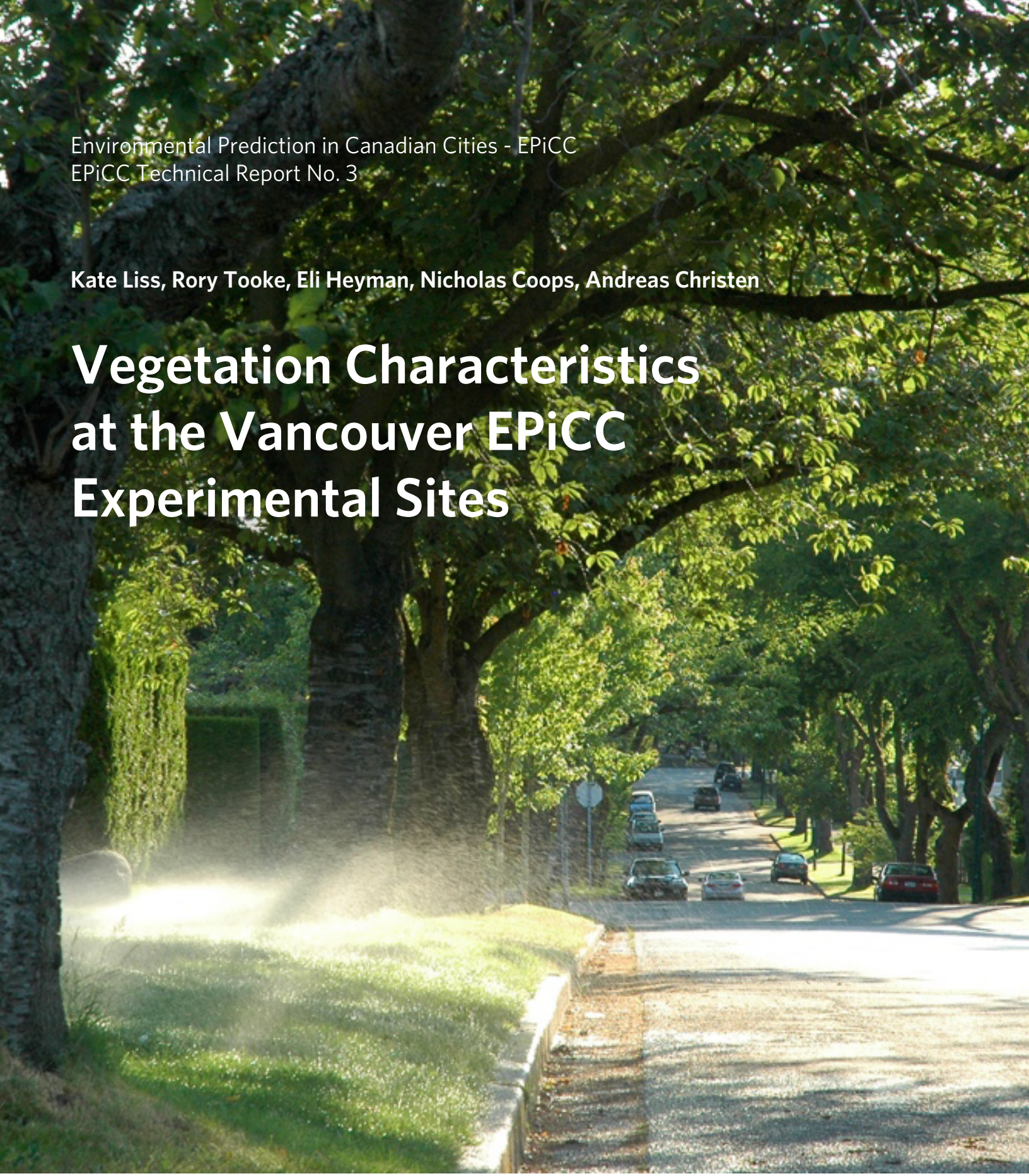

Environmental Prediction in Canadian Cities - EPiCC
EPiCC Technical Report No. 3

Kate Liss, Rory Tooke, Eli Heyman, Nicholas Coops, Andreas Christen

Vegetation Characteristics at the Vancouver EPiCC Experimental Sites

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EPiCC
Environmental Prediction in Canadian Cities

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Cover Photo: Street Trees along W 45th Avenue near Oakridge Tower, Photo by A. Christen

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Vegetation characteristics at the Vancouver EPiCC experimental sites

Kate Liss, Rory Tooke, Eli Heyman, Nicholas Coops and Andreas Christen

University of British Columbia

Version 1.2

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Introduction

This report includes summary statistics and descriptions of the vegetation in the three EPiCC Vancouver experimental neighbourhoods, where flux towers were operated, namely the residential neighbourhoods 'Vancouver-Oakridge', 'Vancouver-Sunset' and the rural reference site Westham Island.

As part of the Environmental Prediction in Canadian Cities Network (EPiCC), the University of British Columbia / Department of Geography monitored energy, water and carbon balances in two suburban neighborhoods in Vancouver, BC, Canada in 2008-2009. Two flux towers, "Vancouver-Sunset" in South-East Vancouver, and 'Vancouver-Oakridge' in South Vancouver, were operated in extensive residential areas composed of single-family homes. In the neighborhood of the two suburban flux towers, a total of eight lawns (OR1-4, SS1-4) were equipped with automatic monitoring systems for soil hydrology parameters (see also Technical Report #2) and carbon dioxide exchange. The lots have been chosen to represent a variety of lawn irrigation regimes and different building volumes, materials and ages. Further, a rural reference site at 'Westham Island' has been operated. Details on the vegetation of the rural reference site are included in this report.

Part 1 of this report lists the two-dimensional plan area fraction and distribution of vegetation in the two urban neighborhoods, Part 2 summarizes the three-dimensional structure of the vegetation at the rural reference site and the urban sites (composition, Leaf Area Index, height) and Part 3 describes the light-response curves for various vegetation components found in the two urban neighborhoods. Appendix 1 lists hemispherical photos of the vegetation state at all EPiCC urban measurement sites. Appendix 2 documents the vegetation state at the urban sites. Appendix 3 documents the vegetation state at the rural reference site. Appendix 4 lists the samples where photosynthesis measurements were carried out.

Part 1 – Vegetation plan area fraction at the urban sites

The plan area fraction of vegetated surfaces λ_v was extracted at a resolution of 2.4m from Quickbird satellite images according to Tooke et al. (2009). The Quickbird data at Vancouver-Sunset was further fused with a LIDAR scan at 1x1 m resolution to separate between the plan area of tree crowns $\lambda_{v,T}$ and the plan area fraction of ground vegetation $\lambda_{v,G}$ (not obscured by trees, < 2m height). Table 1 summarizes the integral vegetation fraction, λ_v for the area around the towers and weighed by the long-term source area of the flux measurements. Table 2 lists the vegetation fractions for Vancouver-Sunset separately for $\lambda_{v,T}$ and $\lambda_{v,G}$.

Table 1 *– Integral vegetation plan area fraction ($\lambda_v = \lambda_{v,G} + \lambda_{v,T}$) at the EPiCC residential sites for radii of various distances from the tower base. Longitude and Latitude refer to tower base.*

	Lon (WGS-84)	**Lat** (WGS-84)	λ_v **250m radius**	λ_v **500m radius**	λ_v **1000m radius**
Vancouver-Oakridge	-123.132894	49.230564	61%	55%	56%
Vancouver-Sunset	-123.078436	49.226125	31%	33%	39%[(a)]

[(a)] 900 m radius instead of 1000m

Table 2 *– Vegetation plan area fractions at Vancouver-Sunset separately for non-obscured ground vegetation* $\lambda_{v,G}$ and above-ground vegetation $\lambda_{v,T}$ *for radii of various distances from the tower base.*

Vancouver-Sunset	Plan area fraction	**250m radius**	**500m radius**	**900m radius**	**Long-term source area**
$\lambda_{v,G}$	Ground vegetation	20.1%	21.6%	26.3%	**20.1%**
$\lambda_{v,T}$	Above-ground vegetation	12.2%	11.9%	12.0%	**12.2%**
$\lambda_v = \lambda_{v,G} + \lambda_{v,T}$	Total vegetation	31.4%	33.4%	38.3%	**32.3%**

All trees within a specific 10º segment of radius 1000m at the two urban towers were mapped. The segment selected was the segment where the remote sensing data indicated that vegetation cover fraction corresponds to the median value of all 36 sectors with a 1000m radius around the tower.

