Development of a biogenic hydrocarbon emission inventory for the Central California Ozone Study domain.

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Introduction

The Biogenic Emission Inventory GIS (BEIGIS) is a spatially and temporally resolved biogenic hydrocarbon emissions inventory model developed by the California Air Resources Board (CARB) that uses California land use/land cover, leaf mass, and emission rate databases within a Geographic Information System (GIS). BEIGIS simulates hourly emissions of isoprene, monoterpenes, and 2-methyl-3-buten-2-ol (MBO, methylbutenol) at a 1 km^2 resolution. Development of BEIGIS has been motivated by a need to account for the state's pronounced plant species diversity and landscape heterogeneity. There are approximately 6000 native plant species in California (25% of the flora of the continental U.S.) distributed over terrain ranging from basins below sea-level to mountain ranges over 3000 m in elevation (Hickman 1993). Plant canopies range from scattered and open canopy structures typical of scrublands and savannas, to more closed canopies typical of coniferous forests. Terrain gradients and proximity to marine influence also give rise to more than a dozen climate zones in the state (CEC 1992). These considerations have prompted the CARB to develop BVOC emission inventory models specific to California.

2. BEIGIS Inputs

2.1 *Land use/land cover maps*

The initial set of inputs to BEIGIS are GIS-based maps of land use and land cover types. A composite land use and land cover GIS map for the Central California Ozone Study (CCOS) domain was compiled from several sources in order to provide sufficient spatial resolution and accuracy to reflect the heterogeneity of vegetation species in the study area.

A biodiversity database and mapping effort undertaken by the U.S. Geological Survey – Biological Resources Division, called the Gap Analysis Project (GAP), was selected to represent natural areas in the California portion of the CCOS domain (Scott et al. 1993; Davis et al. 1995; Chung and Winer 1999). The California GAP database was generated from summer 1990 Landsat Thematic Mapper satellite images, 1990 high altitude color infrared imagery, vegetation maps based on historical field surveys, and other miscellaneous vegetation maps and ground surveys. California's GAP coverage is comprised of approximately 21,000 polygons, aggregated into 272 natural community types. The GAP minimum mapping unit is 100 hectares (1 km^2). Each GAP polygon is comprised of up to three vegetation assemblages (a primary, secondary, and for some polygons, a tertiary assemblage), with each assemblage occupying a fraction of the polygon area. In addition, each assemblage is comprised of up to three co-dominant species, each species contributing ≥ 20% of the assemblage's relative cover. Species canopy cover within individual polygons was estimated as FC × CW, where the parameter FC is the fractional area (ranging between 0 and 1) of the polygon occupied by an assemblage, and CW is a weighting factor for co-dominant species, such that CW = 0.33, 0.50, or 1.0 for assemblages comprised of 3, 2, or 1 species, respectively. For example, a hypothetical 100 km^2 polygon is comprised of primary and secondary assemblages occupying 65% and 35% of the polygon area, respectively. If the primary assemblage is comprised of two species A and B, the co-species weighting factor for each is 0.5 and the canopy cover for each species is (0.65 × 0.5 × 100 km^2). If the secondary assemblage is comprised of species B, C and D, the canopy cover for each species is (0.35 × 0.33 × 100 km^2). The total canopy cover for species B within the polygon is then [(0.65 × 0.5) + (0.35 × 0.33)] × 100 km^2 or 44 km^2. The estimated canopy cover of a given species in a polygon therefore reflects the weighted contributions from all assemblages in that polygon.

Agricultural areas represented by the GAP data set lack crop species information. Therefore, a land use/land cover GIS map showing crop coverages for the CCOS domain was obtained from scientists of the NASA Ames Research Center. The map was compiled from GIS data sets provided by the California Department of Water Resources (DWR) (http://www.waterplan.water.ca.gov/). Land use/land cover maps were developed by the DWR from periodic ground surveys throughout the state. Counties are surveyed and updated on a rotating basis approximately every seven years. In the DWR crop GIS data set, polygons correspond to individual cultivated fields for which are listed the field area, crop type and the fraction of the field cultivated.

Urban areas represented by the GAP data set contain information about urban land use types such as residential and commercial, but lack information about urban vegetation. Urban vegetation databases for three CCOS urban areas (Fresno, Oakland, and Sacramento) were therefore utilized to develop BVOC emission rates for urban areas throughout the CCOS domain.

2.2 *Emission factors, leaf mass and landscape-scale emission rates*

For natural areas, GAP plant species were assigned isoprene and monoterpene emission factors ($\mu g\ g^{-1}$ [dry leaf weight] hr^{-1}) from Benjamin et al. (1996) and specific leaf weight factors (SLW, g [dry leaf weight] m^{-2} leaf area) from a database compiled by Nowak and co-workers (2000) (Table 1). Until relatively recently, emission factor data collected in California have been based on branch enclosure rather than leaf cuvette measurement methods. Leaf cuvette-based isoprene emission factors have been found to be 1.75 to 5 times greater than branch enclosure derived emission factors (Guenther et al. 1994 and 1996a; Harley et al. 1998; Geron et al. 2001), ascribed in part to self-shading by leaves within enclosed branches. Since the majority of published emission factor measurements in California were developed using branch enclosure methods, the BEIGIS model used branch enclosure derived emission factors for isoprene and monoterpenes. Branch enclosure derived emission factors for methylbutenol were unavailable, therefore leaf-cuvette derived methylbutenol emission factors from Harley et al. (1998) were used for the MBO emitting conifer species. Within-canopy vertical variation in leaf mass, temperature and solar radiation were not explicitly accounted for in this modeling. Landscape-scale natural area emission rates at reference conditions (30 °C and 1000 umoles m^{-2} s^{-1} photosynthetically active radiation or PAR) for isoprene, monoterpenes and MBO (mg m^{-2} land hr^{-1}) were derived by mapping GAP species fractional canopy cover (FC), co-dominant species weighting factors (CW), specific leaf weight factors (SLW), and emission factors (EF), to 1km^2 grids and multiplying by a remotely-sensed 1 km^2 resolution leaf area index (LAI, m^2 leaf m^{-2} land) GIS layer from Nikolov (1999).

Landscape-scale crop emission rates at reference conditions were derived by first assigning to the crop GIS layer crop BVOC emission factors and crop specific leaf weight (SLW) factors. The DWR land use/land cover map represents 75 agricultural classes or crop types (Table 2). A database was developed listing BVOC emission factors for isoprene and monoterpenes (μg g^{-1} [dry leaf mass] hr^{-1}) at standard conditions of temperature and light (30 °C and 1000 μmol PAR m^{-2} s^{-1}, where PAR is solar irradiance in the 400-700 ηm range) and specific leaf weight factors (SLW, g [dry leaf mass] m^{-2} leaf area) for each crop type (Table 2). Very few crops are isoprene emitters, while some emit monoterpenes. MBO emissions have been observed in a few conifer species. BVOC emission and SLW factors were assigned to crops based upon values reported in the scientific literature. BVOC emission factors were assigned based upon values reported for measured species, or based upon taxonomic relationship to measured species (Benjamin et al. 1996). SLWs were assigned based upon values for measured species, related species, or class. A crop calendar was also consulted to determine which crop types are in cultivation during the summer ozone season. Crop SLW and emission factors were gridded to 1 km^2 resolution and multiplied by the remotely-sensed 1 km^2 resolution leaf area index GIS layer from Nikolov (1999).

Urban vegetation survey data for Fresno, Oakland, and Sacramento were utilized to develop landscape-scale isoprene and monoterpene emission rates (mg m^{-2} land hr^{-1}) at reference conditions for urban land uses (Table 3). Urban land use emission rates represent aggregations of plant species for urban land use types in Fresno, Oakland and Sacramento (Sidawi and Horie 1992; Nowak 1991; McPherson 1998) and emission factors as developed by Benjamin et al. (1996).

In addition to isoprene, monoterpenes, and MBO, other organic compounds are emitted by vegetation. Guenther et al. (1994) estimate that the other VOCs (OVOCs) comprise 8% to 73% of total BVOCs. BEIGIS however does not explicitly account for OVOCs at this time, because little data exist from which to construct OVOC emission factors or emission algorithms for California vegetation. An adjustment factor of 30% is applied to the total isoprene, monoterpene and MBO inventory to account for the OVOC fraction, to which is applied a chemical speciation profile from Lamanna et al. (1999) (pers. comm., Paul Allen, CARB, 2001). The OVOC chemical speciation profile is based upon above-canopy ambient air BVOC measurements at Blodgett Experimental Forest, a 1315 m elevation Ponderosa Pine plantation in the central Sierra Nevada of California. The assumed OVOC profile therefore may have limited applicability to natural areas of the CCOS domain, which, in addition to conifer forests, are comprised of savannas, chaparral and scrublands.

Landscape-scale 1 km^2 resolution emission rate layers for natural, urban, and agricultural areas were then aggregated to construct single layers of gridded isoprene, monoterpene, and methylbutenol emission rates at reference conditions for the CCOS domain.

2.3 *Application of environmental correction algorithms*

In the BEIGIS model, the effects of spatial variation in ambient air temperature and light intensity on BVOC emissions are taken into account. Isoprene, monoterpene, and MBO emission rate grid layers were environmentally adjusted using emission algorithms (Guenther et al. 1993; Harley et al. 1998) driven by hourly gridded air temperature and solar radiation fields. The isoprene emission algorithm is given as

$$I = I_S \cdot C_L \cdot C_T$$

where I_s is isoprene emission at reference temperature and light conditions and where C_L and C_T are correction factors for ambient temperature and light

$$C_L = \frac{\alpha c_{L1} L}{\sqrt{1+\alpha^2 L^2}}$$

$$C_T = \frac{\exp \dfrac{c_{T1}(T - T_S)}{RT_S T}}{1 + \exp \dfrac{c_{T2}(T - T_M)}{RT_S T}}$$

$$\alpha = 0.0027$$
$$c_{L1} = 1.066$$
$$R = 8.314\ J\ K^{-1}\ mol^{-1}$$
$$c_{T1} = 95{,}000\ J\ mol^{-1}$$
$$c_{T2} = 230{,}000\ J\ mol^{-1}$$
$$T_s = 303\ K$$
$$T_M = 314\ K$$

and where T is ambient temperature (K) and L is ambient sunlight in the PAR range.

