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Deliverable Report:

Report on methodological choices and tests with stage 1 cameras

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Climate change indicators and vulnerability of boreal zone applying innovative observation and modelling techniques (Monimet)

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Contents

1 List of Abbreviations

GCC	Green Chromatic Coordinate
DOY	Day of Year
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
LAI	Leaf Area Index
Metla	Finnish Forest Research Institute
ROI	Region Of Interest (in camera image)

2 Background

This report presents the first analyses of web-camera time series in the Monimet project The intention of this report is to synthetize information acquired from the stage 1 camera installations made during the winter-spring season of the project in 2014 (Figure 1). In this report we will qualitatively assess the image data series and installations so as to provide guidelines for the further planning of the (camera) work in the project. Ultimately, the aim of the action is to facilitate monitoring of variables associated with the seasonality of forests and peatlands in Finland (Box 1).

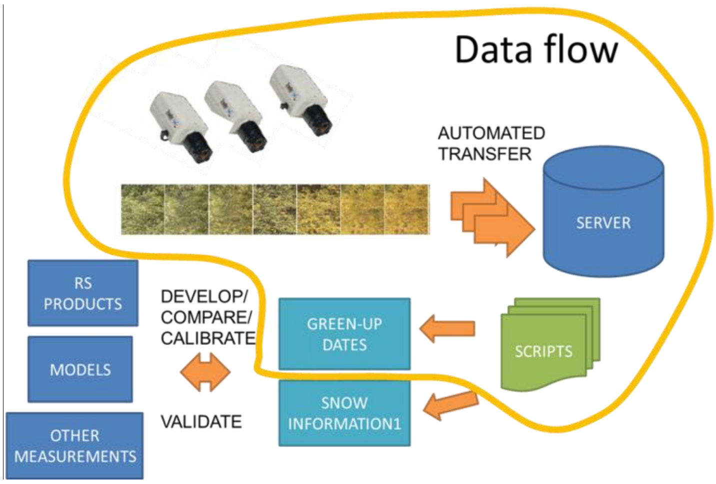

Figure 1 Report deals with feasibility tests of stage 1 camera installations and the data flow process (**surr**ounded by the orange line), whereby cameras automatically transfer images to server where data is analysed (partially manually at this phase)

- Vegetation phenology
  - Canopy phenology
    - Seasonal patterns of canopy greenness
      - Green-up
        - » onset of green-up
        - » Leaf emergence
      - Leaf senescence and abscission
        - » Leaf yellowing
        - » Leaf fall
      - Maturity
      - Maybe also ever green canopies ?? *coniferous*
      - Dormancy??

- Green-up
- Maturity
- Senescence
- Dormancy
- Changing light conditions in forests
- Leaf Area Index
- Canopy-closure estimation
- Vegetation fraction
- Leaf pigmentation
- Biomas
- Leaf emergency

- Snow phenology
    - Snow on ground
    - Snow cover dynamics change in ground snow cover snow melting, but impossible to calculate volume just from camera images

Box 1 List of the most important candidate phenology parameters.

3 Methods

3.1 Camera

In order to test the operation of cameras and acquire experiences on their use, we decided that they will be tested by each partner independently at their own sites, thus providing us useful information on their performance under various conditions. Based on each parties' cameras' performances and experiences there will be an evaluation and comparison among the partners, after which we will make a decision how to proceed in next stages of the project. The main requirements for the camera were that is affordable, proven reliable in field use, there are proofs it can provide useful information about ecosystems, it requires minimal investments on the site infrastructure, it is are easily and highly configurable remotely (e.g. option for fixed white balance, etc), provides various lenses, provides ftp-transfer of images, allows PoE and other power options, and if possible it can provide ancillary weather data.

We screened a number of cameras and selected the Stardot SC 5MP web camera. This camera was also in use in the US Phenocam network (http://phenocam.sr.unh.edu/webcam/about/). US Phenocam network. Their instructions for camera set ups that were available on Internet made it cost-beneficial to quickly acquire first hand experiences on the imaging of phenological processes.

Table 1 Reviewed literature at the start of the project in order to initiate first stage tests.