Table 3 *– Tree density in stems/ha for Vancouver-Sunset and Vancouver-Oakridge for the 10º sector with median tree density.*

	Trees/ha
Vancouver-Oakridge	35.3
Vancouver-Sunset	17.1

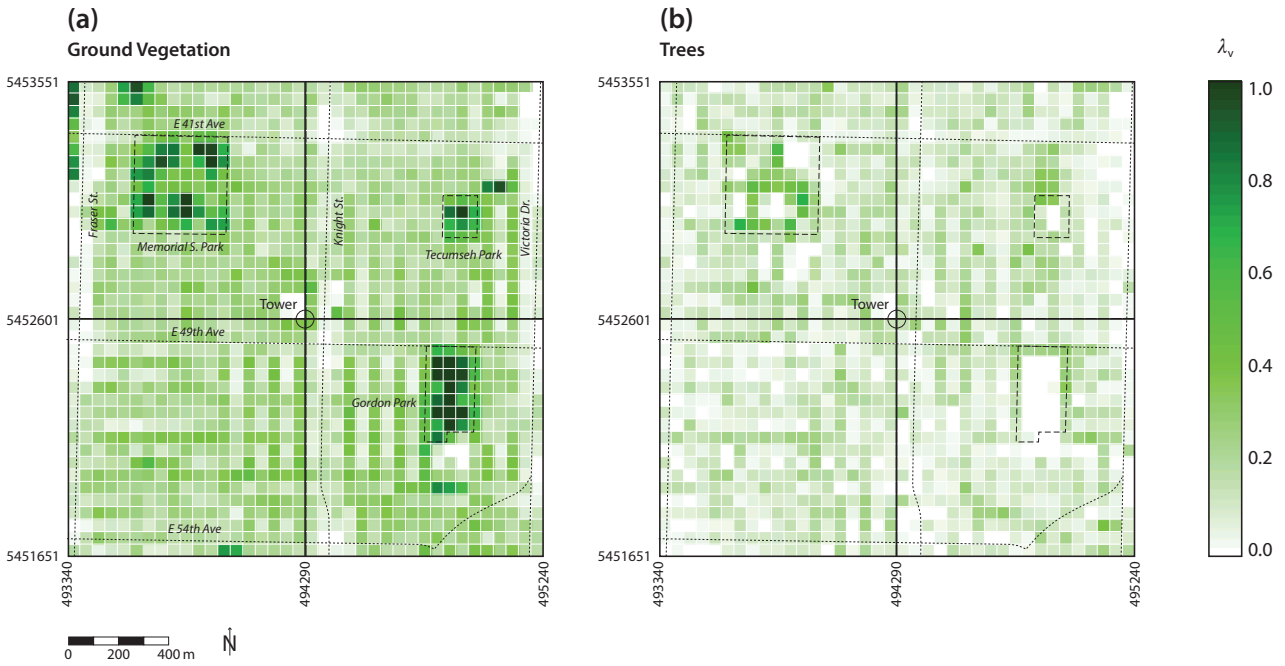


Figure 1 *– Maps of plan area covered by ground (left) and tree vegetation (right) in the Vancouver-Sunset area within 50 x 50 m raster elements.*

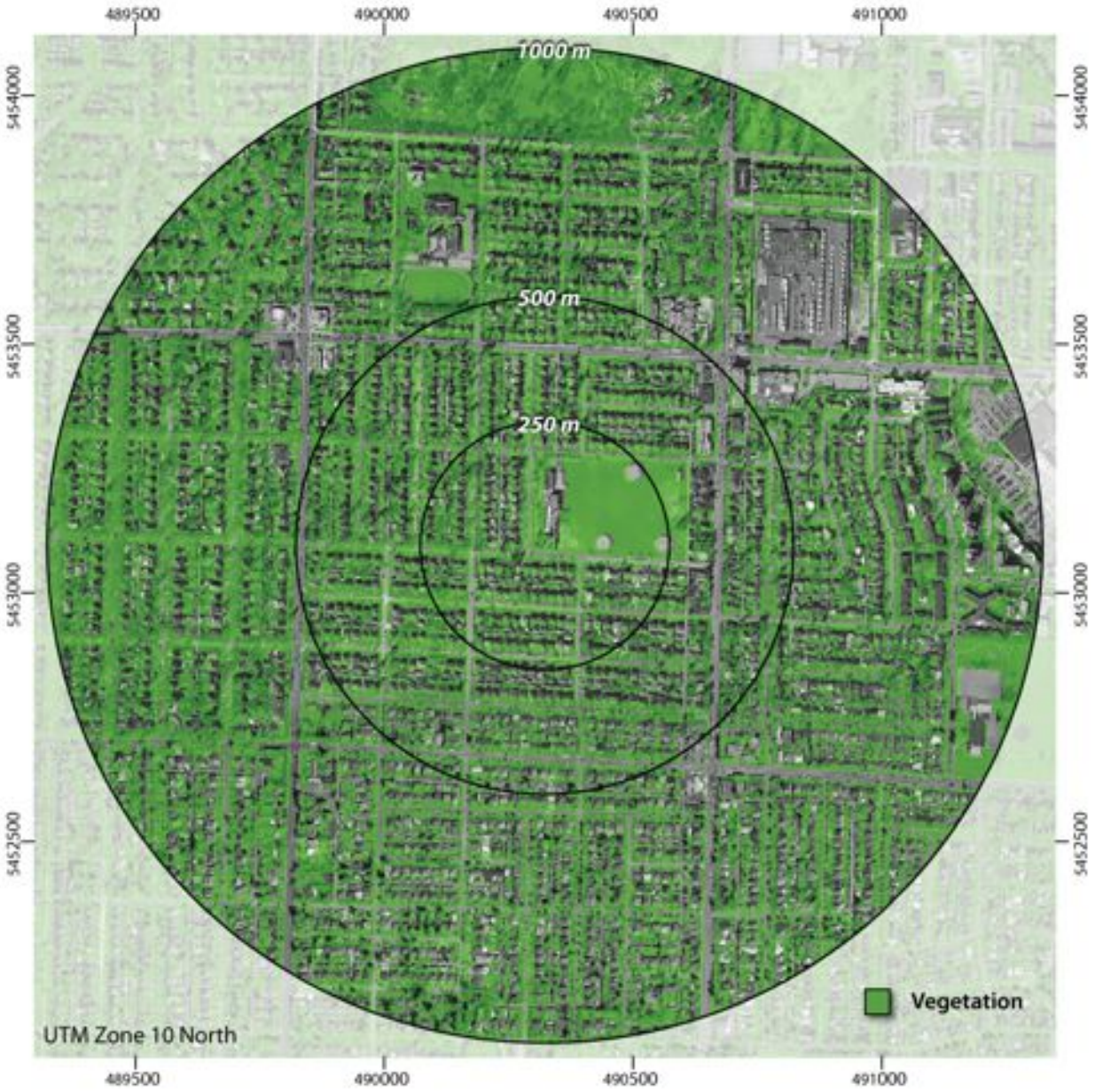


Figure 2 *–Visualization of vegetation fraction in the Vancouver-Oakridge neighborhood based on Quickbird data with 2.4 x 2.4 m resolution.*

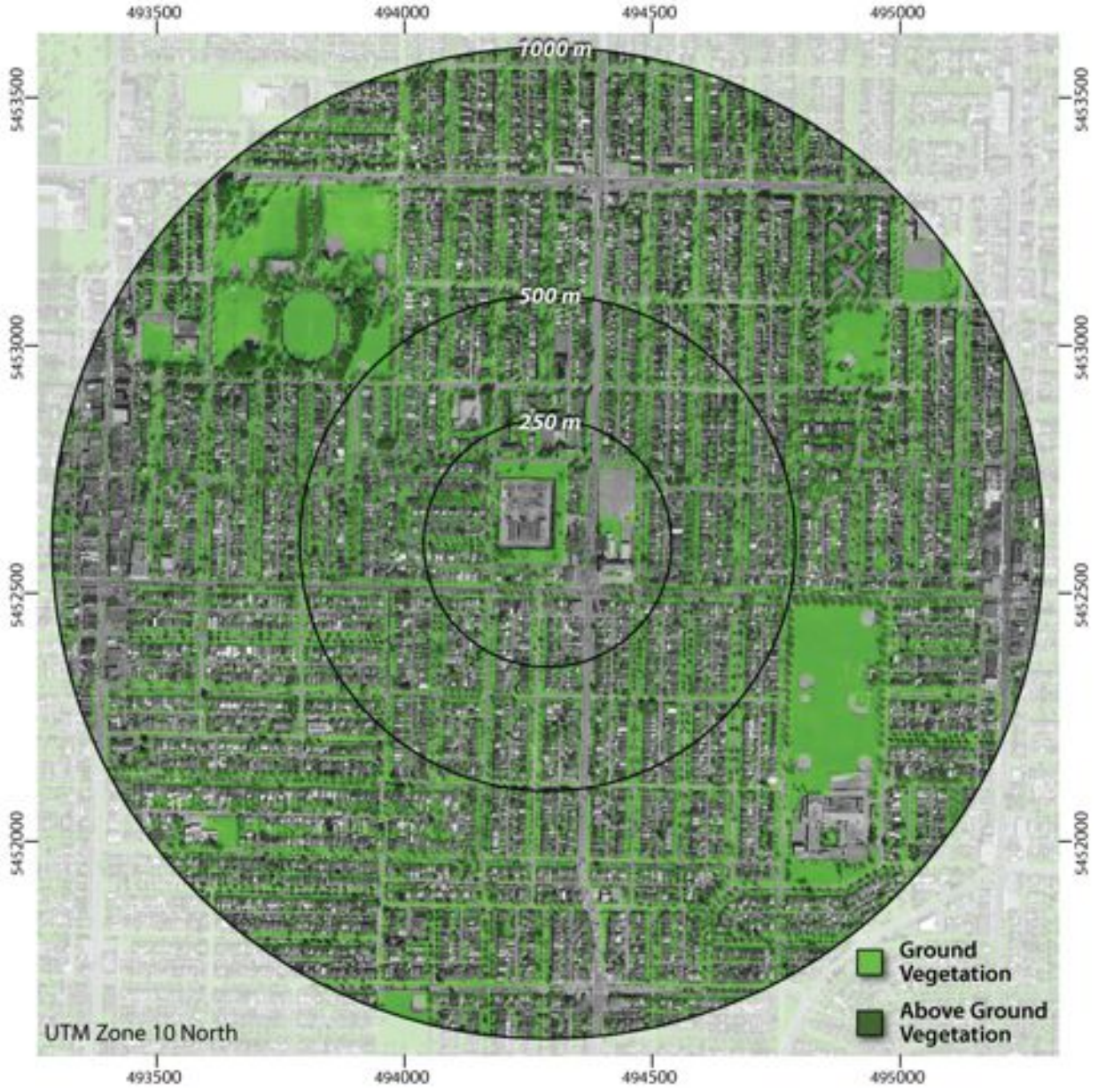


Figure 3 *–Visualization of vegetation fraction in the Vancouver-Sunset neighborhood based on Quickbird data fused with LiDAR data at 1 x 1 m resolution.*

Part 2 –Leaf area index, height and composition

This section describes the three-dimensional structure of the vegetation at the measurement sites, including leaf area index (LAI) estimates, height measurements of trees and grass and composition of the vegetation.