The monoterpene emission algorithm is given as

$$M = M_s \cdot \exp\left(\beta\left(T - T_s\right)\right)$$

where M_s is monoterpene emission at reference temperature and where

$$\beta = 0.09\ K^{-1}$$
$$T_s = 303\ K$$

Methylbutenol emissions are both temperature and light-dependent,

$$MBO = MBO_S \cdot C_L \cdot C_T$$

where MBO_s is MBO emission at reference conditions of temperature and light and where C_L and C_T are correction factors for ambient temperature and sunlight

$$C_L = \frac{\alpha\, c_{L1}\, L}{\sqrt{1 + \alpha^2 L^2}}$$

$$\alpha = 0.0011$$
$$c_{L1} = 1.44$$

$$C_T = \frac{E_{opt}\ c_{T2}\ \exp^{C_{T1}\chi}}{c_{T2} - c_{T1}\left(1 - \exp^{C_{T2}\chi}\right)}$$

$$E_{opt} = 1.52$$
$$c_{T1} = 67\ kJ\ mol^{-1}$$
$$c_{T2} = 209\ kJ\ mol^{-1}$$
$$\chi = \left[\left(1/T_{opt}\right) - \left(1/T\right)\right]/R$$
$$T_{opt} = 312.3\ K$$

Hourly temperature and solar radiation fields gridded at 4 × 4 km resolution for the CCOS domain are generated using the MM5 model (NCAR 2001). PAR is calculated as 0.42 × SRAD × (4.6 μmol photons $m^{-2}\ s^{-1}\ [W\ m^{-2}]^{-1}$), where SRAD is full sun (direct + diffuse) radiation ($W\ m^{-2}$) in the visible spectrum.

3. Field data and model comparison

Canopy-level emissions of monoterpenes and methylbutenol were simulated for a 2 km x 2km area surrounding a measurement site at Blodgett Forest Research Station. Located near Georgetown, California, the Blodgett Forest site (38°53'42.9"N, 120°37'57.9"W) is a long-term micrometeorological flux measurement site located on a Ponderosa Pine plantation and operated by the University of California at Berkeley. It is the only site where canopy-level BVOC fluxes have been measured in California (Baker et al. 1999; Dreyfus et al. 2002; Schade and Goldstein, 2001, 2003; Kurpius and Goldstein, 2003; Lamanna and Goldstein 1999; Bauer et al. 2000; Schade et al. 1999; Goldstein et al. 2000; Schade et al. 2000; Goldstein and Schade 2000). MBO emissions were simulated for two cases. In the first case, emissions were simulated using default BEIGIS land cover inputs. In the second case, emissions were simulated using Blodgett Forest site-specific land cover inputs. Meteorological data from the Blodgett site for the period June 2 – September 8, 1999 were used as input for both simulations. Modeled emissions for both cases were compared to measured MBO fluxes for the same period. Monoterpene emissions were simulated using default BEIGIS land cover inputs and compared to measured fluxes of alpha-pinene, beta-pinene, and 3-carene for the same period.

The Blodgett site is near the nexus of four 1 km^2 BEIGIS model grid cells (labelled A through D), and the boundary of two GAP land cover polygons (GAP id 6658 and 6728)(Figure 1). In BEIGIS, GAP land cover information are gridded at 1 km^2 resolution, therefore grid cells A and C inherit land cover attributes from GAP polygon 6658, while grid cells B and D inherit attributes from polygon 6728. BEIGIS land cover input data for model grid cells A through D are shown in Tables 4 and 5. While the default gridded BEIGIS model inputs and output are at 1 km^2 resolution, Blodgett land cover and flux measurement data represent an upwind "footprint" of only a few hundred meters. Although measurements and model simulations ostensibly represent different spatial scales, comparisons indicate how variable results can be, based on differences in reasonable estimates of the inputs.

Figure 2 compares averaged modeled MBO fluxes for BEIGIS model grid cells A through D, with the average measured fluxes at the Blodgett site for the period June 2 – September 8, 1999. The general shape of the diurnal pattern agrees well with the measurements; however, the modeled MBO fluxes for grid cells A and C underpredict emissions by a factor of 2, while grid cell B overpredicts by a factor of 2. Modeled MBO fluxes for grid cell D are slightly overpredicted. Since there are multiple factors contributing to each term in the model (including factors which may not be known), it is not possible to accurately determine errors associated with each. The greatest uncertainty exists in the determination of leaf mass density (LMD), because of the number of factors which can effect it. The emission factor also has uncertainty due to its' possible seasonal variability. Variability in leaf mass densities and MBO emission factors measured at Blodgett indicate that canopy-scale reference emission rates (i.e. normalized to 30 °C and 1000 μmoles m^{-2} s^{-1} PAR) may have ranged from 1.06 to 6.24 mg C m^{-2} hr^{-1}, with a midvalue of approximately 2.98 mg C m^{-2} hr^{-1} (Baker et al. 1999). The effect of these uncertainties are shown in

Figure 3, where MBO emissions were simulated using Blodgett leaf mass density and emission factor ranges reported in Baker et al. (1999). The figure illustrates that measured leaf mass density and emission factor uncertainties can yield modeled MBO fluxes which are over- or under-predicted by a factor 2. Midvalue inputs yield modeled MBO fluxes which were overpredicted by approximately 25-30%.

Monoterpene fluxes for BEIGIS grid cells A through D were modeled using default BEIGIS land cover inputs and Blodgett meteorological data. Figure 4 compares averaged modeled monoterpene fluxes (converted from units mg monoterpene m^{-2} hr^{-1} to mg C m^{-2} hr^{-1}) for BEIGIS grid cells A through D, with average measured fluxes of three monoterpene species: alpha- and beta-pinene, and 3-carene, for the period June 2 – September 8, 1999. Monoterpene fluxes were not modeled using Blodgett site-specific inputs, as variability in the monoterpene-emitting leaf mass density and emission factors at this site were not available. For simplicity, the three measured monoterpene species are also combined into a single category for comparison with BEIGIS-modeled monoterpene fluxes (which are not speciated). BEIGIS-modeled monoterpene fluxes for grid cells A and C during midday are slightly greater than measured alpha-pinene and 3-carene fluxes, and slightly lower than measured beta-pinene fluxes. BEIGIS-modeled monoterpene fluxes for grid cell B are a factor 2 to 4 greater than the combined alpha- and beta-pinene + 3-carene category, and individual monoterpene species, respectively. BEIGIS-modeled monoterpene fluxes for grid cell D are a factor 2 greater than the individual measured monoterpene species, and in approximate agreement with the combined alpha- and beta-pinene + 3-carene category. Variability in monoterpene fluxes are of the same order as have been shown for MBO fluxes, and presumably due in part to uncertainties in leaf mass densities and monoterpene emission factors.

4. Model Uncertainties

Inputs to BEIGIS, such as emission rates, leaf mass factors, land use/land cover maps, and satellite-derived LAI values have been assessed by a number of researchers (Winer et al. 1998; Chung and Winer 1999; Karlik and McKay 1999; Karlik 2001; Winer and Karlik 2001).

Isoprene and monoterpene emission factors utilized by BEIGIS for plant species in California's urban, agricultural, and natural landscapes are derived from in-situ branch enclosure measurements and taxonomic assignments (Benjamin et al. 1996). Although measured emission rates are used where available, assignment of measured emission factors to unmeasured species based upon taxonomic relationship introduces uncertainties. Karlik and Winer (2001) measured isoprene emission factors of plant species to test taxonomically assigned emission factors of Benjamin et al. (1996). They reported measured branch-level isoprene emission factors for 13 of 19 species were within ± 50% of taxonomically predicted emission factors. Genus-level assignments were in generally good agreement with measured isoprene rates, with the exception of *Quercus*, where emissions varied widely about the predicted mean of 24.8 µg g^{-1} hr^{-1}, from below detection limit for *Q. suber* to 54 µg g^{-1} hr^{-1} for *Q. kelloggii*. The uncertainty associated with the monoterpene and OVOC emissions estimates have not been quantified. OVOCs are an added fraction to the BEIGIS BVOC inventory to which is applied a chemical speciation profile which may not be representative of natural areas in the CCOS domain.

As noted previously, systematic differences have been reported in the literature for leaf cuvette versus branch enclosure derived emission factors. Geron et al. (2001) assessed taxonomic rate assignments of Benjamin et al. (1996) by measuring leaf cuvette isoprene emission factors for a number of eastern U.S. and native California oak species. For *Quercus chrysolepis*, *Q. engelmannii*, *Q. kelloggii*, *Q. falcata* and *Populus trichocarpa*, measured leaf cuvette emissions were approximately a factor of 2 to 5 times greater than the taxonomically predicted branch-level emission factors, attributed in part to differences in enclosure type. Guenther et al. (1996a) also observed that isoprene emissions measured via leaf cuvette ranged between 1.5 to 2 times greater than branch-level measurements, due to differences in leaf orientation, self-shading and other factors.

Plant species composition and abundance predicted by the GAP database have been evaluated for several regions of the state. Field data from 8 sites in the Southern California Ozone Study (SCOS) domain and 6 sites in central California indicate that the GAP database correctly predicted 50% to 70% of the plant species at the sites surveyed (Winer et al. 1998; Chung and Winer 1999; Winer and Karlik 2001). In San Diego County, isoprene and monoterpene emission potentials for 8 polygons estimated according to GAP predicted plant species composition and areal coverage were compared to emission potentials estimated from field sampling (Chung and Winer 1999). For four of the polygons, emission potentials based on GAP predictions were more than 50% different from emission potentials calculated from field data. When summed over all 8 polygons, the total isoprene emission potential based on field data was 7% greater than the total based upon the GAP prediction. The total monoterpene emission potential for the 8 polygons based on field data was 2% lower than the total based upon the GAP prediction.

Modeled BVOC emissions are also sensitive to uncertainties associated with leaf mass density (g [dry leaf weight] m^{-2} land). For natural areas, leaf mass density is computed from remotely sensed leaf area index, fractional canopy cover, co-species weighting factors and plant specific leaf weight factors. Winer and Karlik (2001) found that ground-surveyed leaf area indices measured in California oak savannas (LAI ~ 1.3) agreed with satellite-derived 1 km^2 resolution LAI values (between 1 and 2) for those same sites. In the Winer and Karlik (2001) study, a stand of 14 Blue Oak trees (*Quercus douglasii*) surrounded by open grassland was measured for crown height, crown radii, and diameter at breast height (DBH). All 14 trees were then harvested, and their stem and leaf areas and (fresh and dried) weights recorded. Mean per-tree leaf mass density (LMD) was 730 g m^{-2}, while site leaf mass density, defined as the total leaf mass of the 14 trees divided by the total study area, was 310 g m^{-2}. This site LMD value is in the midrange of LMDs (182 – 643 g m^{-2}) reported by Sidawi and Horie (1992) for oak woodlands in the southern San Joaquin Valley. When the oak leaf mass of the site study area was considered together with surrounding grassland, the LMD decreased by a factor of two. In the BEIGIS model, calculated LMDs for 1 km^2 grid cells in CCOS natural areas are often less than 200 g m^{-2}. Natural area LMDs utilized by Benjamin et al. (1997) for the Southern California Air Quality Management Plan (SCAQMP) domain ranged from 90 (grassland) to

244 (woodland) to 555 g m^{-2} (forest). Although further data analyses are needed, these preliminary results support the use of the satellite-derived LAI database as an input to the BEIGIS model.