Article	Parameters Monitored	Camera type /tools	Image Sensor	Method/Analysis
Ahrends, H.E, et al 2008	• Leaf emergence • Changing illumination	Nikon Coolpix 5400 5-megapixel	CCD	GF=(G/(G+R+B)) And 1st and 2nd derivatives - Uncertainty analysis
Andrews, C., et al 2011	• Lake ice cover • Snow cover • Mountain birch	• Canon datematic 40 mm • Canon powershot G5		Statistical tests
Bernard, E., et al 2013	Snow melting process and snow cover	Based on Lecia D-Lux 3 or D-lux 4 10-megapixel		• Geometric correction • Select image sets and Create mosaics • perform the snow covered area delimination
Heqing, Z., et al 2013	Snow cover	Satellite data		
Hufkens, K., et al 2012	Greenup and senescence	Modis data and phenocam data repository (Richardson et al 2007)		ExGw= 2*G-(R+B)
Migliavacca, M., et al 2011	Canopy greenness	Campbell cc640		Testing color indices, extracting the greenness excess index (Richardson, A.D., et al 2009).
Richardson, A.D., et al 2009	Canopy greenness during Leaf senescence and abscission	- Axis 211 - StarDot; NetCam XL	CCD CMOS	extracting the RGB channels and calculating excess green
Sonnetag, O., et al 2009	Excess green	Previous table in slides		Use of light-grey reference panels ExGw= 2*G-(R+B) Gcc=(G/(G+R+B))

3.1.1 Feature extraction

In the first phase tests, we used a MATLAB based pre-compiled software authored by the US Phenocam network (http://phenocam.sr.unh.edu/webcam/tools/). This program allows one to select regions of interest (ROI) from the image time series, and then to extract colour channel information of these regions and writing those to output text file. ROI were selected based on expert opinion so that they describe area of uniform colours and vegetation.

To integrate the capabilities of Phenocam software to our own established automated process, we started to develop a similar tool. Software development occurs on our server space at FMI. This tool can download images from the FTP server automatically and extract colour channel information for selected regions of interest (ROI). The tool also uses configuration files which can be set up to make different calculations with different ROI, image times and image thresholds, e.g. brightness, by different users. It is also possible to add new calculations to the tool, as new algorithms for data extraction are developed.

The key variable that we have calculated from the images is Green Chromatic Coordinate, which is defined as the relationship of green channel to sum of all channels, i.e.:

$GCC = G /(R + G + B)$.

Is some of the figures we also tested white reference plate scaled GCC, i.e GCC_ref, that was obtained with the above formula but each channel value first divided by the corresponding value of the reference plate.

3.2 Ancillary data

Camera methodology for seasonal monitoring must be validated with other measurements. We will compare image information to the estimates obtained with a number of methodologies. The most equipped study sites contain already a suite of material that can be used, but elsewhere we must establish comparative measurements, which tell about the seasonal development of forests.

3.2.1 Sapflow

Sapflow measures the internal transpiration flux of a tree. The methodology consists of a needle pair injected into the sapwood of a tree. Sapwood contains the water conducting xylem, hence the name ‘sapflow’. The methodology to measure sapflow is described in detail elsewhere (Granier 1987).

The flux of water from soil through the xylem is driven by the atmospheric demand for water, and it is regulated by stomata, i.e. the small pores on the surfaces of leaves of plants. While stomata control the transpiration flux, they also control the CO_2 uptake by the leaves, as the water vapour and CO_2 share the same stomatal route to/from atmosphere. Therefore, the sapflow directly measures the activity of trees, and thus provide important information on the seasonal development of trees, which can be compared to camera images.

3.2.2 Eddy-covariance

The micrometeorological eddy-covariance (EC) method provides us means to estimate the gas exchange between atmosphere and biosphere on an ecosystem level. The methodology is depicted in an earlier project report (Aurela 2014). With a basic EC system we obtain fluxes of CO_2 and H_2O which both can be utilized in assessing the seasonal development of the photosynthetical activity of the ecosystem, which can then be compare with the phenological indexes obtained by the cameras.

4 Installations

During the first year of the project, each other partners installed altogether 14 test cameras (Table 2) to five selected ecosystem sites (Figure 2) to automatically photograph the seasonal phases of vegetation and the development of snow conditions.

We installed cameras to different positions in the ecosystem in order to collect experiences on camera performance in situations and with different targets.