Composition

Trees

For 400m around the tower Vancouver-Sunset, all trees were manually classified based on air photos into either “deciduous” or “evergreen” (Table 4). The Photo in Figure 4 illustrates tree growth in the last 30 years at the site.

***Table 4** – Tree composition for Vancouver-Sunset based on manually sampled trees for 400m circle around the tower.*

	Density (stems / ha)
All trees (n = 965)	19.20
Evergreen [Coniferous] (n = 223)	4.44
Deciduous (n = 742)	14.76

Grassland and Lawns

Species identification of the residential lawns was based on the Turfgrass Identification Tool[1] designed by the Purdue University Turfgrass Science Group in the Department of Agronomy. Up to three dominant species in the grass mixture at each residential lawn site were identified (Table 5). Photos illustrating the state of the residential lawns can be found in Appendix 2. At the rural reference site 'Westham Island', grass species were not identified, but the site was colonized by a diverse set of tall grasses and low shrubs grown to serve as a habitat for small rodents (that in turn were important in the food chain of migrating birds).

***Table 5** – Grass identification at the EPiCC sites.*

Site	**Components of Mixture**
OR1	Creeping Bentgrass, Fine Fescue, Annual Bluegrass
OR2	Tall Fescue
OR3	Rough Bluegrass[(a)], Fine Fescue
OR4	Rough Bluegrass[(a)], Tall Fescue, Fine Fescue
SS1	Perennial Ryegrass, Creeping Bentgrass
SS2	Kentucky Bluegrass, Fine Fescue
SS3	Perennial Ryegrass[(a)], Fine Fescue
SS4	Rough Bluegrass, Creeping Bentgrass
WI	Unidentified tall grasses and low shrubs

[(a)] Identified with less confidence

[1] http://www.agry.purdue.edu/turf/tool/index.html

Leaf Area Index

The LAI is defined as the one-sided leaf area for grasses and broadleaf trees per unit ground area. It is given in $m^2\ m^{-2}$.

Trees

The Leaf Area Index for tall trees was modeled based on urban-specific allometric relationships (tree height and tree crown) developed for urban trees in the US (Nowak, 1996, deciduous species) and for forest trees in the case of coniferous trees. Model results are summarized in Table 6.

Modeling procedure: For a total of 120 trees, crown diameter was manually extracted from air photos (this was done for a particular 10º segment, with 1000m radius around the tower, that showed the median vegetation cover in Vancouver-Sunset). Maximum height for all of the trees was extracted from the LIDAR. Figure 5 illustrates the relationships between LiDAR-derived maximum tree height and crown diameter. The relationships show that deciduous trees grow approx. spherical and coniferous trees are approx. 2 times taller than they are wide in this urban environment. A threshold input height was applied when calculating diameters to trees at h = 10.7 m (i.e. crown diameter stays constant at 10.8 m for trees taller than 10.7 m). This relationship was then applied to all trees within a 400m radius around the tower where tree location and height information from the LiDAR is available. Bushes (< 2 m) are not considered in this calculation.

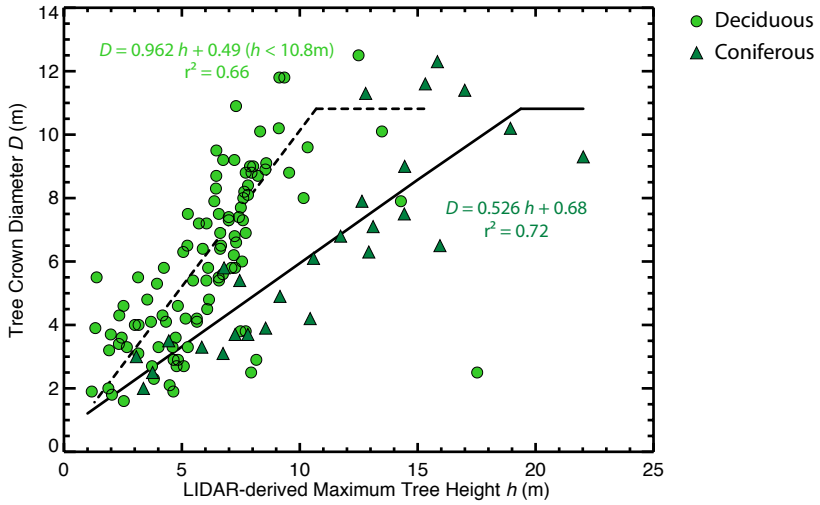


Figure 5 *–The measured relationship between tree height and crown diameter in the Vancouver-Sunset neighbuorhood (n = 120) for deciduous and coniferous trees separately. Note that for the regressions an upper limit for crown diameter applies (see text).*

The equation of Nowak (1996) was used for all deciduous trees with the following standard model settings: Crown height H = tree height h – 2.5m, S_h = 0.83 and $S_a = \pi D(H+D)/2$

$$LA_{Dec} = \exp(-4.3309 + 0.2942\ H + 0.7312\ D + 5.7217\ S_h - 0.0148\ S_a)$$

A separate equation was derived for coniferous trees using on height and diameter and input and based on data published in Teske and Thistle (2004):

$$LA_{Con} = 1.8081\ ln(h)\ \pi\ (D/2)^2$$

Table 6 *–Modeled LA (pre tree) and LAI_{trees} for coniferous, deciduous and the sum of all trees (>2 m) within a 400m radius around the 'Vancouver-Sunset' site.*

	LA per tree (m^2 / tree)	LAI_{trees} per urban area (m^2 / m^2)
Deciduous (n = 742)	231	0.34
Evergreen [Coniferous] (n = 223)	108	0.05
All trees (n = 965)	206	0.39

Grassland and Lawns

The Leaf Area Index of ground vegetation (LAI_{grass}) at the lawn and grass plots and the rural reference site was calculated based on a one-time summertime destructive collection of total aboveground leaf tissue over a 10 cm x 10 cm ground area in summer 2008 (for 3 plots at the rural reference site). Sampling locations were selected to be representative of lawn / grass characteristics at each site. Geometrically scaled scans of a subsample of the grass were analyzed in a quantifying medical / biological imaging software (ImageJ[2], NIH) to determine subsample leaf area, and upscaled by weight to the leaf area of the total sample. The sample at SS3 included a significant moss component at the soil surface. LAI estimated contained grass leafs that were brown or decaying. Values for LAI with the inclusion and exclusion of the moss area are both listed in Table 7.

Table 7 *–Destructive leaf area index of ground vegetation at the EPiCC lawn and grassland sites per square meter lawn.*

Site	***LAI_{grass}*** (m^2 m^{-2})
OR1	6.19
OR2	3.75
OR3	5.00
OR4	4.68
SS1	5.90
SS2	4.64
SS3	15.41[(b)], 10.45[(c)]
SS4	6.57
WI	14.06

[(a)] Identified with less confidence

[2] http://rsbweb.nih.gov/ij/

Please note that LAI_{grass} reported in Table 7 for the urban sites refers to a square meter of lawn, not urban surface, i.e. LAI_{grass} does not represent the neighborhood-wide ecosystem LAI of ground vegetation (that is $LAI_{ground} = LAI_{grass} \cdot \lambda_{V,G}$, where $\lambda_{V,G}$ is the plan area fraction of the urban surface occupied by ground (lawn) vegetation, see Table 2 and 8). The neighborhood-wide LAI is estimated based on $\lambda_{V,G}$ and a map for the Sunset Neighborhood is displayed in Figure 6 (left).