Potential leaf mass estimation biases from multiplying plant species SLWs by fractional canopy cover areas and co-species weighting factors together with LAI values for 1 km^2 grid cells are unknown. Computing species leaf mass densities in this manner may over or under-predict a species' contribution to total emissions. The technique may be less problematic for computing leaf masses and emissions of crops, many of which are cultivated in monocultures greater than 1 km^2.

5. Conclusion

Compared to fluxes measured at the Blodgett Forest site, MBO emissions modeled for four adjacent BEIGIS 1 km^2 grid cells using default BEIGIS inputs were under-predicted in two adjoining 1 km^2 grid cells and over-predicted emissions in one adjoining 1 km^2 grid cell. Modeled MBO emissions in the remaining grid cell were in relatively good agreement with measured MBO fluxes. MBO fluxes modeled using variable Blodgett site-specific inputs for leaf mass density and MBO emission factors showed similar magnitudes of over- and under-prediction, and relatively good agreement when using midvalue inputs. Monoterpene fluxes modeled using default BEIGIS inputs showed a similar pattern of over- and under-prediction, when compared to measured fluxes of specific monoterpene compounds.

Studies have shown that uncertainties in canopy biomass distributions and "flux footprint" determination can confound BVOC emission model validation using micrometeorological flux measurements (Lamb et al. 1996; Guenther et al. 1996; Baldocchi et al. 1999; Huber et al. 1999). Model performance is usually achieved only after detailed parameterization of the BVOC-emitting leaf mass density within the upwind flux "footprint" of the measurement site. At the Blodgett Forest site, Shade et al. (2000) were able to achieve good agreement between modeled and measured MBO fluxes by representing the MBO-emitting Ponderosa Pine leaf mass according to (three) needle leaf age classes, by assigning different emission factors to each age class, by varying the emission factors and leaf mass over the growing season, and by adopting a sunlit vs. shade leaf PAR scheme.

Comparisons between BEIGIS modeled and measured BVOC fluxes are preliminary. Further analyses of BEIGIS performance with Blodgett data are needed. Regional and canopy-scale flux measurements to test model estimates of BVOC emissions for other regions and land cover types of the state are also needed.

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Table 1. BVOC emission and specific leaf weight (SLW) factors assigned to GAP vegetation species.

GAP species code	Common name	Scientific name	Vegetation Class	specific leaf wt g dry leaf/m2 leaf	in-leaf season emission factor ug/g dry leaf wt/hr @ ref conditions		
				SLW	ISO	MONO	MBO
42034	Coulter pine	Pinus coulteri	1	91	0	4	71
42044	Foothill pine	Pinus sabiniana	1	91	0	1	67
41006	Oregon oak	Quercus garryana	3	110	59	1	0
32433	Oregon oak (shrub form)	Quercus garryana var. breweri	3	110	59	1	0
41001	Black oak	Quercus kelloggii	3	103	54	1	0
41015	Willow	Salix spp.	3	62	51	0	0
41009	Quaking aspen	Populus tremuloides	3	89	50	0	0
41012	Fremont cottonwood	Populus fremontii	3	85	36	0	0
41004	Coast live oak	Quercus agrifolia	2	141	35	0	0
41010	Black cottonwood	Populus balsamifera ssp. trichocarpa	3	85	33	0	0
41030	Eucalyptus	Eucalyptus spp.	2	130	28	5	0
42059	Shore pine	Pinus contorta var. contorta	1	149	0	4	25
42014	Lodgepole pine	Pinus contorta var. murrayana	1	149	0	4	25
42015	Ponderosa pine	Pinus ponderosa	1	91	0	4	25
41003	Canyon live oak	Quercus chrysolepis	2	169	26	1	0
32065	Canyon live oak (Shrub form)	Quercus chrysolepis	2	169	26	1	0
32428	Huckleberry oak	Quercus vaccinifolia	**5,2**	110	26	1	0
41002	Blue oak	Quercus douglasii	3	122	26	0	0
41027	Engelmann oak	Quercus engelmannii	3	152	25	1	0
41055		Quercus alvordiana	2	110	25	1	0
32073	Desert scrub oak	Quercus cornelius-mullerii	2	110	25	1	0
32061	Leather oak	Quercus durata	**5,2**	110	25	1	0
32220	Tuckers Oak	Quercus john-tuckeri	3	110	25	1	0
32455	Saddlers oak	Quercus sadleriana	**5,2**	110	25	1	0
11400	Transportation and Utilities		7				
32096	California broom	Lotus scoparius	**5,3-2**	127	22	2	0
32229		Psorothamnus arborescens	**5,2-3**	127	22	2	0
32215		Psorothamnus emoryi	**5,2-3**	127	22	2	0
32230		Psorothamnus polydenius	**5,2-3**	127	22	2	0
41022	Smoke tree	Psorothamnus spinosa	**5,2-3**	127	22	2	0
41013	Valley oak	Quercus lobata	3	101	21	0	0
11100	Residential		7				
11600	Mixed Urban		7				
11700	Other Urban		7				
41005	Interior live oak	Quercus wislizenii	2	158	13	1	0
11200	Commercial and services		7				
41060	Black locust	Robinia pseudoacacia	3	50	12	2	0
32068	Interior live oak (Shrub form)	Quercus wislizenii	2	158	13	1	0
32143	Desert lavender	Hyptis emoryi	**5,2**	127	0	13	0
42043	Brewer spruce	Picea breweriana	1	191	10	2	0
32000	Unidentified chaparral shrubs		6	100	8	4	0
32104	Low sagebrush	Artemisia arbuscula	**5,2-3**	312	0	12	0
32302	California sagebrush	Artemisia californica	**5,2-3**	312	0	12	0
32108	Silver sagebrush	Artemisia cana	**5,2-3**	312	0	12	0
32109	Tarragon	Artemisia dracunculus	**5,2-3**	312	0	12	0
32110	Black sagebrush	Artemisia nova	**5,2-3**	312	0	12	0
32111	Rothrock sagebrush	Artemisia rothrockii	**5,2-3**	312	0	12	0
32112	Bud sagebrush	Artemisia spinescens	**5,2-3**	312	0	12	0
32103	Great basin sagebrush	Artemisia tridentata	**5,2-3**	312	0	12	0
32151	Regeneration shrubs	Artemisia tridentata, Chrysothamnus spp., etc.	**5,2-3**	312	0	12	0
32005	Coyote brush	Baccharis pilularis	**5,2**	192	0	12	0
32102	Rabbitbrush	Chrysothamnus nauseosus	**5,2**	168	0	12	0
32118	Rabbitbrush	Chrysothamnus parryi	**5,2**	168	0	12	0
32119	Rabbitbrush	Chrysothamnus viscidiflorus	**5,2**	168	0	12	0
32033	Mule fat	Baccharis salicifolia	**5,2**	127	0	12	0
41029	Sycamore	Platanus racemosa	3	52	11	0	0
41020	Fan palm	Washingtonia filifera	4	152	10	0	0
42012	Jeffrey pine	Pinus jeffreyi	1	91	0	4	5
42003	Coast redwood	Sequoia sempervirens	1	106	0	9	0
42027	Giant sequoia	Sequoiadendron giganteum	1	106	0	9	0
11500	Industrial and Commercial Complexes		7				
32305	White sage	Salvia apiana	**5,2-3**	250	0	8	0
32507	Desert sage	Salvia dorrii	**5,2-3**	250	0	8	0
32306	Purple sage	Salvia leucophylla	**5,2-3**	250	0	8	0
32307	Black sage	Salvia mellifera	**5,2-3**	250	0	8	0
32318	Pitcher sage	Salvia spathecea	**5,2-3**	250	0	8	0
42009	Sitka spruce	Picea sitchensis	1	191	4	1	0
42017	Mountain hemlock	Tsuga mertensiana	1	60	1	3	0
42005	Douglas fir	Pseudotsuga menziesii	1	55	1	3	0
42058	Western hemlock	Tsuga heterophylla	1	54	1	3	0