We adopted guidelines of US Phenocam for the installations of cameras (http://phenocam.sr.unh.edu/pdf/PhenoCam_Install_Instructions.pdf). However, in most of the cases, we found out that the guidelines can be followed more or less approximately due to the many site specific features associated with infrastructure and mounting of the cameras, as well as individual illumination conditions at the mounting locations. Moreover, we installed cameras at different elevations with the aims of acquiring information about snow depth and ground storey phenology, which means below canopy installations.

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The following set-ups are used.

Canopy cameras take images from canopies of trees and landscapes, and they may contain several regions of interest (ROI) differing in their phenological timing. See e.g. left panel of Figure 3

Crown cameras take images of individual trees in order to provide information on the structural and ontological developments associated with their phenology, e.g. shoot growth and flowering of trees, which is unlikely seen through colour space analysis. See e.g. right panel of Figure 4.Crown cameras are mounted close to the object, so that the upper half of the crown is visible in the images.

Ground cameras take images from ground vegetation under the forest canopy, or in open positions on peat lands. See e.g. right panel of Figure 3.

Although each of the camera set ups was planned for the above listed targets, in many of the occasions cameras provide somewhat parallel information.

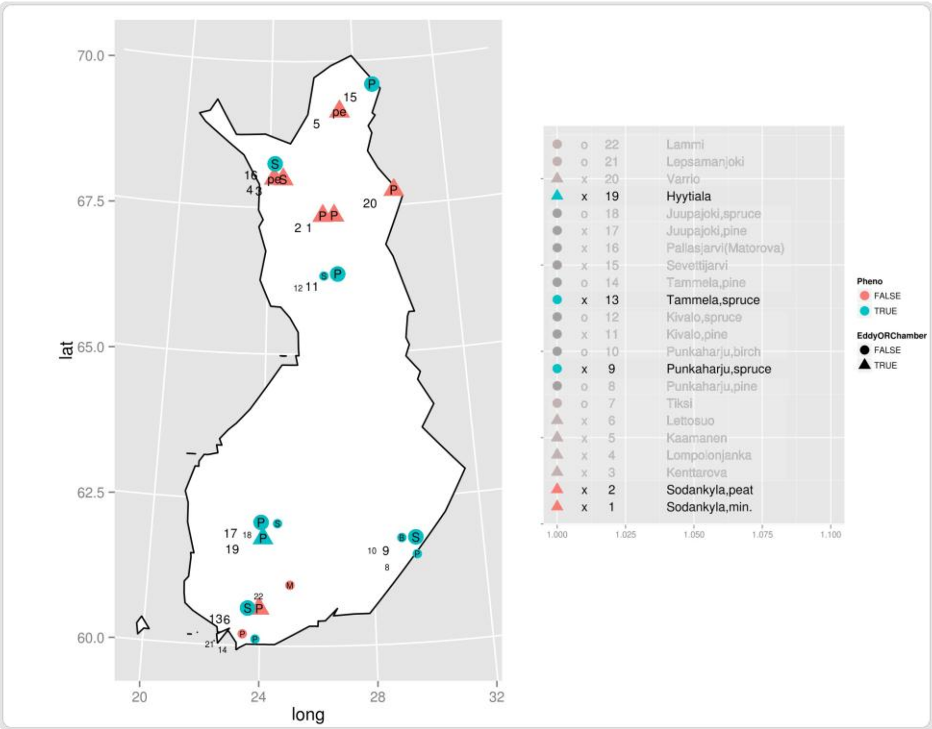

Figure 2 First stage cameras (black text). Grayed text shows candidate sites, which may be used in future. Note, Sodankylä, min means Sodankylä pine forest mentioned elsewhere in the document.

Table 2 Installed cameras and instruments at the sites (X installed in Monimet, x existed earlier).

Site	Camera	Sapflow	Eddy-covariance	Other measurements
Tammela, spruce	Canopy Ground	X		

	Crown (broken)			
Punkaharju, spruce	Canopy	X		
	Crown			
	Crown-IR (Broken)			
	Ground			
Hyytiälä	Crown x 2	x	x	
	Ground			
Sodankylä, pine	Canopy		x	Spectrometer
	Crown			
	Ground			
Sodankylä, peatland	Ground		x	

Figure 3 Tammela spruce site canopy and ground vegetation cameras, 6th Oct 2014

Figure 4 Sodankylä pine canopy and crown cameras, 6th Oct 2014

5 Results

5.1 Methodological tests associated with colour analyses of images

In general, GCC information obtained with cameras correlates with the development of the season. The extent of the response, i.e. how much the GCC values increase, is dependent on the target and ROI.