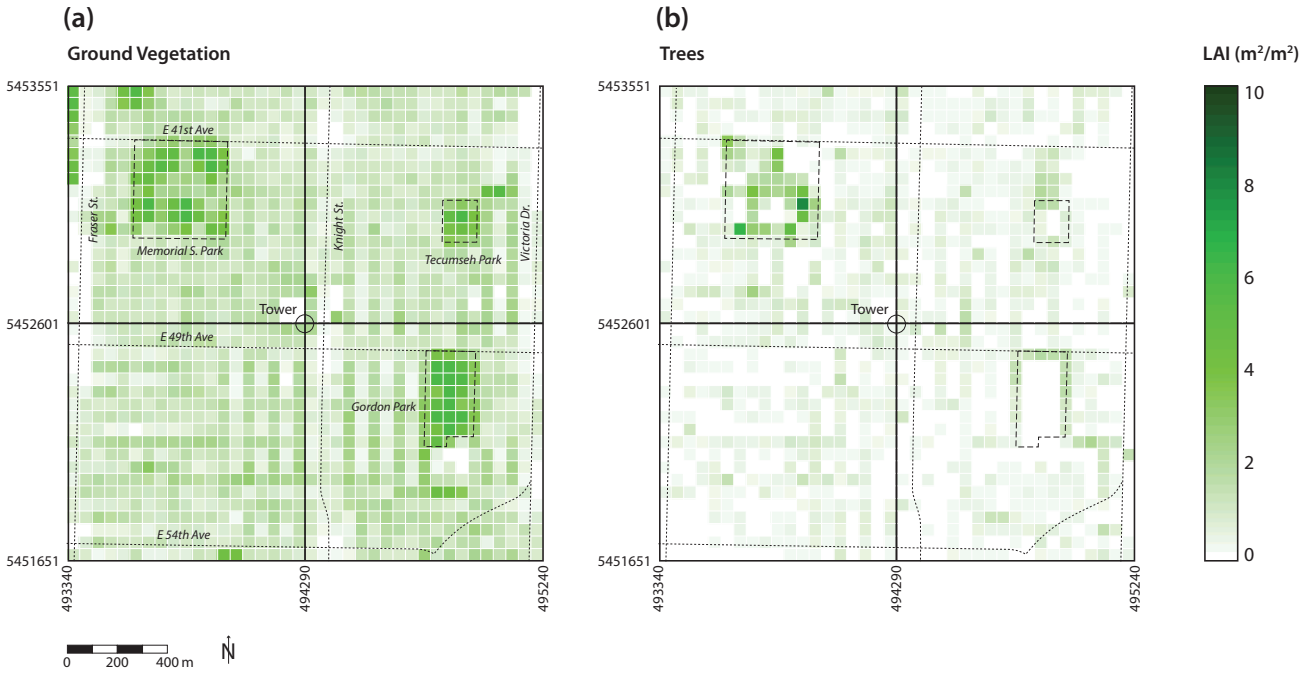


Figure 6 *- Maps of leaf area index of ground (left) and tree vegetation (right) in the Vancouver-Sunset area within 50 x 50 m raster elements for the whole urban surface. The areas with increased LAI are on the maps are parks (South Memorial Park, Gordon Park).*

***Table 8** – Neighborhood-wide statistics for **LAI_{ground}** of lawn surfaces at urban sites (Vancouver-Oakridge, Vancouver-Sunset) compared to the total **LAI_{ground}** at rural sites (Westham Island, UBC Farm).*

Site	**Average LAI_{grass}** (m^2 m^{-2})	**Minimum LAI_{grass}** (m^2 m^{-2})	**Maximum LAI_{grass}** (m^2 m^{-2})	**Ground vegetation fraction** $\lambda_{v,G}$ [(a)]	**Average ecosystem** [(b)] **LAI_{ground}**
Vancouver-Oakridge (OR1-4, *N*=4)	4.90	3.75	6.19	0.56 [(e)]	2.74
Vancouver-Sunset (SS1-4, *N*=4)	5.90	4.64	10.45	0.22	1.27
Westham Island (*N*=3)	2.99 [(c)] + 11.07 [(d)]	1.65 [(c)] + 7.19 [(d)]	5.41 [(c)] + 15.00 [(d)]	1.00	14.06
UBC Farm (*N*=3)	5.92	4.17	9.35	1.00	5.92

[(a)] for 950 m x 950 m box radius around the towers; [(b)] Does not include tall vegetation (trees, bushes) at the urban sites. No trees / bushes were present at the rural sites; [(c)] Ground vegetation; [(d)] Tall grass, includes stems and dead components; [(e)] Includes tree coverage - for a circle of 1000m around site

***Table 9** – Summary of Leaf Area Index estimates for Vancouver-Sunset. LAI_{ground}, LAI_{trees} and LAI_{total} (=LAI_{ground}+LAI_{trees}) for circles of various radii around the Flux Tower and weighted for the long-term source area of the turbulent fluxes (May 2008 – Apr 2010):*

	LAI_{grass} per urban area (m^2 / m^2)	LAI_{trees} per urban area (m^2 / m^2)	LAI_{total} per urban area (m^2 / m^2)
250m around tower	1.19	0.36	1.55
500m around tower	1.27	0.37	1.64
900m around tower	1.55	0.39	1.97
Weighted by long-term source area	**1.18**	**0.37**	**1.56**

Vegetation heights and maintenance

Trees

Tree heights for Vancouver-Sunset were extracted from first-return LiDAR data based on tree locations that were manually digitized. Tree heights for Vancouver-Sunset are summarized in Table 10. No data exists for Vancouver-Oakridge.

Table 10 – Average tree height (m) at Vancouver Sunset for all trees 400m around the tower.

	Average tree height (m)	Median tree height (m)
All trees (n = 965)	9.0	
Coniferous (n = 223)	11.1	10.6
Broadleaf (n = 742)	8.4	6.5

Grass

Grass heights were estimated at each of the nine urban lawn sites (OR1-4, SS1-4) and at Westham Island (WI) during every maintenance visit (Tables 11-13). All residential lawns were maintained and regular mowing occurred. The rural site 'Westham Island' was previously agricultural land (2006 and before) but not agriculturally managed (abandoned, not irrigated, fertilized or harvested). The only exception was that unexpectedly, the grass at the Westham Island plot was harvested once on August 4, 2007 (down to 10 cm). This was not done in 2008 or 2009 after discussing the associated problems for this research with the farmer.

Table 11 *–Measured grass height (in cm) during the operation period of the Westham Island site. Grass heights were measured during each site maintenance visit.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007							100	15[(a)]	25	30	20	10
2008	10	10	10	10	90	135	160	160	160	155	70[(b)]	50
2009	50[(b)]	50	50[(b)]	55[(c)]	80	155	170	175	150			

[(a)] Grass cut on August 4, 2007 (down to 10 cm); [(b)] No measurements available for given month – value estimated; [(c)] Measurements rejected (observer error) – value estimated

***Table 12** – Summary statistics: grass height (in cm) at the residential sites based on site maintenance records*

	OR1	OR2	OR3	OR4	SS1	SS2	SS3	SS4
Yearly Average	**3.81**	**3.34**	**3.32**	**5.31**	**5.70**	**4.71**	**5.25**	**4.77**
January	3.00	3.00	3.00	3.67	4.00	4.00	4.00	6.00
February	2.00	2.00	2.00	2.00	2.50	3.00	-	-
March	-	-	-	2.00	1.00	2.00	2.00	2.00
April	3.00	2.33	3.33	2.33	2.00	-	3.00	3.00
May	0.00	2.00	2.00	3.50	4.00	2.50	3.00	3.33
June	3.60	3.25	2.50	8.80	6.25	4.50	5.75	3.67
July	5.00	4.00	3.20	6.83	7.00	5.40	5.00	5.00
August	3.50	3.14	3.50	5.50	7.00	5.00	5.33	6.33
September	3.25	3.33	3.60	4.40	4.25	4.00	5.00	3.75
October	4.25	4.00	3.67	5.33	8.00	5.50	7.00	4.50
November	4.00	3.50	3.00	5.00	4.00	5.00	4.00	5.00
December	3.50	2.50	1.00	2.00	-	-	-	-

The maximum height of the grass was also measured at each soil CO_2 flux sampling location (5 per site) during the CO_2 chamber measurement (a total of >400 measurements). However, chamber measurements were concentrated primarily in the summer and spring.

***Table 13** – Summary statistics: grass height (in cm) at the residential sites based on chamber measurement records (summer only, larger sample)*

	OR1	OR2	OR3	OR4	SS1	SS2	SS3	SS4
Average	**3.51**	**3.65**	**4.45**	**5.28**	**5.09**	**3.90**	**3.94**	**4.03**
Maximum	5.6	7.6	7.6	8.2	9.0	6.2	6.5	8.0
Minimum	1.0	1.6	1.8	3.2	3.3	2.6	1.0	2.6
Standard deviation	1.16	1.20	1.54	1.38	1.30	0.86	1.47	1.25

Part 3 – Photosynthesis measurements

Using a LI-6400 Portable Photosynthesis system, photosynthetic response and light response curves were measured for (a) tall vegetation (conifers and broadleaf) and (b) turfgrass in summer 2009.

Tall vegetation

From July to September 2009, 91 survey measurements of photosynthetic response were measured under controlled conditions at 22 representative trees and shrubs in the Sunset and Oakridge neighbourhoods of Vancouver (Table 14). The target conditions in the measurement cuvette were as follows: RH = 60%, T_{leaf} = 25° C, CO_2 Concentration = 380 ppm, Photosynthetically Active Radiation (PAR) = 1000 μmol m^{-2} s^{-1}.

Table 14 *– Sample documentation of tall vegetation sampled using the LI-6400.*

Sample	Species	DBH[(a)] (m)	Circumf.[(a)] (m)	Height[(b)] (m)	Location	Irrigation type
1	Sugar Maple *Acer saccharum*	0.13	0.8	-	OR4	auto
2	[Unidentified shrub species]	-	-	1.25	OR4	auto
3	Purple Leaf Flowering Plum *Prunus cerasifera*	-	0.15	-	street tree (OR)	-
9	Whitcomb Cherry *Blossumus cherrius equistitas*	0.12	0.75	-	OR1	manual
10	White Ash *Fraxinus americana*	0.11	0.67	-	OR1	manual
12	Western redcedar excelsa *Thuja plicata excelsa*	-[(c)]	-[(c)]	-	OR1	manual
13	Dwarf rhododendron *Rhododendron minus*	-	-	1	OR1	manual
16	Douglas-fir *Pseudotsuga menziesii*	0.34	2.15	-	street tree (OR)	-
18	Rosebay rhododendron *Rhododendron catawbiense*	-	-	2	OR3	auto
19	[Unidentified shrub species]	-	-	0.5	OR3	auto
22	Deodar cedar *Cedrus deodara*	0.14	0.85	-	street tree (OR)	-