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GAP species code	Common name	Scientific name	Vegetation Class	specific leaf wt g dry leaf/m2 leaf	in-leaf season emission factor ug/g dry leaf wt/hr @ ref conditions		
				SLW	ISO	MONO	MBO
42915	Mid-elevation plantations		8	100	0	4	0
42951	Upper-elevation plantations		6	100	0	4	0
42026	Whitebark pine	Pinus albicaulis	1	91	0	4	0
42013	Knobcone pine	Pinus attenuata	1	91	0	4	0
42011	Foxtail pine	Pinus balfouriana	1	91	0	4	0
42029	Limber pine	Pinus flexilis	1	91	0	4	0
42053	Sugar pine	Pinus lambertiana	1	91	0	4	0
42028	Bristlecone pine	Pinus longaeva	1	91	0	4	0
42030	Single leaf pinyon	Pinus monophylla	1	91	0	4	0
42031	Western white pine	Pinus monticola	1	91	0	4	0
42010	Bishop pine	Pinus muricata	1	91	0	4	0
42040	Torrey pine	Pinus torreyana	1	91	0	4	0
42057	Washoe Pine	Pinus washoensis	1	91	0	4	0
11300	Industrial		7				
42052	Subalpine fir	Abies lasiocarpa	1	165	0	3	0
42045	Incense cedar	Calocedrus decurrens	1	106	0	3	0
22104	Dryland grain crops		8				
22200	Orchards, Vineyards, Nurseries		8				
22201	Evergreen orchard		8				
22202	Deciduous orchard		8				
22400	Other Agricultural Land		8				
22101	Irrigated row and field crops		8				
22100	Cropland and Pasture		8				
22203	Vineyard		8				
42033	Bristlecone fir	Abies bracteata	1	98	0	3	0
42022	White fir	Abies concolor	1	98	0	3	0
42051	Red fir	Abies magnifica	1	98	0	3	0
41033	Box elder	Acer negundo	3	92	0	3	0
42006	Grand fir	Abies grandis	1	72	0	3	0
41053	Mountain maple	Acer glabrum	3	59	0	3	0
41050	Bigleaf maple	Acer macrophyllum	3	59	0	3	0
42046	Noble fir	Abies procera	1	58	0	3	0
41032	California walnut	Juglans californica var. californica	3	57	0	3	0
41043	California black walnut	Juglans californica var. hindsii	3	57	0	3	0
32450	Vine maple	Acer circinatum	3	32	0	3	0
41016	Catclaw	Acacia greggii	**5,2**	240	0	2	0
41019	Mesquite	Prosopis glandulosa	3	215	0	2	0
41051	Screwbean	Prosopis pubescens	3	215	0	2	0
41017	Desert ironwood	Olneya tesota	3	145	0	2	0
32059	Chaparral Pea	Pickeringia montana	**5,2**	127	0	2	0
32018	Mountain whitethorn	Ceanothus cordulatus	**5,2-3**	127	0	2	0
32034	Hoaryleaf ceanothus	Ceanothus crassifolius	**5,2-3**	127	0	2	0
32003	Buckbrush	Ceanothus cuneatus	**5,2-3**	127	0	2	0
32421	Monterey ceanothus	Ceanothus cuneatus var. rigidus	**5,2-3**	127	0	2	0
32416	Cropleaf ceanothus	Ceanothus dentatus	**5,2-3**	127	0	2	0
32035	Desert ceanothus	Ceanothus greggii	**5,2-3**	127	0	2	0
32087		Ceanothus impressus	**5,2-3**	127	0	2	0
32072		Ceanothus incanus	**5,2-3**	127	0	2	0
32017	Deerbrush	Ceanothus integerrimus	**5,2-3**	127	0	2	0
32417	Muskbrush	Ceanothus jepsonii	**5,2-3**	127	0	2	0
32036	Chaparral whitethorn	Ceanothus leucodermis	**5,2-3**	127	0	2	0
32037	Bigpod ceanothus	Ceanothus megacarpus	**5,2-3**	127	0	2	0
32038	Hairy ceanothus	Ceanothus oliganthus	**5,2-3**	127	0	2	0
32042	Jimbrush	Ceanothus oliganthus var. sorediatus	**5,2-3**	127	0	2	0
32039	Palmer ceanothus	Ceanothus palmeri	**5,2-3**	127	0	2	0
32040	Wartleaf ceanothus	Ceanothus papillosus	**5,2-3**	127	0	2	0
32420	Littleleaf ceanothus	Ceanothus parvifolius	**5,2-3**	127	0	2	0
32041	Squaw carpet	Ceanothus prostratus	**5,2-3**	127	0	2	0
32043	Greenbark ceanothus	Ceanothus spinosus	**5,2-3**	127	0	2	0
32095	Ceanothus	Ceanothus spp.	**5,2-3**	127	0	2	0
32422	Bluebrush, Wild lilac	Ceanothus thyrsiflorus	**5,2-3**	127	0	2	0
32071	Woolyleaf ceanothus	Ceanothus tomentosus	**5,2-3**	127	0	2	0
32002	Tobacco brush	Ceanothus velutinus	**5,2-3**	127	0	2	0
32044	Wartystem ceanothus	Ceanothus verrucosus	**5,2-3**	127	0	2	0
32016		Lupinus albicaulus	**5,herb.**	127	0	2	0
32013		Lupinus albifrons	**5,herb.**	127	0	2	0
32022	Yellow bush lupine	Lupinus arboreus	**5,herb.**	127	0	2	0
32012	Bush lupine	Lupinus chamissonis	**5,herb.**	127	0	2	0
32321	Grape soda lupine	Lupinus excubitus	**5,herb.**	127	0	2	0
32323		Lupinus spp.	**5,herb.**	127	0	2	0
32216		Caesalpina virgata	**5,3-2**	91	0	2	0

GAP species code	Common name	Scientific name	Vegetation Class	specific leaf wt g dry leaf/m2 leaf	in-leaf season emission factor ug/g dry leaf wt/hr @ ref conditions		
				SLW	ISO	MONO	MBO
42039	Sargent cypress	Cupressus sargentii	1	127	0	1	0
41044	Tanoak	Lithocarpus densiflorus	2	127	0	1	0
42035	Monterey pine	Pinus radiata	1	91	0	1	0
42019	California juniper	Juniperus californica	1	86	0	1	0
42055	Western juniper	Juniperus occidentalis	1	86	0	1	0
42063	Sierra juniper	Juniperus occidentalis australis	1	86	0	1	0
42054	Utah juniper	Juniperus osteosperma	1	86	0	1	0
42062	Western red cedar	Thuja plicata	1	56	0	1	0
42007	Bigcone spruce	Pseudotsuga macrocarpa	1	55	0	1	0
32322		Eriophyllum staechadifolium	**5,2 herb**	127	0	0	0
41056	California wax myrtle	Myrica californica	**5,2**	345	0	0	0
32074	Sugarbush	Rhus ovata	**5,2**	323	0	0	0
32117	Allscale saltbush	Atriplex polycarpa	**5,3**	256	0	0	0
32454	Beargrass	Xerophyllum tanex	**6, grass**	244	0	0	0
32452	Boxleaf silktassel	Garrya buxifolia	**5,2**	223	0	0	0
32435	Silktassel	Garrya elliptica	**5,2**	223	0	0	0
32050	Pale silktassel	Garrya flavescens	**5,2**	223	0	0	0
32051	Fremont silktassel	Garrya fremontii	**5,2**	223	0	0	0
32052	Veatch silktassel	Garrya veatchii	**5,2**	223	0	0	0
32207	Shadscale	Atriplex confertifolia	**5,2-3**	188	0	0	0
32114	Desert holly	Atriplex hymenolytra	**5,2-3**	188	0	0	0
32115	Lenscale	Atriplex lentiformis	**5,2-3**	188	0	0	0
32116	Saltbush	Atriplex parryi	**5,2-3**	188	0	0	0
32144	Triangle leaf	Atriplex phyllostegia	**5,2-3**	188	0	0	0
32105	Saltbush	Atriplex spp.	**5,2-3**	188	0	0	0
32062	Lemonade berry	Rhus integrifolia	**5,2-3**	183	0	0	0
32501	Skunkbrush	Rhus trilobata	**5,2-3**	183	0	0	0
32094	Scrub oak	Quercus berberidifolia, etc.	2	149	31	0	0
32444	Western azalea	Rhododendron occidentalis	**5,3**	147	0	0	0
41011	California bay	Umbellularia californica	2	145	0	0	0
41018	Joshua tree	Yucca brevifolia	**5,2**	145	0	0	0
32136	Mohave yucca	Yucca schidigera	**5,2**	145	0	0	0
32064	Our lords candle	Yucca whipplei	**5,2**	145	0	0	0
32328	Hawthorn	Craetaegus douglasii	3	133	0	0	0
32049	Fremontia or Flannel bush	Fremontodendron californicum	**5,3**	127	0	0	0
32009	Monkshood	Aconitum columbianum	**5, 3 herb**	127	0	0	0
31048	Arizona three-awn	Aristida hamulosa	**5, grass**	127	0	0	0
31033	Balsam root	Balsamorhiza sagittata	**5, grass**	127	0	0	0
32415	Barbarry	Berberis nervosa	**5,3**	127	0	0	0
31029	Japanese brome (exotic)	Bromus japonicus	**5, grass**	127	0	0	0
31026	Cheatgrass (exotic)	Bromus tectorum	**5, grass**	127	0	0	0
32221	Crucifixion Thorn	Castela emoryi	5	127	0	0	0
31052	Star thistle	Centaurea spp.	**5, 3 herb**	127	0	0	0
32504	Fern bush, desert sweet	Chamaebatiaria millefolium	**5,2-3**	127	0	0	0
32045	Virgins bower	Clematis ligusticifolia	**5, 3 herb**	127	0	0	0
32083	Giant coreopsis	Coreopsis gigantea	**5, herb**	127	0	0	0
32425	Scotchbroom	Cytisus scoparius	**5, 3**	127	0	0	0
31031	One-spike oatgrass	Danthonia unispicata	**5, grass**	127	0	0	0
31054	Pitcher plant bogs	Darlingtonia bogs	**5, 3 herb**	127	0	0	0
31015	California poppy	Eschscholtzia californica	**5, 3 herb**	127	0	0	0
32138		Forestiera neomexicana	**5, 2-3 herb**	127	0	0	0
31032	Wood strawberry	Fragaria vesca	**5, 3 herb**	127	0	0	0
32091	Peak rush-rose	Helianthemum scoparium	**5, 3 herb**	127	0	0	0
31023	Foxtail barley	Hordeum jubatum	**5, grass**	127	0	0	0
32149	Bladderpod	Isomeris arborea	**5,3-2**	127	0	0	0
31044	Desert dandelion	Malacothrix glabrata	**5, 3 herb**	127	0	0	0
32145		Menodora spinescens	**5, 2-3 herb**	127	0	0	0
31024		Nitrophila occidentalis	**5,herb**	127	0	0	0
32228		Nolina parryi	**5,herb**	127	0	0	0
31027	Reed canary grass (exotic)	Phalaris arundinacea	**5, grass**	127	0	0	0
31035	Sandbergs bluegrass	Poa secunda	**5, grass**	127	0	0	0
31051	Water smartweed	Polygonum amphibium	**5, 3 herb**	127	0	0	0
32432		Polygonum davisiae	**5, 3 herb**	127	0	0	0
32509		Ribes aureum	**5,3**	127	0	0	0
32431	Squaw or wax currant	Ribes cereum	**5,3**	127	0	0	0
32442	Sierra gooseberry	Ribes roezlii	**5,3**	127	0	0	0
32511		Ribes spp.	**5,3**	127	0	0	0
32010	Currant	Ribes velutinum	**5,3**	127	0	0	0
32441	Sticky currant	Ribes viscossimum	**5,3**	127	0	0	0
32503	Wood rose	Rosa gymnocarpa	**5,3**	127	0	0	0
31021	Bulrush	Scirpus robustus	**5,herb**	127	0	0	0