Greening of the pine crowns in Hyytiälä was gradual in comparison to that of the deciduous crowns (Figure 6). Increase of GCC in deciduous species is partially related to the onset of leaves. None of these changes of GCC were associated with changes in sun elevation angle, which could modulate light spectrum, for example, as similar trends are observed for the entire day and grouping data by elevation angle (Figure 5).

A clear increase of GCC was also detected for ground vegetation in Hyytiälä. Lingonberry is an evergreen specie, so its GCC increase may not entirely be related to onset of new leaves. Lingonberries do, however, produce new leaves during the spring which may partially explain their clear increase of GCC between DOY 140 and 165 in Hyytiälä. Alternative explanation could stem from the greenup of aboveground conifers and changes of colour distribution of incoming radiation to the ground vegetation. However conifer GCC increase was more gradual effect than the increase of GCC of Lingonberries.

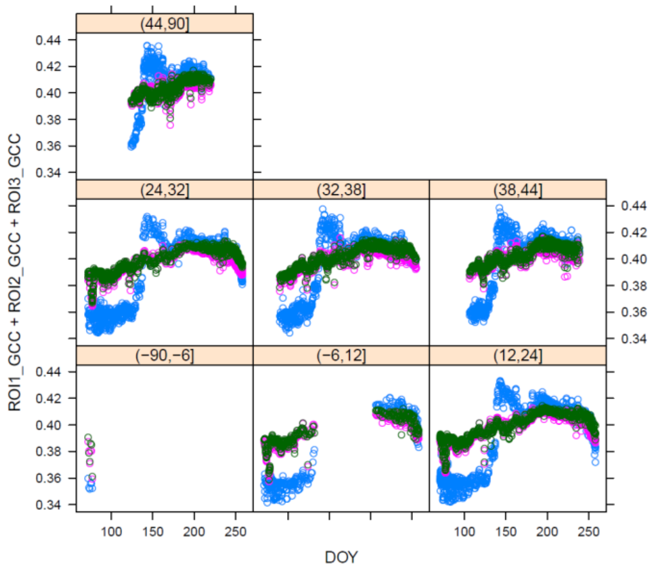

Figure 5 Hyytiälä crown camera ROIs' GCC by sun elevation angle.

Sodankylä pine site had more flat response of GCC than Hyytiälä (Figure 7). Some pattern still existed, in contrast to reference white plates, although it was condensed to a narrow margin. It is also notable that the downward bump in Sodankylä GCC pine GCC occurred at the same time as the decrease of GCC in the peatland site, i.e. approximately between DOY 165 and 175 (Figure 8). Further investigation is required to associate the variability detected to variations of weather and fluxes of carbon.