Sample	**Species**	**DBH**[(a)] (m)	**Circumf.**[(a)] (m)	**Height**[(b)] (m)	**Location**	**Irrigation type**
23	Yellow-Wood *Cladrastis lutea*	0.11	0.67	-	SS3	none
26	Mugho Pine *Pinus mugo*	-	-	2	SS3	none
29	Cherry laurel *Prunus laurocerasus*	-	-	2.2	SS2	manual
32	American Chestnut *Castanea dentata*	0.10	0.65	-	street tree (SS)	-
33	Oregon Ash *Fraxinus latifolia*	0.12	0.76	-	SS4	none
34	European Beech *Fagus sylvatica*	0.09	0.55	-	SS4	none
35	Engelmann Spruce *Picea engelmannii*	0.04	0.28	-	street tree (SS)	-
42	American Elder *Sambuscus canadensis*	0.03	0.16	-	street tree (SS)	-
55	Easter White Cedar cultivar *Thuja occidentalis*	-	-	3	OR4	auto
56	*Cedrus libani*	-	Multiple Stems > .7	-	street tree (OR)	-
60	Silver Maple *Acer saccharinum*	0.14	0.86	-	OR1	manual

[(a)] Tall trees only. [(b)] Shrubs only [(c)] Stem not accessible

***Table 15** – Average measured photosynthesis of tall vegetation sampled using the LI-6400 system from July - August 2009 under controlled conditions (see text).*

Sample	**Ps** (μmol $m^{-2}s^{-1}$)	**# of measurements**
1	8.77	4
2	8.89	4
3	7.22	4
9	11.25	4
10	9.46	4
12	5.87[(a)]	5
13	10.84	4
16	4.80[(a)]	2
18	7.74	4
19	9.31	4
22	7.28[(a)]	5
23	8.32	4
26	5.57[(a)]	4
29	9.99	4
32	7.55	4
33	6.72	4
34	5.76	4
35	8.29[(a)]	4
42	1.67	4
55	5.23[(a)]	5
56	5.06[(a)]	2
60	6.24	3

[(a)] Coniferous samples were measured under ambient light conditions. Incident PAR was commonly lower than the target condition of 1000 μmol m^{-2} s^{-1}

One light response curve was measured for each sample between July 31st and August 4th, 2009. Consistent weather conditions were maintained throughout this measurement campaign, with no measured precipitation. The target conditions in the cuvette were as follows: RH(%) = 60; T_{leaf} (°C) = 25; sample CO_2 (ppm) = 380; sample PAR was varied as follows (μmol $m^{-2}s^{-1}$) – 1400 / 1200 / 1000 / 800 / 600 / 400 / 200 / 100 / 50 / 0 .

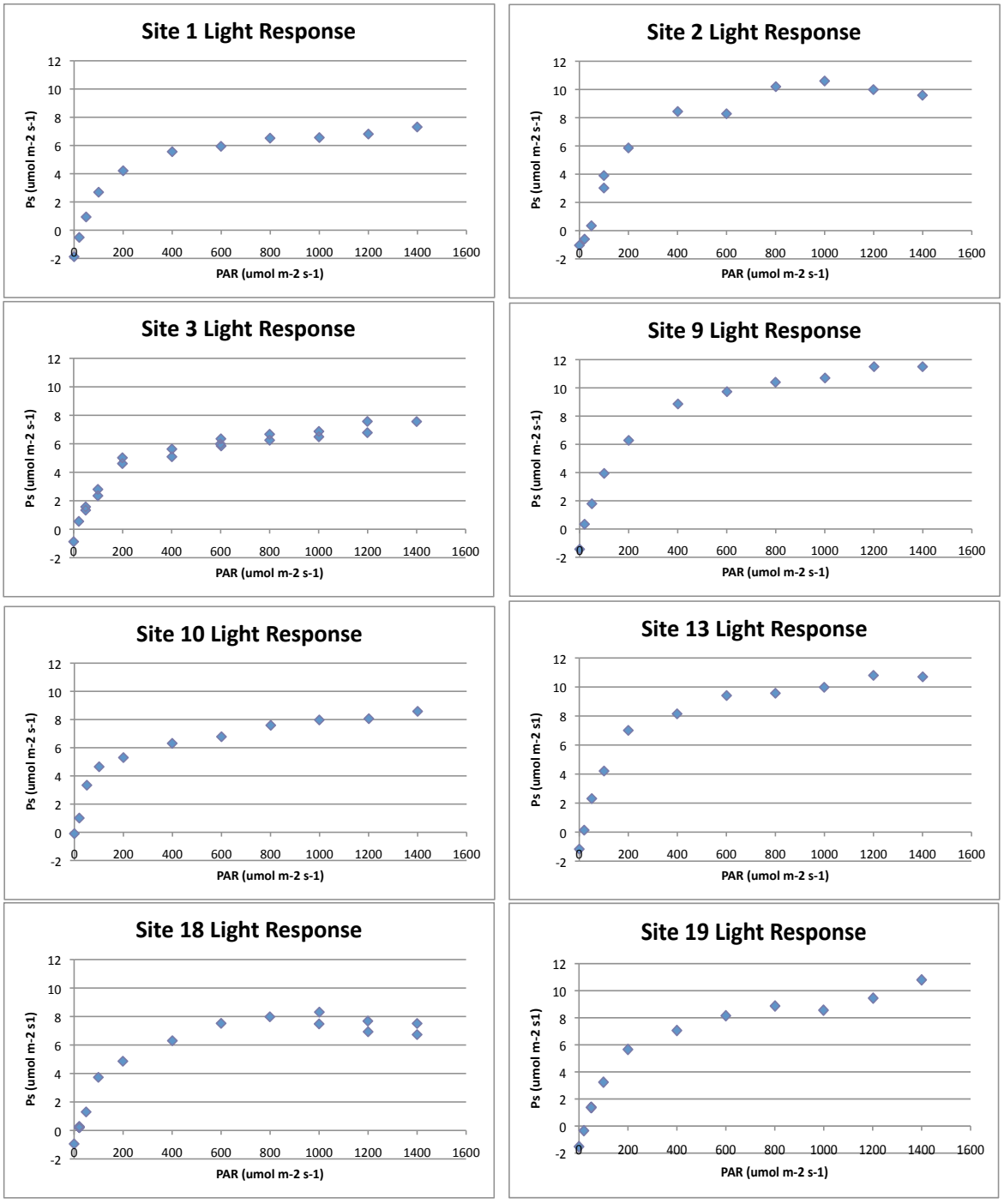


Figure 7 – *Light response curves for tall vegetation (samples 1-19).*

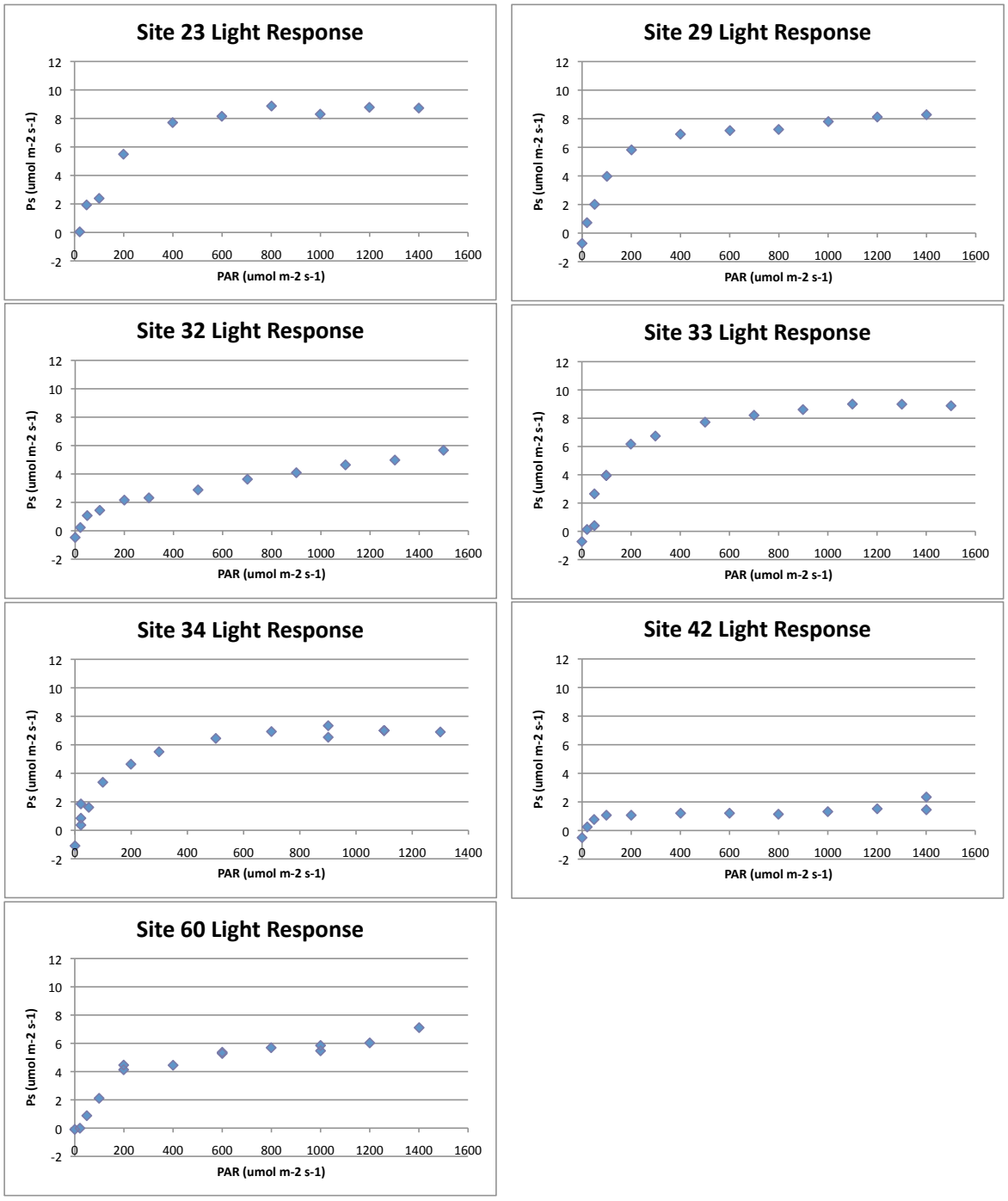


Figure 8 – *Light response curves for tall vegetation (samples 23-60).*

Table 16 - *Measurement conditions in the Li-6400 chamber and soil conditions for the tall vegetation light response curves.*