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GAP species code	Common name	Scientific name	Vegetation Class	specific leaf wt g dry leaf/m2 leaf SLW	in-leaf season emission factor ug/g dry leaf wt/hr @ ref conditions ISO	MONO	MBO
32001	Chamise	Adenostoma fasciculatum	**5,2**	127	0	0	0
32026	Redshanks	Adenostoma sparsifolium	**5,2**	127	0	0	0
32213		Agave deserti	**5,herb**	127	0	0	0
22600	Great Basin dry farmed grain/rural	Agropyron desertorum, Elyrigia epens, etc.	5	127	0	0	0
41059	Tree of heaven	Ailanthus altissima	3	127	0	0	0
32209	Iodine bush	Allenrolfea occidentalis	**5,3-2**	127	0	0	0
32210	Burro-weed (a ragweed)	Ambrosia dumosa	**5, herb**	127	0	0	0
31055	European beachgrass	Ammophila arenaria	**5, grass**	127	0	0	0
41007	Madrone	Arbutus menziesii	2	127	0	0	0
32402	Manzanita	Arctostaphylos auriculata	**5,2**	127	0	0	0
32403	Hoary manzanita	Arctostaphylos canescens	**5,2**	127	0	0	0
32456	Hairy manzanita	Arctostaphylos columbiana	**5,2**	127	0	0	0
32027	Eastwood manzanita	Arctostaphylos glandulosa	**5,2**	127	0	0	0
32028	Bigberry manzanita	Arctostaphylos glauca	**5,2**	127	0	0	0
32404	Common manzanita	Arctostaphylos manzanita	**5,2**	127	0	0	0
32406	Indian manzanita	Arctostaphylos mewukka	**5,2**	127	0	0	0
32447	Morro manzanita	Arctostaphylos morroensis	**5,2**	127	0	0	0
32089	Ione manzanita	Arctostaphylos myrtifolia	**5,2**	127	0	0	0
32407	Pinemat manzanita	Arctostaphylos nevadensis	**5,2**	127	0	0	0
32408	Eldorado manzanita	Arctostaphylos nissenana	**5,2**	127	0	0	0
32409	Littleberry manzanita	Arctostaphylos nummularia	**5,2**	127	0	0	0
32029	Serpentine manzanita	Arctostaphylos obispoensis	**5,2**	127	0	0	0
32030	Parry manzanita	Arctostaphylos parryana	**5,2**	127	0	0	0
32004	Greenleaf manzanita	Arctostaphylos patula	**5,2**	127	0	0	0
32446	Pecho manzanita	Arctostaphylos pechoensis	**5,2**	127	0	0	0
32410	La panza manzanita	Arctostaphylos pilosula	**5,2**	127	0	0	0
32075	Pink-bracted manzanita	Arctostaphylos pringlei	**5,2**	127	0	0	0
32069	Mexican manzanita	Arctostaphylos pungens	**5,2**	127	0	0	0
32031	Purisima manzanita	Arctostaphylos purissima	**5,2**	127	0	0	0
32055	Refugio manzanita	Arctostaphylos refugioensis	**5,2**	127	0	0	0
32412	Shagbark manzanita	Arctostaphylos rudis	**5,2**	127	0	0	0
32451	Manzanita spp.	Arctostaphylos spp.	**5,2**	127	0	0	0
32032	Woollyleaf manzanita	Arctostaphylos tomentosa	**5,2**	127	0	0	0
32405	Mariposa manzanita	Arctostaphylos viscida var. mariposa	**5,2**	127	0	0	0
32414	Whiteleaf manzanita	Arctostaphylos viscida var. viscida	**5,2**	127	0	0	0
32008	Santa Cruz manzanita	Arctostaphylus andersonii	**5,2**	127	0	0	0
31011	Giant Reed	Arundo donax	**5, herb**	127	0	0	0
31001	Non-native annual grassland	Avena spp., Bromus spp., etc.	**5, grass**	39	0	0.02	0
31010	Wild Mustard	Brassica ssp.	**5, herb**	127	0	0	0
31017	Great Basin bunchgrass vegetation	Bromus tectorum, Festuca idahoensis, etc.	**5, grass**	39	0	0.02	0
31016	Great Basin annual grasses	Bromus tectorum, Taenian therum caput-medusae,	**5, grass**	39	0	0.02	0
31043		Carex nebrascensis	**5, herb**	127	0	0	0
31059	Great Basin wet meadow spp.	Carex spp., Juncus spp.,etc.	**5, herb**	127	0	0	0
31007	Freshwater Sedge - Rush marsh	Carex spp., Juncus, spp.,	**5, herb**	127	0	0	0
32020	Mountain misery	Chamaebatia foliolosa	**5,2**	127	0	0	0
32208	Blackbush	Coleogyne ramosissima	5	127	0	0	0
31020	Pampas grass	Cortaderia jubata	**5, grass**	127	0	0	0
32046	Bush poppy	Dendromecon rigida	**5, herb**	127	0	0	0
31012	Saltgrass	Distichlis spicata	**5, grass**	127	0	0	0
32303	California encelia	Encelia californica	**5,2-3**	127	0	0	0
32120	Brittlebush	Encelia farinosa	**5,2-3**	127	0	0	0
32140	California ephedra	Ephedra californica	**5, herb**	127	0	0	0
32121	Mormon tea	Ephedra nevadensis	**5, herb**	127	0	0	0
32122	Green ephedra	Ephedra viridis	**5, herb**	127	0	0	0
31056		Erharta calycina	5	127	0	0	0
32434	Goldenfleece	Ericameria arborescens	**5,2-3**	127	0	0	0
32502	Goldenbush	Ericameria bloomeri	**5,2-3**	127	0	0	0
32311	Heather goldenbush	Ericameria ericoides	**5,2-3**	127	0	0	0
32127	Narrowleaf goldenbush	Ericameria linearifolius	**5,2-3**	127	0	0	0
32224	Coopers goldenbrush	Ericamerica cooperi	**5,2-3**	127	0	0	0
32139	Ericamerica	Ericamerica spp.	**5,2-3**	127	0	0	0
32047	Yerba santa	Eriodictyon californicum	**5,2**	127	0	0	0
32090	Lompoc yerba santa	Eriodictyon capitatum	**5,2**	127	0	0	0
32048	Thick leafed yerba santa	Eriodictyon crassifolium	**5,2**	127	0	0	0
32025		Eriodictyon tomentosum	**5,2**	127	0	0	0
32084		Eriodictyon trichocalyx	**5,2**	127	0	0	0
32309	Ashyleaf buckwheat	Eriogonum cinerium	**5,herb**	127	0	0	0
32438	Flat-topped buckwheat	Eriogonum deflexum	**5,herb**	127	0	0	0
32301	California buckwheat	Eriogonum fasciculatum	**5,herb**	127	0	0	0
32325		Eriogonum fasciculatum var. fasciculatum	**5,herb**	127	0	0	0
32324		Eriogonum fasciculatum var. polifolium	**5,herb**	127	0	0	0

GAP species code	Common name	Scientific name	Vegetation Class	specific leaf wt g dry leaf/m2 leaf	in-leaf season emission factor ug/g dry leaf wt/hr @ ref conditions		
				SLW	ISO	MONO	MBO
32076	Toyon	Heteromeles arbutifolia	**5,2**	127	0	0	0
32128	White burrobush	Hymenoclea salsola	5	127	0	0	0
32326		Isocoma menziesii var. vernioides	**5,2-3**	127	0	0	0
31022	Rush	Juncus balticus	**5, herb**	127	0	0	0
31005	Wet meadow Sedge - Rush	Juncus spp., Eleocharis spp.,etc.	**5, herb**	127	0	0	0
32099		Keckiella cordifolia	5	127	0	0	0
32223	Winterfat	Krascheninnikovia lanata	**5,2-3**	127	0	0	0
32201	Creosote	Larrea tridentata	**5,2**	127	0	0	0
32131	Scalebroom	Lepidospartum squamatum	**5, herb**	127	0	0	0
32098	Prickly flox	Leptodactylon californicum	**5, herb**	127	0	0	0
32056	Granite gilia	Leptodactylon pungens	**5, herb**	127	0	0	0
31018	Great Basin Alkali sink grasses	Leymus cinereus, Distichlis spicata, etc.	**5,herb**	127	0	0	0
32063	Laurel sumac	Malosma laurina	**5,2**	127	0	0	0
31057	Sphagnum bog species	Menyanthes trifoliata, Sphagnum squarrosum, etc.	**5, herb**	127	0	0	0
31014	Ice plant	Mesembryanthemum spp.	**5, herb**	127	0	0	0
32086		Mimulus aurantiacus	**5, herb**	127	0	0	0
32445	Alpine cushion plants	Misc alpine shrubs	**5, herb**	127	0	0	0
31047	Purple needlegrass	Nassella pulchra	**5, grass**	127	0	0	0
41045	Tree tobacco	Nicotiana glauca	**5, herb**	127	0	0	0
32218	Buckhorn cholla	Opuntia acanthocarpa	**5, herb**	127	0	0	0
32204	Jumping cholla	Opuntia biglovii	**5, herb**	127	0	0	0
32217	Golden cholla	Opuntia echinocarpa	**5, herb**	127	0	0	0
32079	Prickly pear	Opuntia littoralis	**5, herb**	127	0	0	0
32212	Pencil cactus	Opuntia ramosissima	**5, herb**	127	0	0	0
32226	Mixed succulents	Opuntia spp., Ferocactus spp., Echinocereus sp	**5, herb**	127	0	0	0
31013	Galleta	Pleuraphis rigida	**5, grass**	127	0	0	0
32202	Arrowweed	Pluchea sericea	**5,3 herb**	127	0	0	0
22500	Great Basin pasture/grainfield	Poa pratensis, Agropyron desertorum, etc.	**5, grass**	127	0	0	0
31046	Braken	Pteridium aquilinum	**5, herb**	127	0	0	0
32101	Antelope bush	Purshia tridentata	**5,2-3**	127	0	0	0
31003	Estuarine emergent wetland	Salicornia virginica, Suaeda californica, etc.	**5, herb**	127	0	0	0
31038	Russian thistle or tumbleweed	Salsola tragus	**5, herb**	127	0	0	0
32015	Blue elderberry	Sambucus mexicana	**5,3**	127	0	0	0
32449	Red elderberry	Sambucus racemosa	**5,3**	127	0	0	0
32448	Elderberry spp.	Sambucus spp.	**5,3**	127	0	0	0
31045	Apricot mallow	Sphaeralcea ambigua	**5, herb**	127	0	0	0
31042	Alkali sacaton	Sporobolus airoides	**5, grass**	127	0	0	0
31002	Native perennial grassland	Stipa spp., Elymus spp., etc.	**5, grass**	39	0	0.02	0
31028	Medusaehead (exotic)	Taeniantherum caput-medusae	6	127	0	0	0
41023	Tamarisk	Tamarix spp.	**3,2,5**	127	0	0	0
32021	Poison oak	Toxicodendron diversilobum	**5,3**	127	0	0	0
31008	Freshwater Sedge-Cat-tail marsh	Typha spp., Carex spp., etc.	**5, herb**	127	0	0	0
31025	Mules ears	Wyethia mollis	**5, herb**	127	0	0	0
32070		Xylococcus bicolor	**5,2-3**	127	0	0	0
32011	Mountain mahogany	Cercocarpus betuloides	**5,2**	123	0	0	0
32106	Mountain mahogany	Cercocarpus ledifolius	**5,2**	123	0	0	0
32113	Four-wing saltbush	Atriplex canescens	**5,2-3**	119	0	0	0
22300	Confined Feeding Operations		8				
22102	Irrigated hayfield		8				
22105	Rice fields		8				
22106	Pasture		8	93	0	0	0
31049	Ruderal spp.		6	93	0	0	0
31060	Northern hardpan vernal pool spp.		6	93	0	0	0
31061	Northern claypan vernal pool spp.		6	93	0	0	0
32007	Rhododendron	Rhododendron macrophyllum	**5,2**	93	0	0	0
32135	Greasewood	Sarcobatus vermiculatus	**5,2**	93	0	0	0
22700	Reclaimed Lakebed/Waterfowl mgmt/ag	Scirpus spp., Typha spp., and cultivated grain	**5, herb**	93	0	0	0
42049	Parry pinyon	Pinus quadrifolia	1	91	0	0	0
32023	Salal	Gaultheria shallon	**5,3 herb**	90	0	0	0
41026	Buckeye	Aesculus californica	3	88	0	0	0
41014	White alder	Alnus rhombifolia	3	86	0	0	0
32401	Seviceberry	Amelanchier utahensis	**3,5**	81	0	0	0
32060	Western choke cherry	Prunus virginiana	3	78	0	0	0
32423	Western redbud	Cercis occidentalis	**5,3**	77	0	0	0
41037	Desert willow	Chilopsis linearis	3	77	0	0	0
41054	Water Birch	Betula occidentalis	3	76	0	0	0
32078	Flowering ash	Fraxinus dipetala	3	72	0	0	0
41040	Oregon ash	Fraxinus latifolia	3	72	0	0	0
32510	Desert peach	Prunus andersonii	3	72	0	0	0
41049	Bitter cherry	Prunus emarginata	3	72	0	0	0
32082	Bitter cherry (Shrub form)	Prunus emarginata	3	72	0	0	0