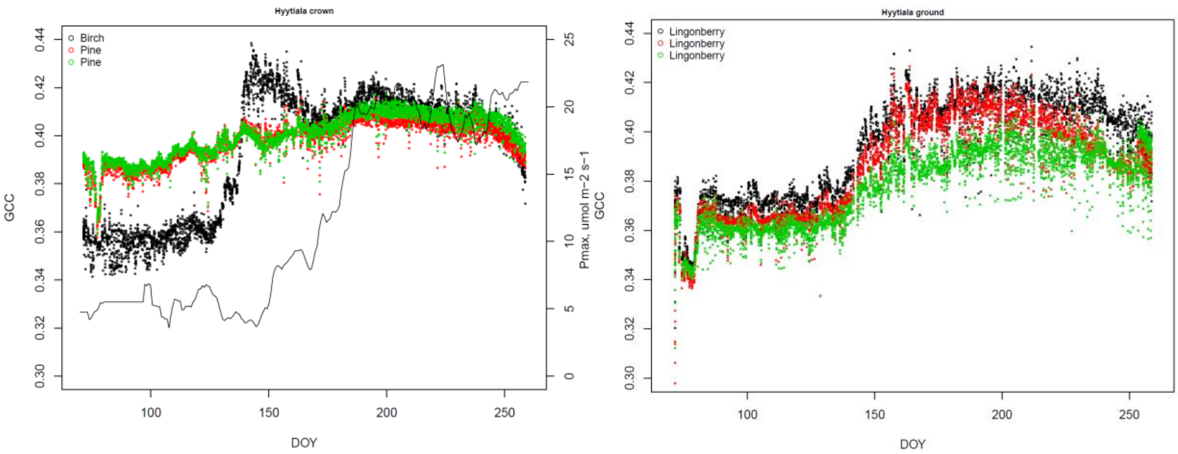

Figure 6 Hyytiälä crowns GCC (left) and understorey GCC (right). Line in the left panel shows the development of photosynthetic capacity (P_{max}, rate of light-saturated photosynthesis in prevailing temperature) of the pine stand, including ground vegetation. P_{max} was estimated daily in moving time window of 9 days from CO_2 fluxes measured by eddy covariance.

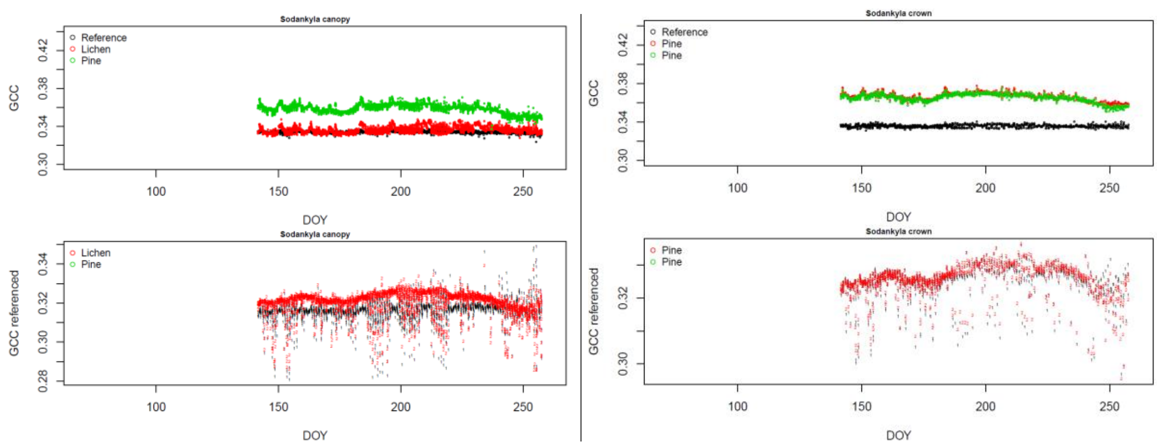

Figure 7 Sodankylä canopy (left) and crown (right) cameras give flat patterns of GCC (top left). White referenced GCC (bottom panels; each RGB channel value is first referenced to white reference plate value) provide a comparable pattern, but with more fluctuation in values.

Sodankylä ground storey camera showed modest variation of GCC, except for the rapid increase of the GCC of bare soil around DOY 195 (Figure 8). Peatland site's GCC increase was very clear.

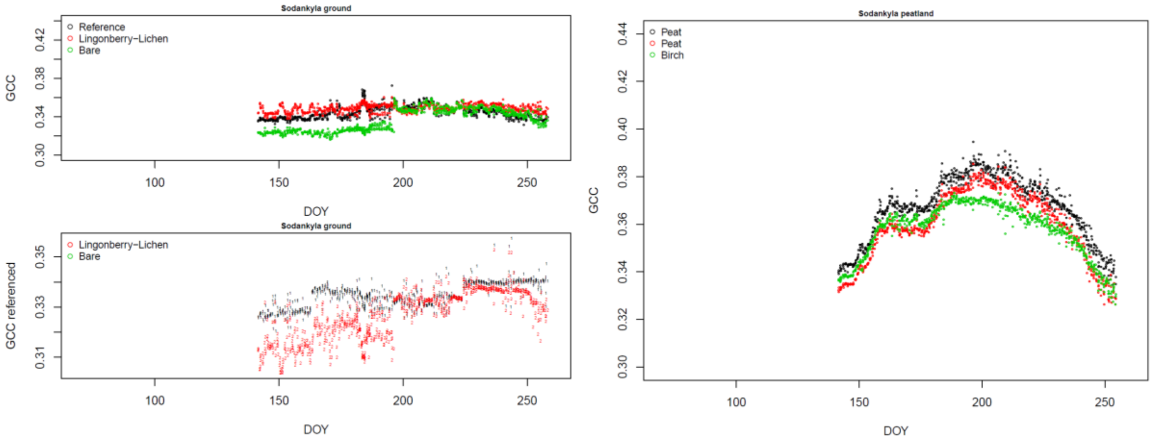

Figure 8 Sodankylä ground vegetation GCC (top left) and white referenced GCC (bottom left). Peatland site has a clear seasonal change in GCC.