	Date	**Time** (PST)	**T_{air} min** (º C)	**T_{air} max** (º C)	**$[CO_2]$ min** (ppm)	**$[CO_2]$ max** (ppm)	**RH min** (%)	**RH max** (%)	**θ_w** ($m^3\ m^{-3}$)
1	2009/08/03	06:35	24.8	25.2	378.8	381.3	60.0	64.2	0.31
2	2009/08/03	05:35	24.5	25.1	373.2	383.4	58.4	69.2	0.36
3	2009/08/04	07:10	24.9	25.1	373.6	384.7	59.5	60.4	0.15
9	2009/08/03	07:35	25.9	26.1	379.3	380.8	65.6	65.7	0.05
10	2009/08/03	07:05	24.9	25.1	278.4	381.3	60.1	60.2	0.05
13	2009/08/02	07:25	25.9	26.1	378.5	380.4	55.0	65.4	0.14
18	2009/08/02	06:00	25.0	25.1	375.5	381.7	60.0	60.4	0.11
19	2009/08/02	06:45	25.0	25.2	378.9	381.3	71.2	75.5	0.14
23	2009/08/04	05:30	24.4	24.5	372.0	384.0	58.4	60.2	0.06
29	2009/07/31	10:40	24.9	25.1	377.7	383.4	65.0	67.1	0.09
32	2009/07/31	07:10	24.6	25.1	377.1	386.5	52.49	60.1	0.04
33	2009/07/31	07:55	24.2	25.1	374.6	384.1	58.8	60.1	0.07
34	2009/07/31	08:35	24.9	25.1	374.4	386.1	59.9	60.2	0.05
42	2009/07/31	09:45	23.1	24.6	378.8	381.9	57.7	61.9	0.05
60	2009/07/31	06:30	24.34	25.11	371.6	384.7	57.4	60.3	0.05

Turfgrass

At a representative location on each monitored turfgrass lawn (OR1-4, SS1-4), light response curves for a subsample was measured once in summer 2009 and scaled based on the leaf area of the sample. Measurement conditions for the light response curves of the turfgrass are summarized in Table 5.

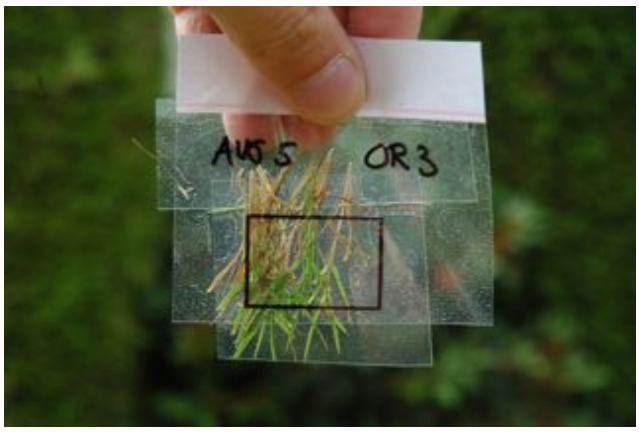



Figure 9 – *Li6400 system during measurement of light response curves (left) and subsamples conserved after measurement to estimate leaf area in cuvette (right).*

Table 17 - *Measurement conditions in the Li-6400 chamber and soil conditions for the turfgrass light response curves.*

Site	**Date**	**Time** (PST)	**T_{air} min** (º C)	**T_{air} max** (º C)	**$[CO_2]$ min** (ppm)	**$[CO_2]$ max** (ppm)	**RH min** (%)	**RH max** (%)	**Sampled Leaf Area** (cm^2)	θ_w ($m^3\ m^{-3}$)	**T_{soil}** (ºC)
OR1	2009/08/05	12:35	25.4	25.6	378.4	381.2	59.2	60.6	1.75	0.15	21.8
OR2	2009/08/05	10:41	22.9	23.5	378.5	380.3	60.0	61.8	2.26	0.19	23.2
OR3	2009/08/05	09:58	20.9	21.1	378.5	381.1	59.9	60.2	3.21	0.42	23.2
OR4	2009/08/05	09:07	20.9	21.1	378.7	380.8	60.0	60.7	4.67	0.32	24.6
SS1	2009/08/05	13:43	23.2	24.3	377.9	381.9	58.3	62.7	1.16	0.24	22.0
SS2	2009/08/06	09:08	20.9	21.1	378.9	381.1	59.2	60.4	2.64	0.15	22.8
SS3	2009/08/06	11:17	25.9	28.6	378.7	381.1	59.0	61.0	3.19	0.09	25.0
SS4	2009/08/06	10:13	23.4	24.1	378.7	381.5	59.9	61.0	3.37	0.09	23.6

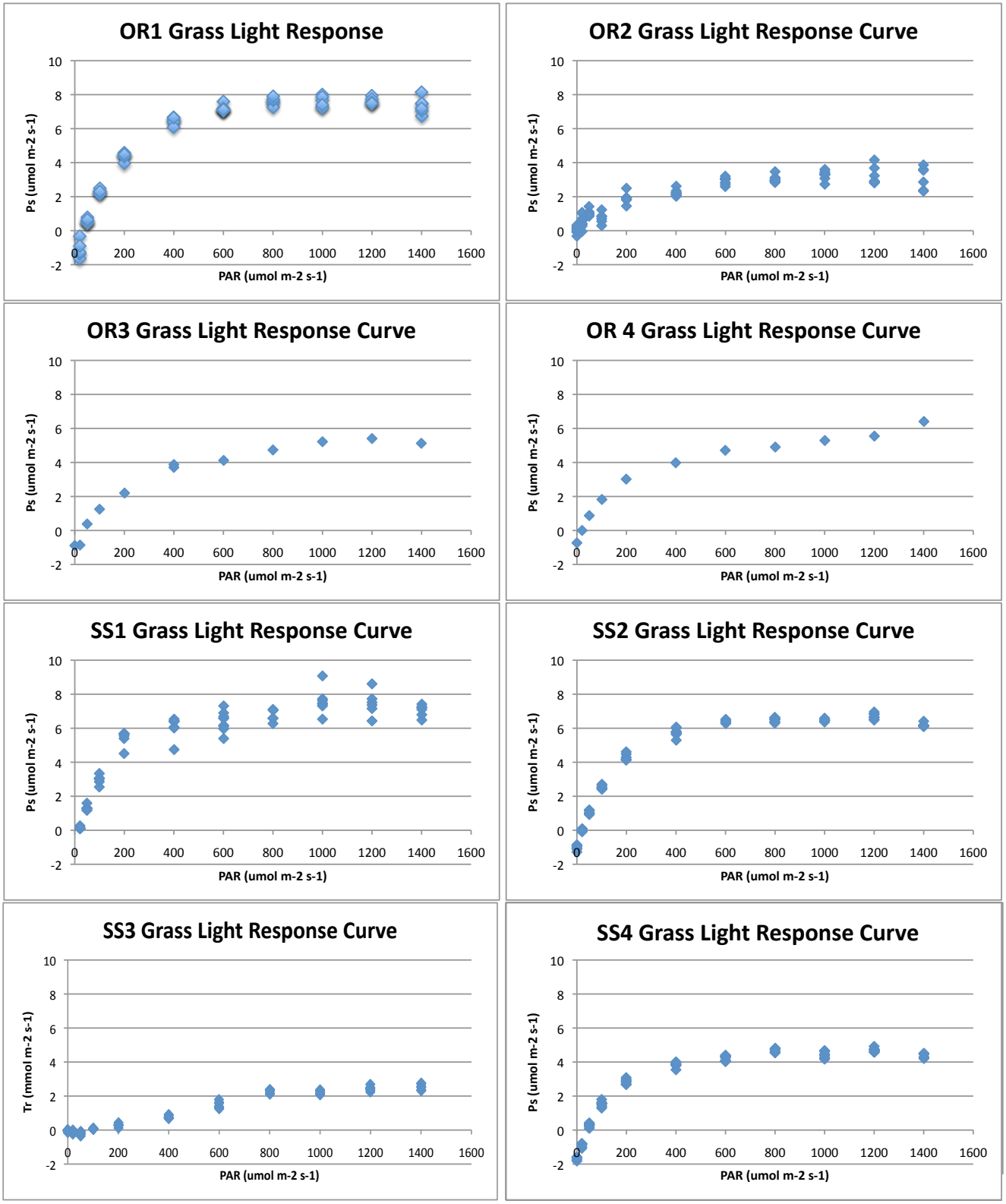


Figure 10 – *Light response curves measured for representative turfgrass samples at each monitoring site, using the Li-6400 system.*

References

Nowak, DJ (1996): 'Estimating Leaf Area and Leaf Biomass of Open-Grown Deciduous Trees', *Forest Science* 42 (4), 1996, p 504 – 507.

M.E. Teske, H.W. Thistle (2004): 'A library of forest canopy structure for use in interception modeling' *Forest Ecology and Management* 198. 341–350

Tooke, R., Coops, N.C., Goodwin, N.R., & Voogt J.A. (2009): 'The influence of Vegetation Characteristics on Spectral Mixture Analysis in an Urban Environment'. *Remote Sensing of Environment*, 113, 398-407

Appendix 1 – Hemispherical photos at the EPiCC measurement sites

The following figures show hemispherical fish-eye photos of vegetation state at OR1-4 and SS1-4, all taken at ground level where the long-term soil climate measurements are located. Photos are shown separately for Summer (left) and winter (right). High-resolution images are available upon request.