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GAP species code	Common name	Scientific name	Vegetation Class	specific leaf wt g dry leaf/m2 leaf	in-leaf season emission factor ug/g dry leaf wt/hr @ ref conditions		
				SLW	ISO	MONO	MBO
41057	Pacific dogwood	Cornus nuttallii	**3,5**	57	0	0	0
32429	Snowberry	Symphoricarpos rotundifolius	**5,3**	56	0	0	0
32058	Southern honeysuckle	Lonicera subspicata	**5,3**	56	0	0	0
32077	Coffeeberry	Rhamnus californica	**5,3-2**	56	0	0	0
32316	Redberry buckthorn	Rhamnus crocea	**5,3-2**	56	0	0	0
32327	Cascara	Rhamnus purshiana	**5,3-2**	56	0	0	0
32081	Snowberry	Symphoricarpos mollis	**5,3**	56	0	0	0
32053	Ocean spray or Cream bush	Holodiscus discolor	**5,3**	48	0	0	0
32054	Cream bush	Holodiscus microphyllus	**5,3**	48	0	0	0
32430	Huckleberry	Vaccinium ovatum	**5,3**	39	0	0	0
32457	Thimbleberry	Rubus parviflorus	**5,3**	37	0	0	0
32014	California blackberry	Rubus ursinus	**5,3**	37	0	0	0
31058	Northern basalt vernal pool spp.		6	0	0	0	0
31062	Misc. vernal pool spp.		6	0	0	0	0
78000	Mud Flats		6	0	0	0	0
99200	Glaciers		6	0	0	0	0
55400	Bays and estuaries		6	0	0	0	0
77100	Dry Salt Flats		6	0	0	0	0
77200	Beaches		6	0	0	0	0
77300	Sandy areas other than beaches		6	0	0	0	0
55300	Reservoirs		6	0	0	0	0
55210	Intermittent lake		6	0	0	0	0
77401	Bare exposed lava		6	0	0	0	0
77500	Quarries, and gravel pits		6	0	0	0	0
99100	Perennial snowfields		6	0	0	0	0
55310	Intermittent reservoir		6	0	0	0	0
77400	Bare exposed rock		6	0	0	0	0
77600	Transitional bare areas		6	0	0	0	0
77700	Mixed barren land		6	0	0	0	0
77701	Badlands		6	0	0	0	0
55200	Lakes		6	0	0	0	0
55100	Streams and canals		6	0	0	0	0

Vegetation class

1=conifer
2=broadleaf evergreen
3=broadleaf deciduous
4=palm
5=shrub; "5, 2" = shrub, broadleaf evergreen
5=shrub; "5, 2-3" = shrub, broadleaf evergreen to broadleaf deciduous if cold or water stressed
5=shrub; "5, 3-2" = shrub, basically deciduous but can be evergreen if conditions favorable
"5, herb"=herbaceous (rather than woody) shrub
"5, grass" = grass
6=unknown
7=urban land use
8=ag land use

Table 2. Crop BVOC (isoprene, monoterpenes) emission factors (ug g^{-1} [dry leaf weight] hr^{-1}) at standard conditions (30 C, 1000 umole PAR m^{-2} s^{-1})
Emission factor assignment types: 1 (measured species); 2 (genus average); 3 (family average); 4 (crop class average); 5 (no emission factor assigned)
SLW: Specific Leaf Weight (g [dry leaf weight] m^{-2} leaf area)

Crop Code	Class	Subclass	Species	Family	Isoprene	Monoterpenes	BVOC assignment type	BVOC reference	SLW
G 1	Grain & Hay Crops	barley	Elyhordeum sp.	Poaceae	0.010	0.010	1	h	37.00
G 2		wheat	Triticum sp.	Poaceae	0.000	0.000	1	k	33.70
G 3		oats	Avena sp.	Poaceae	0.010	0.020	1	h	39.00
G 6		misc. & mixed grain and hay		Poaceae	0.007	0.010	3	r	36.57
R	Rice	rice	Oryza sp.	Poaceae	0.000	0.000	1	k	37.00
F 1	Field Crops	cotton	Gossypium hirsutum	Malvaceae	0.000	0.700	1	k	69.44
F 2		safflower	Carthamus tinctorius	Asteraceae	0.000	0.030	1	k	33.30
F 3		flax	Linum usitatissimum	Linaceae			5		33.30
F 4		hops	Humulus lupulus	Cannabaceae	0.000	0.000	1	i	77.00
F 5		sugar beets	Beta vulgaris	Chenopodiaceae	0.000	0.000	1	e	75.00
F 6		corn (field & sweet)	Zea mays	Poaceae	0.000	0.030	2	n	67.00
F 7		grain sorghum	Sorghum bicolor	Poaceae	0.000	0.030	1	k	67.00
F 8		sudan	Sorghum bicolor	Poaceae	0.000	0.030	2	n	67.00
F 9		castor beans	Ricinus communis	Euphorbiaceae	0.000	0.000	1	i	67.00
F10		beans (dry)	Phaseolus vulgaris	Fabaceae	0.000	0.000	2	p	28.25
F11		misc. field			0.000	0.077	4		56.14
F12		sun flowers	Helianthus sp.	Asteraceae	0.000	0.030	3	m	33.30
P 1	Pasture	alfalfa mix	Medicago sativa	Fabaceae	0.000	0.200	1	k	34.30
P 2		clover	Trifolium repens	Fabaceae	0.000	0.000	1	d	22.20
P 3		mixed pasture		Poaceae	0.000	0.020	1	l	39.00
P 4		native pasture		Poaceae	0.000	0.020	1	l	39.00
P 5		induced high water table native pasture		Poaceae	0.000	0.020	1	l	39.00
P 6		misc. grasses		Poaceae	0.000	0.020	1	l	39.00
P 7		turf farms	Fescue sp	Poaceae	0.000	0.000	1	e	39.00
T 1	Truck, Nursery & Berry Crops	artichokes	Cynara scolymus	Asteraceae	0.000	0.030	3	m	33.30
T 2		asparagus	Asparagus officinalis	Liliaceae	0.000	0.000	1	i	123.30
T 3		green beans	Phaseolus vulgaris	Fabaceae	0.000	0.000	1	k	28.25
T 4		colecrops	Brassica sp.	Cruciferae	0.000	0.000	1	e	144.30
T 6		carrots	Daucus carota	Umbelliferae	0.000	0.900	1	k	70.00
T 7		celery	Apium graviolens	Umbelliferae	0.000	0.900	3	q	70.00
T 8		lettuce	Latuca sativa	Asteraceae	0.000	0.000	1	j	49.30
T 9		melons, squash, cucumbers		Cucurbitaceae			5		85.47
T10		onion, garlic	Allium sp.	Amaryllidaceae, Liliaceae	0.000	0.000	1	j	123.30
T11		peas	Pisum sativum	Fabaceae	0.000	0.000	3	p	28.25
T12		potatoes	Solanum tuberosum	Solanaceae	0.000	0.010	1	g	35.00
T13		sweet potatoes	Ipomoea batatas	Convolvulaceae			5		35.00
T14		spinach	Spinacia oleracea	Chenopodiaceae	0.000	0.000	3	o	144.30
T15		tomatoes	Lycopersicon esculentum	Solanaceae	0.000	20.000	1	k	80.22
T16		flower, nursery, Christmas tree farm					5		
T17		mixed			0.004	1.447	4		83.08
T18		misc. truck			0.004	1.447	4		83.08
T19		bushberries	Rubus ursinus	Rosaceae	0.080	0.000	1	c	37.31
T20		strawberries	Fragaria sp.	Rosaceae	0.000	0.000	1	e	82.99