Ground vegetation green up in Tammela was very clear (Figure 9), and it occurred during the same time of the season as that in Hyytiälä. The response of GCC in the Tammela spruce canopy was also fairly clear, and it appeared even more clearly when we re-scaled the GCC signal (Figure 10). It is notable that the ROI associated with deciduous species in Tammela is within a spruce forest, so that the potential green-up effect gets mixed with spruce signal (Figure 10). Still the GCC increase of the ROI of deciduous species occurred earlier than the ROI increase of the spruce ROI. Sudden increase of GCC of spruces could be associated with the increase of sapflow that is partially driven by the new shoots that grow in spring. Further investigations are, however, required.

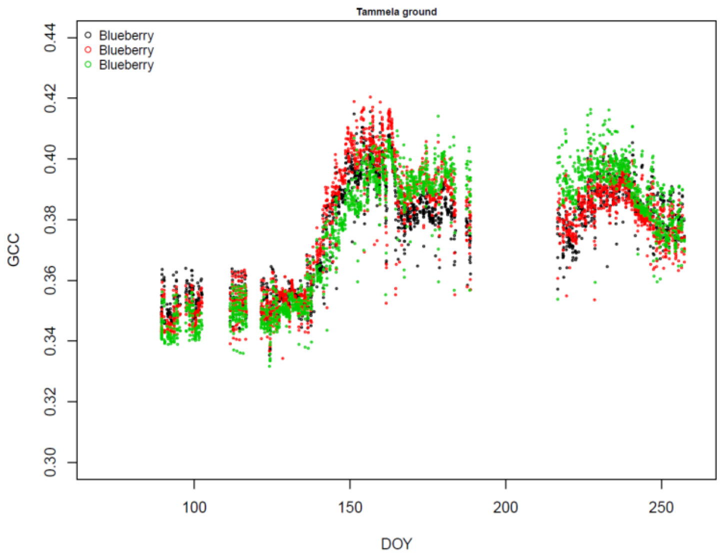

Figure 9 Tammela ground storey shows clear increase of GCC in the spring. (Tammela site time series was interrupted in July due to the lightning storms.)

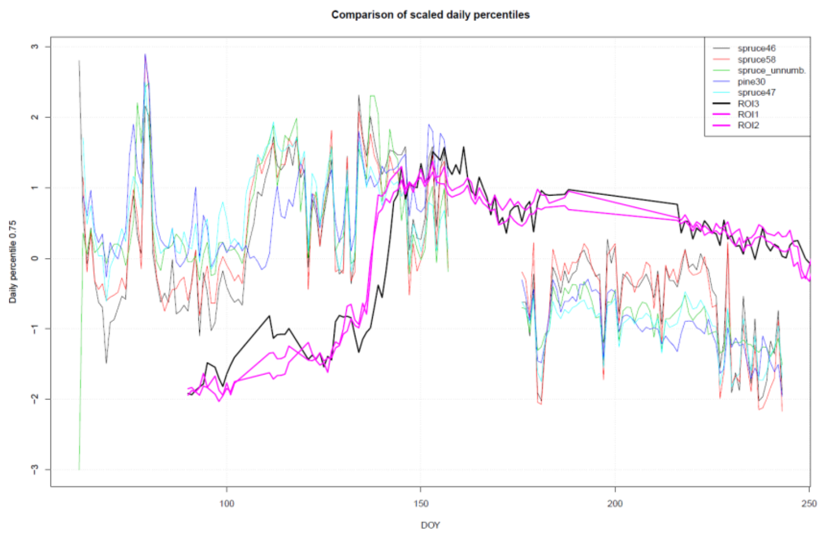

Figure 10 Comparison between sapflow phenology (light lines) and canopy camera (ROIs) GCC (bold lines) at Tammela site. ROI3 is associated with spruce trees' GCC, while ROI1 and ROI32? are deciduous trees. Figure y-axis shows each of the observation series (daily 75 percentiles shown) as scaled with their mean and standard deviations.