Fig A1.1 *– OR 1 Summer*

Fig A1.2 *– OR 1 Winter*

Fig A1.3 *– OR 2 Summer*

Fig A1.4 *– OR 2 Winter*

Fig A1.5 *– OR 3 Summer*

Fig A1.6 *– OR 3 Winter*

Fig A1.7 *– OR 4 Summer*

Fig A1.8 *– OR 4 Winter*

Fig A1.9 *– SS 1 Summer*

Fig A1.10 *– SS 1 Winter*

Fig A1.11 *– SS 2 Summer*

Fig A1.12 *– SS 2 Winter*

Fig A1.13 *– SS 3 Summer*

Fig A1.14 *– SS 3 Winter*

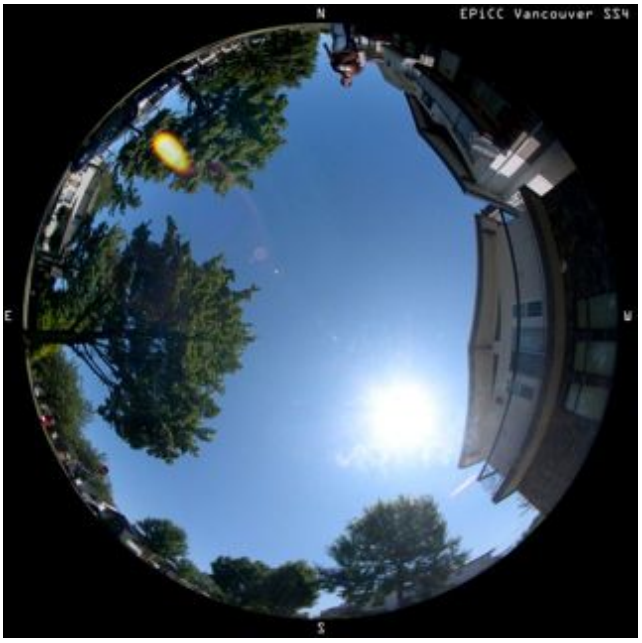


Fig A1.15 *– SS 4 Summer*

Fig A1.16 *– SS 4 Winter*

Appendix 2 – Lawn, yard and street vegetation at the EPiCC measurement sites

This set of figures shows horizontal photos of vegetation, lawn and ground state at OR1-4 and SS1-4, all taken at approx. 1.5 m height at the location where the long-term soil climate measurements are located. High-resolution images, and images pointing in all four cardinal directions are available upon request.

Winter: January 9, 2009

Spring: April 20, 2009

Summer: July 22, 2008

Fall: October 28, 2008

Fig A2.1 *– Representative photos of the monitored lawn at OR1 for each season with view towards East.*

Winter: February 21, 2008

Spring: April 20, 2009

Summer: July 29, 2009

Fall: October 28, 2008

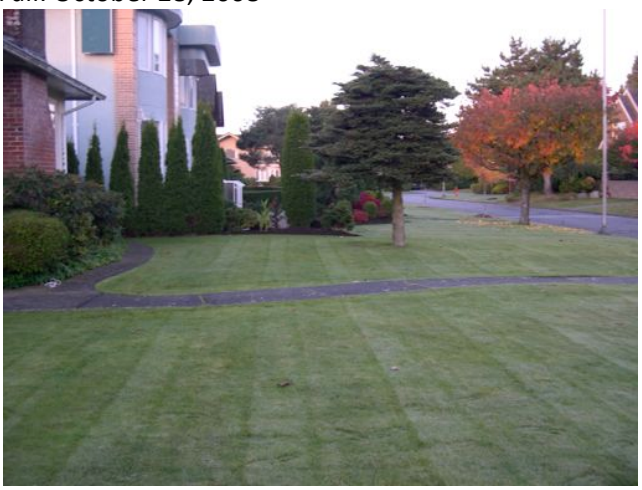
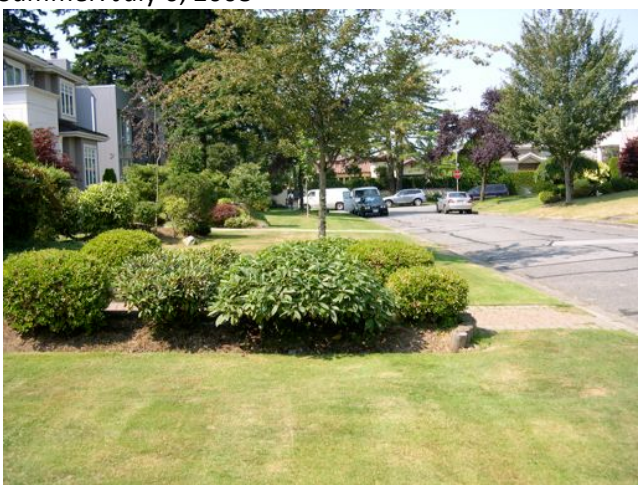


Fig A2.2 *– Representative photos of the monitored lawn at OR2 for each season with view towards West.*

Winter: January 17, 2009

Spring: April 20, 2009

Summer: July 6, 2008



Fall: September 24, 2009

Fig A2.3 *– Representative photos of the monitored lawn at OR3 for each season with view towards West.*

Winter: January 12, 2009

Spring: April 20, 2009

Summer: July 9, 2008

Fall: October 20, 2008

Fig A2.4 *– Representative photos of the monitored lawn at OR4 for each season with view towards South.*

Winter: January 16, 2009

Spring: April 20, 2009

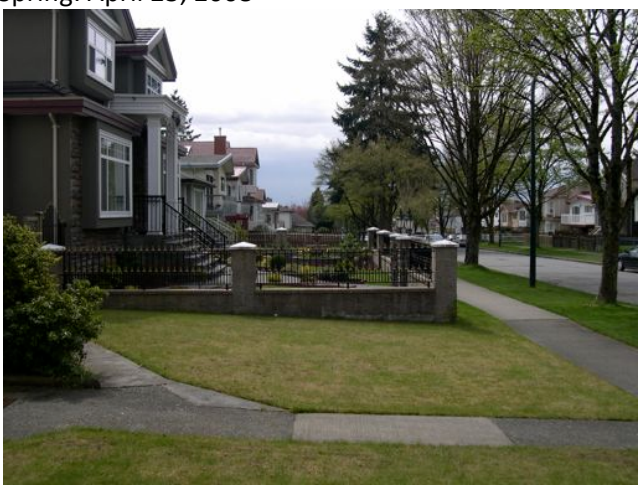
Summer: July 9, 2009

Fall: November 5, 2008

Fig A2.5 *– Representative photos of the monitored lawn at SS1 for each season with view towards East.*

Winter: December 15, 2008

Spring: April 23, 2008



Summer: July 23, 2008

Fall: October 17, 2008

Fig A2.6 *– Representative photos of the monitored lawn at SS2 for each season with view towards South.*

Winter: December 15, 2008

Spring: March 27, 2008

Summer: August 6, 2008

Fall: November 5, 2008

Fig A2.7 *– Representative photos of the monitored lawn at SS3 for each season with view towards East.*

Winter: January 17, 2009

Spring: April 23, 2008

Summer: July 29, 2008

Fall: October 17, 2008

Fig A2.8 *– Representative photos of the monitored lawn at SS4 for each season with view towards South.*

Appendix 3 – Vegetation at the rural EPiCC measurement site

January 8, 2008

February 8, 2008

March 27, 2008

April 15, 2008

May 5, 2008

May 28, 2008

June 18, 2008

July 9, 2008

August 21, 2008

September 22, 2008

October 10, 2008

December 12, 2008

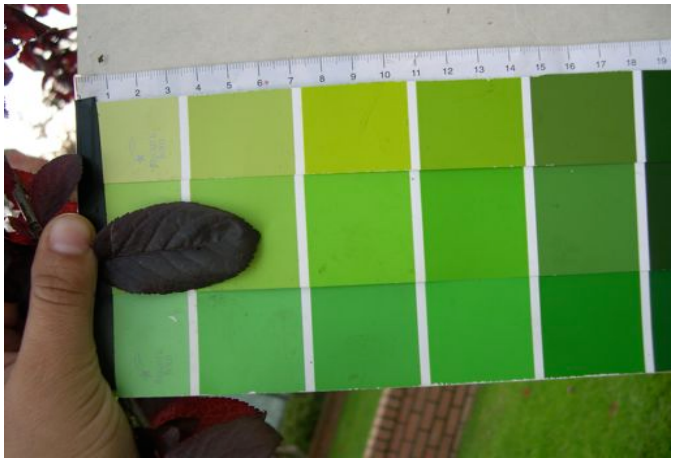
Fig A3.1 - *These photos show the vegetation and ground state (view towards West from the tripod) at the rural site 'Westham Island' over the course of the year 2008.*

Appendix 4 – Vegetation Samples (Li6400 Measurements)