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C 1	Citrus	grapefruit	Citrus paradisi	Rutaceae	0.000	1.500	2	a	140.74	nn
C 2	and Subtropical	lemons	Citrus limonia	Rutaceae	0.000	1.500	2	a	140.74	nn
C 3		oranges	Citrus sinensis	Rutaceae	0.000	0.900	2	a	140.74	nn
C 4		dates	Phoenix dactylifera	Arecaceae	15.800	0.000	1	a	290.00	mm
C 5		avocados	Persea americana	Lauraceae	0.000	0.000	1	a	73.39	nn
C 6		olives	Olea europea	Oleaceae	0.000	0.300	1	a	78.34	nn
C 7		misc. subtropical			8.089	1.489	4		143.95	Subtropical average
C 8		kiwis	Actinidia deliciosa	Actinidiaceae			5		77.00	oo
C 9		jojoba	Simmondsia chinensis	Buxacea	0.000	0.000	1	i	225.00	tt
C10		eucalyptus	Eucalyptus sp.	Myrtaceae	57.000	9.200	2	b	129.60	nn
V 1	Vineyards	table grape	Vitis vinifera	Vitaceae	0.000	0.000	1	k	66.18	nn
V 2		wine grape	Vitis vinifera	Vitaceae	0.002	0.002	1	f	66.18	nn
V 3		raisin grape	Vitis vinifera	Vitaceae	0.000	0.000	1	k	66.18	nn
I	Idle	idle		Poaceae	0.000	0.020	3	l	39.00	gg
I 2		idle		Poaceae	0.000	0.020	3	k	39.00	gg

BVOC emission factor reference

a	Benjamin et al. 1996
b	Benjamin et al. 1996 (E. globus)
c	Drewitt et al. 1998
d	Flyckt et al. 1980
e	Hewett and Street 1992
f	Koenig et al. 1995
g	Lamb et al. 1993
h	Lamb et al. 1993 and Pierce et al. 1998
i	Rassmussen 1978
j	Winer et al. 1989
k	Winer et al. 1992
l	Winer et al. 1992 ("grasslands, annual")
m	Winer et al 1992 (safflower)
n	Winer et al 1992 (sorghum)
o	Winer et al. 1989 (beet); Hewitt and Street 1992
p	Winer et al. 1992 (bean)
q	Winer et al. 1992 (carrot)
r	Winer et al. 1992 (wheat)

Specific Leaf Weight (SLW) factor reference

aa	Cao and Tibbitts 1997
bb	Clark et al. 1997
cc	Cole 1974
dd	Danalatos et al. 1994
ee	de la Rosa et al. 2000, sunflower surrogate
ff	de la Rosa et al. 2000
gg	Garnier et al. 1997
hh	Garnier et al. 1997, grass surrogate
ii	Jovanovic et al. 1999
jj	Jovanovic et al. 1999, cabbage surrogate
kk	Jovanovic et al. 1999, carrot surrogate
ll	Jovanovic et al. 1999, lettuce surrogate
mm	Miller and Winer 1984
nn	Nowak 1998
oo	Nowak 1998, structural class
pp	Nowak 1998, Rosaceae average
qq	Nowak 1998, tomato surrogate
rr	Rebetzke and Richards 1999
ss	Robinson et al. 1992.
tt	Wardlaw et al. 1983

Table 3. GAP regional urban land use reference BVOC emission rates.

GAP urban land use code	Description	Urban land use reference BVOC emission rates					
		Isoprene (mg/m2/hr)			Monoterpene (mg/m2/hr)		
		Oakland	Sacramento	Fresno	Oakland	Sacramento	Fresno
11100	residential	1.91	1.28	0.31	0.27	0.76	0.16
11200	commercial + services	0.23	0.00	0.05	0.04	0.29	0.01
11300	industrial	0.23	0.00	0.05	0.04	0.29	0.01
11400	transportation + utilities	1.34	0.01	0.05	0.22	0.00	0.01
11500	industrial and commercial complexes	0.23	0.00	0.05	0.04	0.29	0.01
11600	mixed urban	2.00	1.04	0.11	0.28	0.67	0.05
11700	other urban	2.00	1.04	0.11	0.28	0.67	0.05

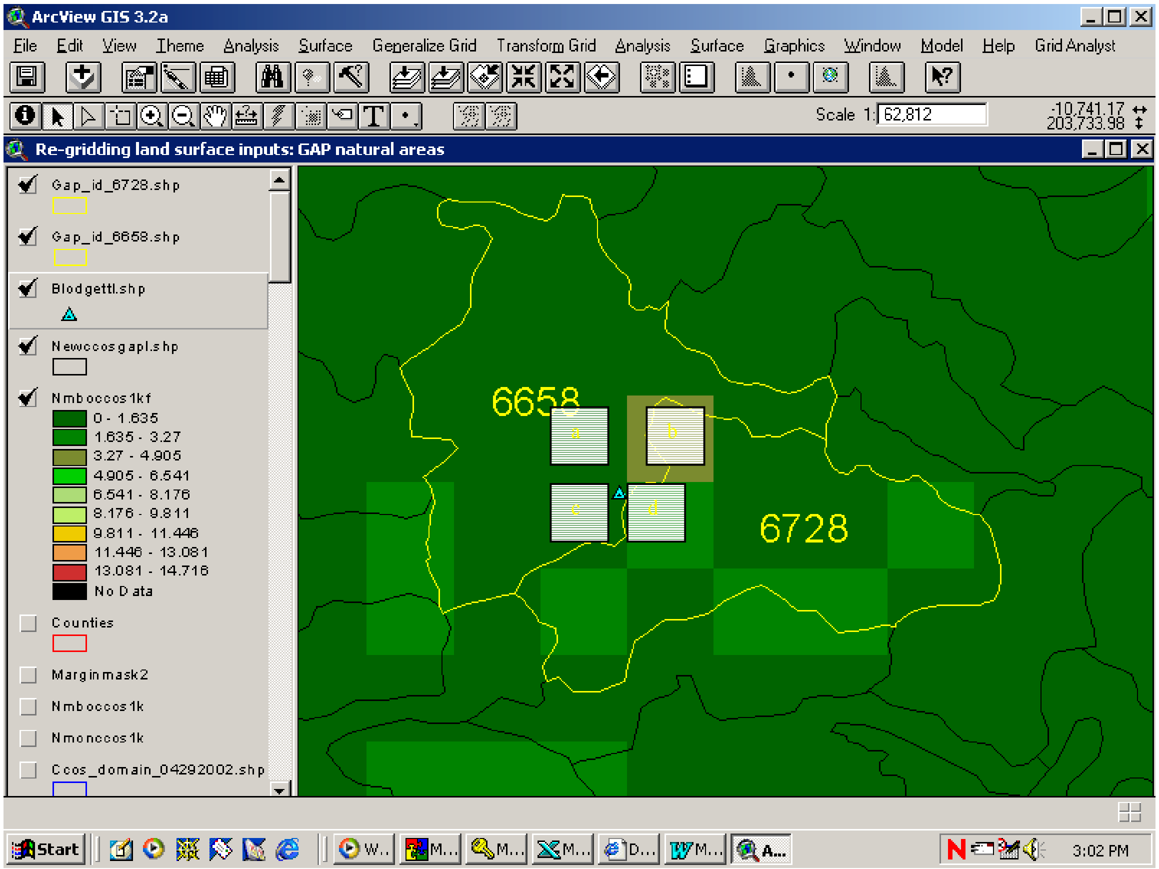

Figure 1. Blodgett Forest research site (triangle symbol). Site is near edge of BEIGIS model GAP polygons 6658 and 6728, and the nexus of four 1 x 1 km BEIGIS model grid cells (labeled A through D).

Table 4. Canopy-scale reference BVOC emission rates for BEIGIS grid cells A and C, derived from emission factor, specific leaf weight, GAP land cover and satellite LAI inputs

GAP polygon ID 6658

Primary assemblage

		Emission Factor[2]			Primary Assemblage	Co-species	Satellite LAI[3]		Leafmass Density[4]		Emission Rate[5]: cell A			Emission Rate[5]: cell C		
Species	SLW[1]	MON	MBO	ISO	Fractional Cover	Weighting	cell A	cell C	cell A	cell C	MON	MBO	ISO	MON	MBO	ISO
Pinus ponderosa	91	4	25	0	0.45	0.333	1.4	1.4	19	19	0.08	0.48	0	0.08	0.48	0
Abies concolor	98	3	0	0	0.45	0.333	1.4	1.4	21	21	0.06	0	0	0.06	0	0
Quercus kelloggii	103	1	0	54	0.45	0.333	1.4	1.4	22	22	0.02	0	1.17	0.02	0	1.17

Secondary assemblage

		Emission Factor			Secondary Assemblage	Co-species	Satellite LAI		Leafmass Density		Emission Rate: cell A			Emission Rate: cell C		
Species	SLW	MON	MBO	ISO	Fractional Cover	Weighting	cell A	cell C	cell A	cell C	MON	MBO	ISO	MON	MBO	ISO
Pinus lambertiana	91	4	0	0	0.25	0.333	1.4	1.4	11	11	0.04	0	0	0.04	0	0
Pinus ponderosa	91	4	25	0	0.25	0.333	1.4	1.4	11	11	0.04	0.27	0	0.04	0.27	0
Pseudotsuga menziesii.	55	3	0	1	0.25	0.333	1.4	1.4	6	6	0.02	0	0.01	0.02	0	0.01

Tertiary assemblage

		Emission Factor			Secondary Assemblage	Co-species	Satellite LAI		Leafmass Density		Emission Rate: cell A			Emission Rate: cell C		
Species	SLW	MON	MBO	ISO	Fractional Cover	Weighting	cell A	cell C	cell A	cell C	MON	MBO	ISO	MON	MBO	ISO
Ceanothus integerrimus	127	2	0	0	0.35	0.5	1.4	1.4	31	31	0.06	0	0	0.06	0	0
Arctostaphylos viscida	127	0	0	0	0.35	0.5	1.4	1.4	31	31	0	0	0	0	0	0
NA	NA	NA	NA	NA	NA	NA										

Total LMD		Total Emission Rate: cell A			Total Emission Rate: cell C		
cell A	cell C	MON	MBO	ISO	MON	MBO	ISO
151	151	0.33	0.74	1.17	0.33	0.74	1.17

[1] Specific Leaf Weight, g dry leaf weight/m^2 leaf

[2] MON: ug monoterpene/g dry leaf weight/hr, MBO: ug Carbon/g dry leaf weight/hr, ISO: ug isoprene/g dry leaf weight/ at reference conditions 30 C and 1000 micromoles/m^2/s PAR

[3] Leaf Area Index, m^2 leaf area/m^2 land area

[4] LMD, g dry leaf weight/m^2 land area

[5] MON: mg monoterpene/m^2 land/hr, MBO: mg Carbon/m^2 land/hr, ISO: mg isoprene/m^2 land/hr, at reference conditions.