5.2 Phenological feature identification based on digital camera images

Phenological cameras can facilitate phenological monitoring of trees by providing image time series of target trees. Recent research shows that coarse resolution web camera images can provide useful information about canopy colour changes, namely in the form of green chromatic coordinate, which follow the other phenological developments of trees and correlate with gas fluxes measured above ecosystems. Correlation of colour changes with fluxes is clear in deciduous forests, where seasonal cycle is dominated by the onset and offset of leaves, while they are less clear in conifer forests.

Another motivation of imaging phenological processes stems from the fact that automated images can facilitate field monitoring of phenological events, which requires frequent visits to field sites. Practical problems, however, are ahead. Some of the phenological cues require careful inspection where the object is brought close to eyes of the monitor. Even though the cameras can be mounted rigidly, the objects – the trees – tend to move with the wind, making images blurry. Many modern cameras, however, have high resolution, light sensitive image cells and physical (or electronic) shake reduction/compensation systems, which allow short exposures and sharp images even under dim light. Such cameras could be weather protected and mounted to ecosystem sites when equipped with appropriate mini-computers and 3G modems. Alternatively, cheaper less sophisticated web-cameras could be mounted on the sites to facilitate monitoring by providing some easily detectable first cues of phenologically active periods.

Our first experiences with web cameras showed that few of the important phenological features can be identified. It seemed that only cone production of spruces and start of shoot growth can be estimated with some accuracy. We therefore continued assessing how good cameras and images are really required. More specifically, we asked what phenological features can be detected if we have a very good camera at our disposal.

Methodology

Camera: Canon EOS 1D Mark III

Lens: Canon 24 – 70 f 2,8.

Distances from objects: vertical images 5 m, horizontal images 7.5 m

Images were taken at overcast conditions.

The camera was let to automatically select the exposure time, aperture, and ISO setting, to optimize the image quality. Images therefore imply what is achievable feature identification with high standard imaging equipment currently. Images were analysed at the resolution of 150 dpi, which provides files of 700 kB, that is upper limit what is acceptable for storing and data transfer from forest locations. Note still, that in spite of the low image resolution, the camera is of very high quality, and minimally sensitive to e.g. variation in illumination conditions.

Due to the fact that the images were taken during a one day in early June 2014, they can describe one phenophase of vegetation. Figure 11 shows example images from pine crown, which were analyzed. Reference to and evaluation of the other phenological features was made using expert judgment.

Figure 11 Examples of photos used in the analyses. Images of larger size were analysed. Photos Erkki Oksanen, Metla.

5.2.1 Conifer phenology

Onset of height growth

Onset of height growth starts from the bud burst of a shoot. The bud is small (diameter 3-4 mm), so the timing of bud burst is very difficult to detect.

Elongation of shoot

Once the bud has burst and started to grow, it is possible to follow the length growth of the shoot.

End of height growth (shoot extension)

End of shoot growth is possible to detect from the moment the shoot stops growing with an accuracy of few days.

Timing of needle growth

Needle growth of pine should be clearly visible as it is accompanied with colour changes. Especially the spruce has clearly light green new needles.

Onset of male flowering

Pine male flowers are fairly large, so they are likely detectable. Spruce male flowers require more from the cameras because they are smaller. Associated colour changes? Especially pine male flowers are clearly visible as it is associated with colour changes of a shoot.

Most of male flowers of both trees are located lower in the canopy than female flowers, which also requires higher mounting of the camera.

Onset of pollen release

The onset of pollen release is likely impossible to detect from structural features of trees. However, high peaks in pollen release could possibly be captured from exact colour analysis of crown details as pollen can land on needle surfaces.

Onset of female flowering

This is important feature of tree phenology, and it should be detectable with spruce. For spruce the female flowers are distinctly red or light green. However, the resolution needs to be high to detect whether the flowers are open or closed, as it is ecologically the most important aspect.

For pine, the female flowers are much smaller (diameter approx. 5 mm), and require a very good image in order to see whether the flower is open or not.

Female flowering finished, 100%

This is fairly difficult variable, but there is potential for its monitoring with repeated images (whether the flower is closed).