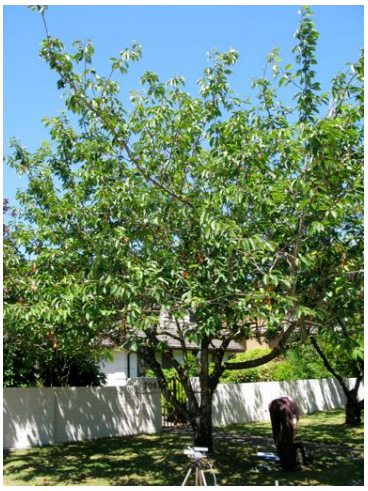
Sample 1


Sample 2

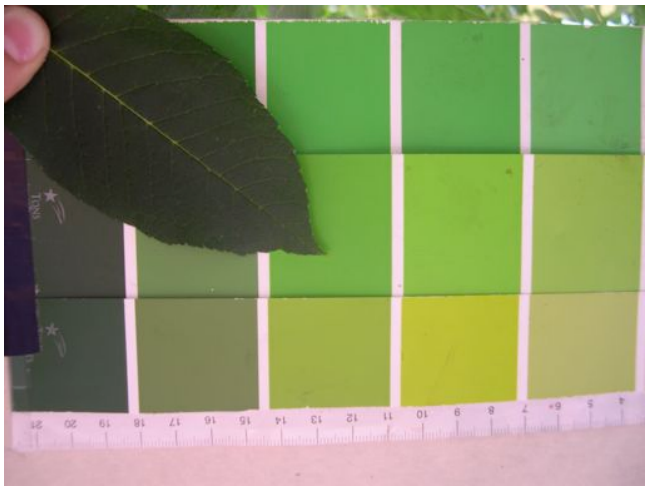

Sample 3

Sample 9



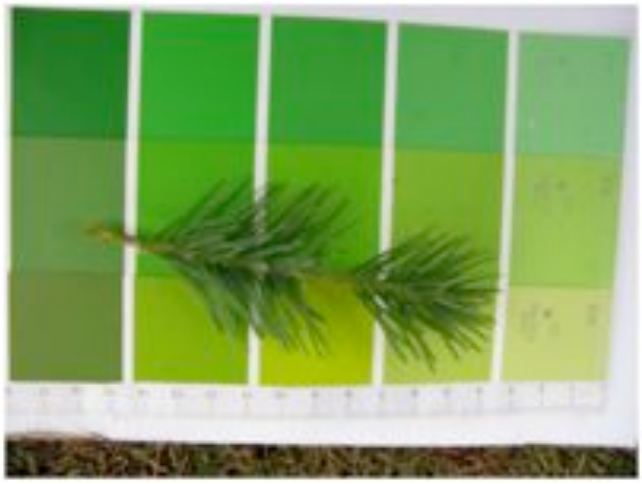

Sample 10

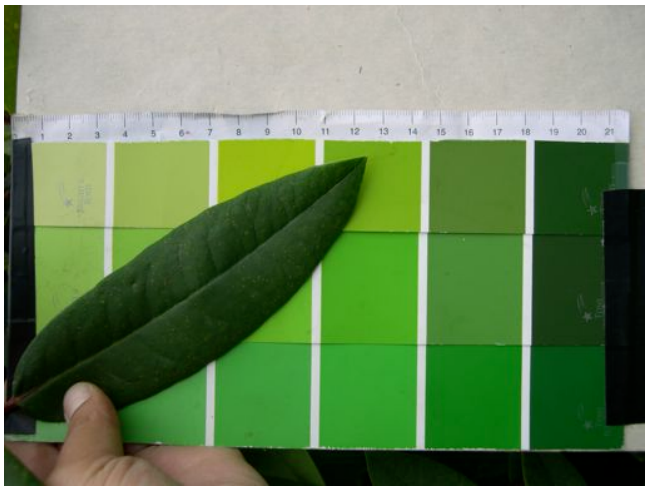
Sample 12


Sample 13


Sample 16

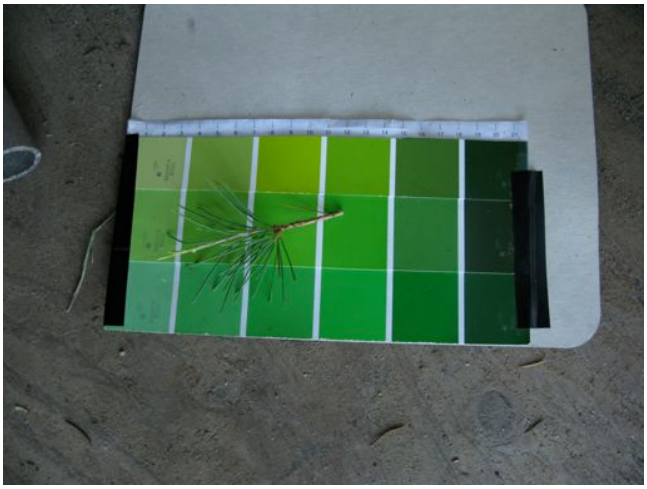



Sample 18

Sample 19

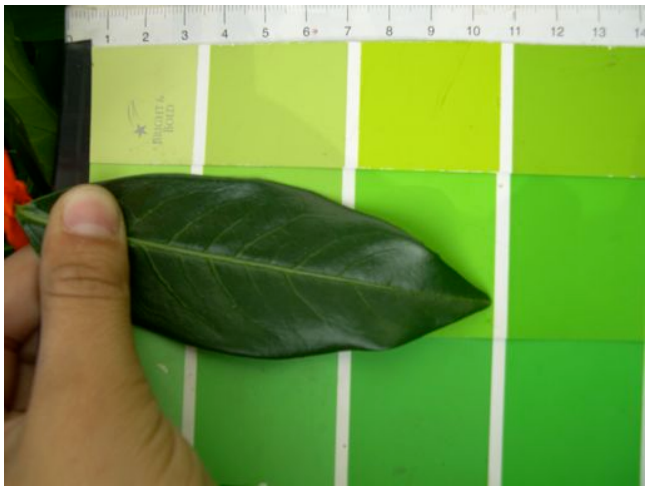

Sample 22

Sample 23

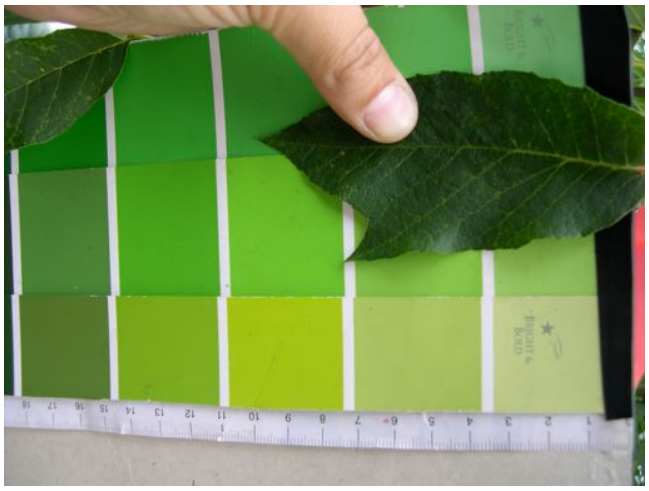

Sample 26


Sample 29

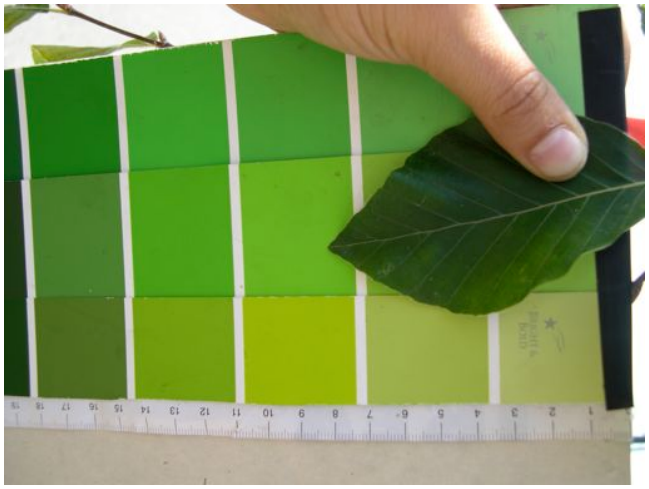



Sample 32


Sample 33

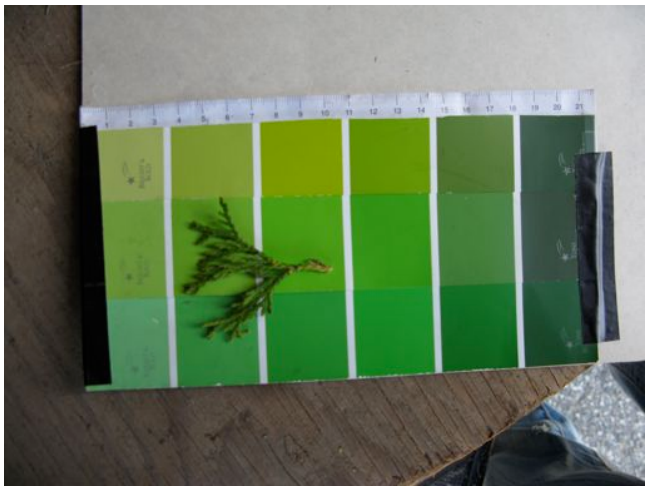
Sample 34

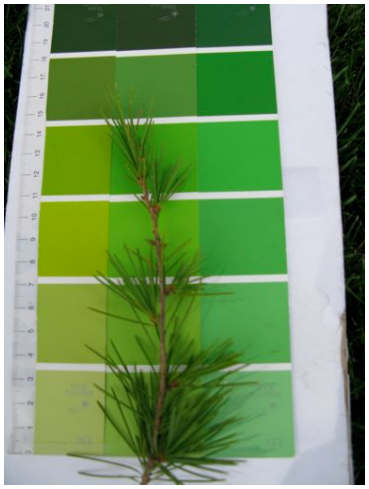
Sample 35


Sample 42


Sample 55

Sample 56

Sample 60