Table 5. Canopy-scale reference BVOC emission rates for BEIGIS grid cells B and D, derived from emission factor, specific leaf weight, GAP land cover and satellite LAI inputs

GAP polygon ID 6728

Primary assemblage

		Emission Factor[2]			Primary Assemblage	Co-species	Satellite LAI[3]		Leafmass Density[4]		Emission Rate[5]: cell B			Emission Rate[5]: cell D		
Species	SLW[1]	MON	MBO	ISO	Fractional Cover	Weighting	cell B	cell D	cell B	cell D	MON	MBO	ISO	MON	MBO	ISO
Pinus ponderosa	91	4	25	0	0.55	0.333	6.6	3.8	110	63	0.44	2.75	0	0.25	1.58	0
Abies concolor	98	3	0	0	0.55	0.333	6.6	3.8	118	68	0.36	0	0	0.20	0	0
Quercus kelloggii	103	1	0	54	0.55	0.333	6.6	3.8	125	72	0.12	0	6.72	0.07	0	3.87

Secondary assemblage

		Emission Factor			Secondary Assemblage	Co-species	Satellite LAI		Leafmass Density		Emission Rate: cell B			Emission Rate: cell D		
Species	SLW	MON	MBO	ISO	Fractional Cover	Weighting	cell B	cell D	cell B	cell D	MON	MBO	ISO	MON	MBO	ISO
Pinus ponderosa	91	4	25	0	0.35	0.333	6.6	3.8	70	40	0.28	1.75	0	0.16	1.01	0
Abies concolor	98	3	0	0	0.35	0.333	6.6	3.8	75	43	0.23	0	0	0.13	0.00	0
Arctostaphylus patula	127	0	0	0	0.35	0.333	6.6	3.8	98	56	0	0	0	0	0	0

Tertiary assemblage

		Emission Factor			Secondary Assemblage	Co-species	Satellite LAI		Leafmass Density		Emission Rate: cell B			Emission Rate: cell D		
Species	SLW	MON	MBO	ISO	Fractional Cover	Weighting	cell B	cell D	cell B	cell D	MON	MBO	ISO	MON	MBO	ISO
Arctostaphylus patula	127	0	0	0	0.15	0.5	6.6	3.8	63	36	0	0	0	0	0	0
Ceanothus cordulatus	127	2	0	0	0.15	0.5	6.6	3.8	63	36	0.13	0	0	0.07	0	0
NA	NA	NA	NA	NA												

Total LMD		Total Emission Rate: cell B			Total Emission Rate: cell D		
cell B	cell D	MON	MBO	ISO	MON	MBO	ISO
722	416	1.55	4.50	6.72	0.89	2.59	3.87

[1] Specific Leaf Weight, g dry leaf weight/m^2 leaf

[2] MON: ug monoterpene/g dry leaf weight/hr, MBO: ug Carbon/g dry leaf weight/hr, ISO: ug isoprene/g dry leaf weight/ at reference conditions 30 C and 1000 micromoles/m^2/s PAR

[3] Leaf Area Index, m^2 leaf area/m^2 land area

[4] LMD, g dry leaf weight/m^2 land area

[5] MON: mg monoterpene/m^2 land/hr, MBO: mg Carbon/m^2 land/hr, ISO: mg isoprene/m^2 land/hr, at reference conditions.

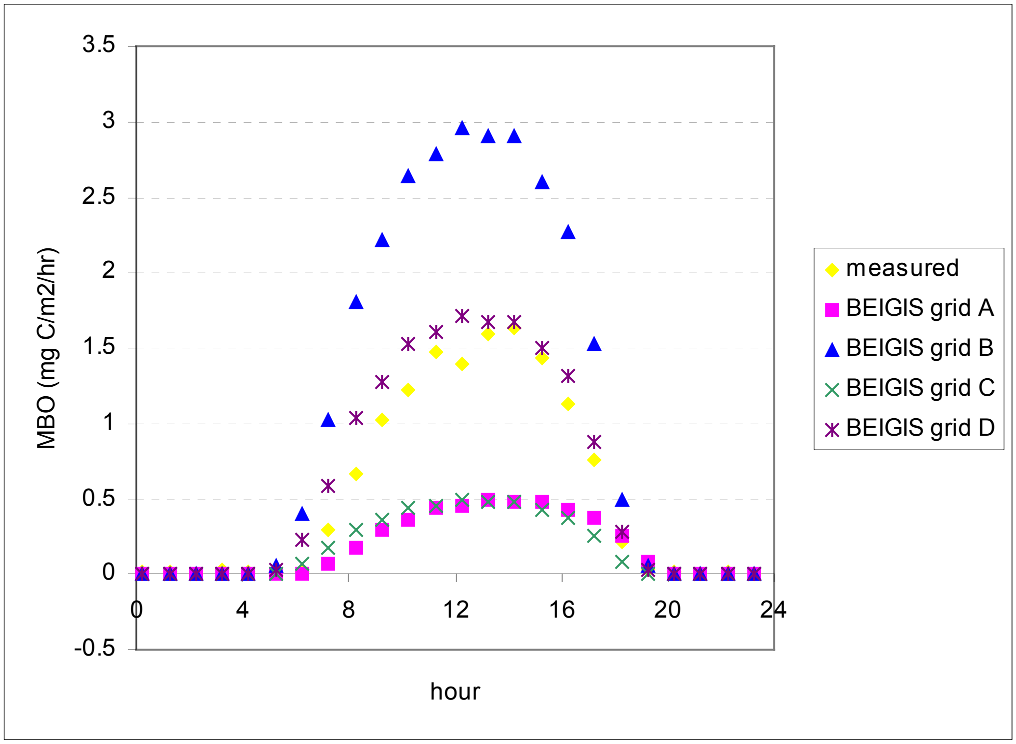

Figure 2. Measured vs. modeled MBO fluxes.

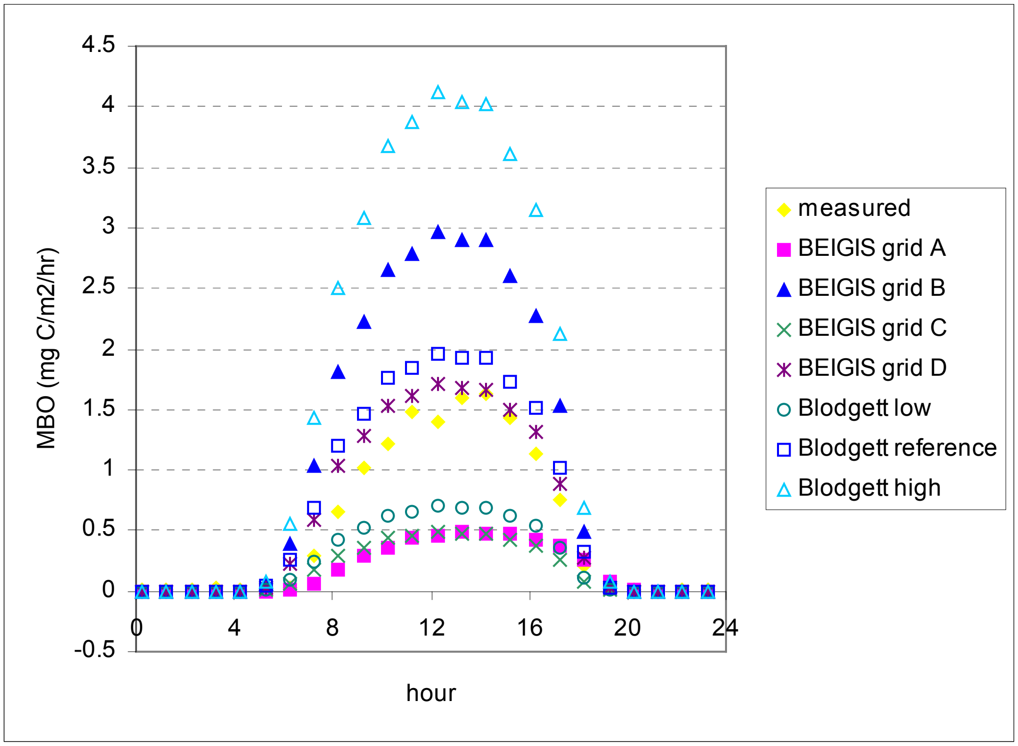

Figure 3. MBO fluxes modeled with default BEIGIS vs. on-site Blodgett inputs, compared to measured fluxes.

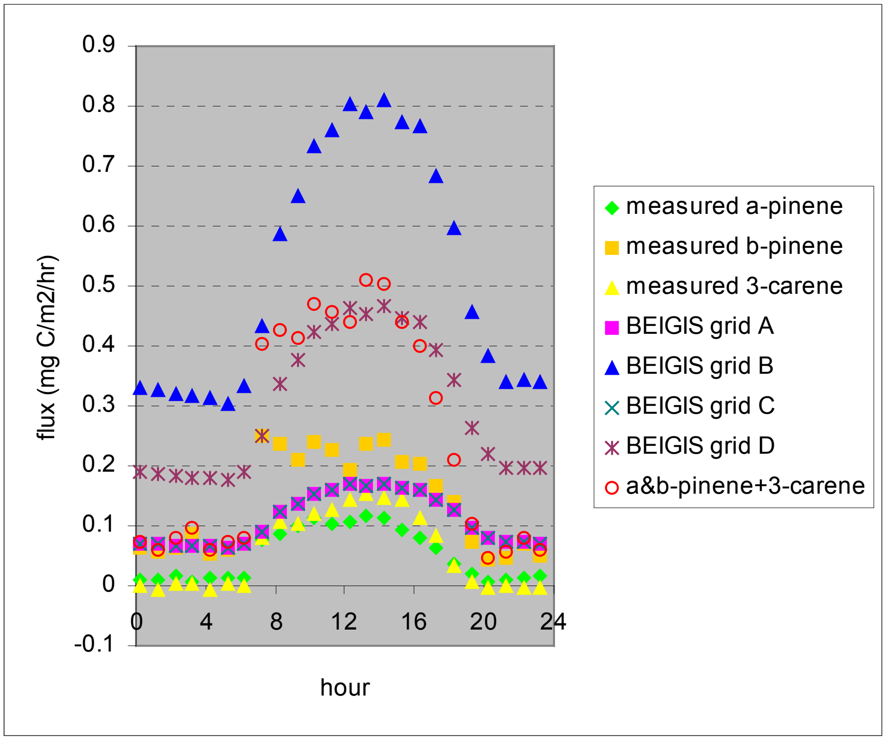

Figure 4. Monoterpene fluxes modeled with default BEIGIS inputs, vs. measured monoterpene fluxes.