkafichte	Ερνθρελατη	Picea di Sitka
Abies alba	Sapin pectiné	Weiβtanne	Λενκη ελατη	Abete bianco
Larix decidua	Mélèze d'Europe	Europäische Lärche	Λαριξ ενρ϶παικη	Larice

Botanical Name	Portuguese	Russian	Spanish	Swedish
Fagus sylvatica	Faia	áóê ëåñíîé	Haya	Bok
Quercus petraea	Carvalho branco Americano	äóá ñêàëúíûé	Roble albar	Bergek
Quercus robur	Carvalho roble	äóá ÷åðåùàòûé	Roble común	Ek
Quercus ilex	Azinheira	äóá êàìåííûé	Encina	Stenek
Quercus suber	Sobreiro	äóá ïðîáêîâûé	Alcornoque	Korkek
Pinus sylvestris	Pinheiro silvestre	ñîñíà îáûêíîâåííàÿ	Pino silvestre	Tall
Pinus nigra	Pinheiro Austriaco	ñîñíà ÷¸ðíàÿ	Pino laricio	Svarttall
Pinus pinaster	Pinheiro bravo	ñîñíà ïðèìîðñêàÿ	Pino negral	Terpentintall
Pinus halepensis	Pinheiro de alepo	ñîñíà àëåïñêàÿ	Pino carrasco	Aleppotall
Picea abies	Picea	åëü åâðîïåéñêàÿ	Abeto rojo	Gran
Picea sitchensis	Picea de Sitka	åëü ñèòõèíñêàÿ	Picea de Sitka	Sitkagran
Abies alba	Abeto branco	ïèõòà áåëàÿ	Abeto común	Sivergran
Larix decidua	Larício Europeu	ëèñòâåííèöà åâðîïåéñêàÿ	Alerce	Europeisklärk

Botanical Name	Danish	Dutch	English	Finnish
Fagus sylvatica	Bøg	Beuk	Common beech	Pyökki
Quercus petraea	Vintereg	Wintereik	Sessile oak	Talvitammi
Quercus robur	Stilkeg	Zomereik	European oak	Metsätammi
Quercus ilex	Steneg	Steeneik	Holm oak	Rautatammi
Quercus suber	Korkeg	Kurkeik	Cork oak	Korkkitammi
Pinus sylvestris	Skovfyr	Grove den	Scots pine	Metsämänty
Pinus nigra	Østrisk fyr	Oostenrijkse/ Corsicaanse zwarte den	Corsican/Austrian black pine	Euroopanmusta-mänty
Pinus pinaster	Strandfyr	Zeeden	Maritime pine	Rannikkomänty
Pinus halepensis	Aleppofyr	Aleppoden	Aleppo pine	Aleponmänty
Picea abies	Rødgran	Fijnspar	Norway spruce	Metsäkuusi
Picea sitchensis	Sitkagran	Sitkaspar	Sitka spruce	Sitkankuusi
Abies alba	Ædelgran	Zilverden	Silver fir	Saksanpihta
Larix decidua	Lærk	Europese lariks	European larch	Euroopanlehti-kuusi

15 SUPPLEMENTARY DOCUMENTS

The American Biogenic Emission Inventory System (BEIS) has resulted in extensive lists of emission potentials. The latest published version is Geron et al. (1994). The updated BEIS-3 version is currently under preparation by Guenther et al. (1998). (Some of these rates have been already adopted in Table 8.1).

A qualitative list of isoprene and monoterpene emitting species is held at:

Hewitt, C. N., Street R.A. and Scholefield P.A. (1998):
Isoprene and monoterpene-Emitting Species Survey 1998.
http://www.es.lancs.ac.uk/es/people/pg/pas/download.html

16 VERIFICATION PROCEDURES

If satellite data have been used in the land-use mapping process it is essential that these be independently verified by on-the-ground surveys. Large errors are possible in the identification of vegetation types and biomass from remote sensing methods.

In general all of the emission potentials are built upon very few data. More measurements are required of at least the major sources, and several different measurement techniques need to be applied in order to eliminate the artefacts (usually enhanced emissions) easily generated by disturbances to the vegetation.

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