Needle yellowing and shedding

Spruce sheds needles mainly during spring fairly evenly throughout the year, while pine sheds its needles in comparatively short period (mostly from the oldest cohort) in late summer and early autumn after the season. Pine shedding is associated with yellowing of those needles that are going to be shed. The extent of yellowing varies by year, but it should be detectable for pine.

5.2.2 Birch phenology

Bud burst

First signs of colour changes associated with budburst (peeking green from the bud) should be detectable. However, the can be a systematic bias in comparison to site monitoring, because the subjective criteria of budburst may not exactly correspond to the criteria defined for image analyses.

Onset of pollen release

Male flowers can be detected from close up images with a good camera resolution. The onset of pollen releases is likely impossible to observe due to small size of pollen and low density of occasional pollen clouds.

Leaves full-sized

Determination whether the leave size has matured requires good resolution images, and can be then determined with a likely accuracy of few days.

Shedding of seeds

Shedding of seeds is likely impossible, but perhaps possible from ground cameras images, as high number of seeds tends to accumulate on ground. However, automation of this process is difficult, or the terrain must be specifically prepared for such analyses.

Leaf colouring

Leaf colour changes are possible to detect.

Leaf fall

Timing of leaf fall extends to long periods, but it is possible to detect from image time series, e.g. a point when approximately 90% leaves have fallen.

6 Recommendations for further work

It seems that monitoring phenology can be facilitated with cameras, especially that of deciduous species, peatlands and ground vegetation. Thus, they can provide important ground reference e.g. to satellite observations. Monitoring of conifer phenology seems more challenging. Our data so far, however, suggests that greenness varies according to weather conditions (temporal reduction of GCC in Sodankylä), but exact reasons are still unclear. Illumination conditions (solar elevation), on the other hand, seem to affect little the analysis. Relationship of GCC needs to be investigated further and in relation to existing and new supporting measurements at sites.

Experiences with cameras so far, suggest that we should allocate tree crown and canopy cameras of conifer trees to sites where we have plenty of supporting data. Additional measurements are also needed in order to disentangle the reasons for greenness variations, which require further measurements on e.g. leaf level attributes during the forthcoming period of the project.

Installations of cameras to the sites require many time-consuming considerations, and it is rare that any given detailed reference set up can be followed as it is. We found out this while following PhenoCam guidelines for the canopy cameras. For example, adult trees tend to be as high as masts, so we must make compromises on the viewing angle selection, which makes it more difficult evaluate LAI of canopy. We cannot follow guided reference sensitivities of camera colour channels because they easily induced overexposure of images. We may not be always able to point cameras towards north to minimise shadow formation on images, as there may not be suitable targets at that direction (e.g. Punkaharju spruce forest, where winter storm cleared the forest from north side of the mast). It would be also ideal to detect the phenology of deciduous species within deciduous background to avoid partial mixture of signals with conifers, but this is rarely possible in mixed forests. Experiences on installation so far, seem to indicate the most of such compromises are not fatal, as we were able to extract clear GCC changes from images.

Stardot SC 5 MP cameras showed fairly flat response of GCC, which could be associated partially with the camera image cell characteristics, and partially to image sensitivity settings. Comparison to GCC information produced by other cameras is required before further purchase of cameras. During the stage 1 tests, also two of our cameras (Punkaharju crown IR-enabled camera and Tammela crown camera) were dropped off from the network, indicating likely technical failure. We will investigate reasons for this, and reconsider the selection of the camera brand for the further purchases.

We had succeeded fairly well in selecting the exposure ratio for cameras (slightly underexposed selected), so there were few overexposed images. However, some of the white reference plates showed saturation at blue channel. This can be avoided by selecting slightly darker grey paint for the future reference plates.

Monitoring of phenological features, such as cone production and flowering requires close-up images made with high quality cameras. It seems unlikely that web cameras offer that in near future unless moved to the very vicinity of the target, in which case the within crown representativeness of the camera images is severely hampered. The same camera may not then be applicable for the detection of male and female flowering of trees next to each other because flowers tend to be concentrated in different parts of the crown. Automated extraction of phenological features, however, requires more elaborate algorithms than those used for colour analyses. We will investigate realistic high quality camera set-ups that could be mounted close to the canopy.

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