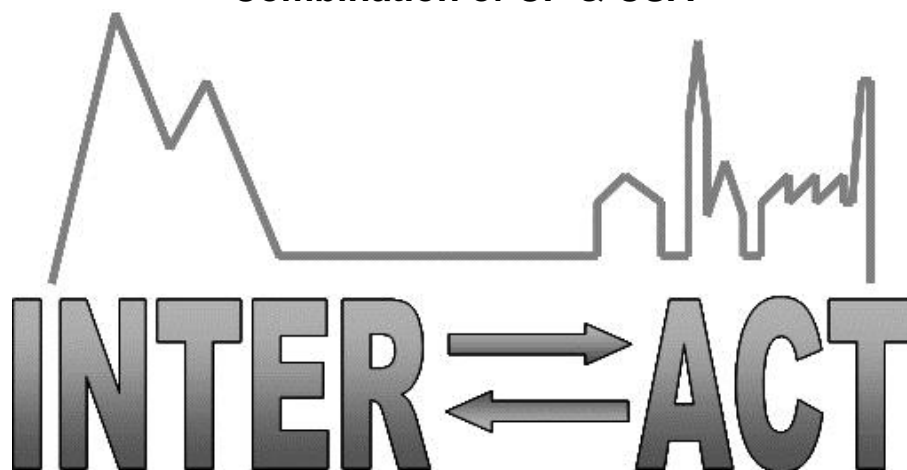# Combination of CP & CSA

D5.3- Tested Prototype
Automatic Monitoring System for Phenology

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

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Publishable Executive Summary

We devised a new workflow for phenology monitoring based on pictures taken in the field. This is the necessary first step towards an automatic monitoring system for phenology. Our workflow allows for an offline, reproducible counting of plants at various stages of their development. The image time series thus acquired in the field can be reused for other purposes or distributed as raw data for documentation. The field test we conducted at Zackenberg shows very promising results

1. Introduction

1.1. Manual Phenology Monitoring

One of the Biobasis long term monitoring programs at Zackenberg focuses on inter-annual variability of plant phenology and productivity [6]. The goal is to elucidate specific vegetation responses to climactic variations [6]. This is the program we target in this work.

There are various ways of measuring phenology but we are interested in the one based on plot counts. Plots are structures designed to mark a piece of land that is interesting. Counting elements of interest within the plot boundary is the preferred method to measure what occurs inside. Examples of measured variables are: percentage of snow cover, Number of fully open leaves and number of males of a species.

To do the plot counts a technician covers the plot describing a zig-zag pattern (see Figure 1). The plot is divided in strips of 1 meter in width. The technician will start in one corner of the plot and walk from one side to the other within one of these imaginary strips. When the end of the strip is reached, she jumps to an adjacent strip and walks in the opposite direction. This will go on until the plot is covered completely or the maximum amount of plants has been counted.

Figure 1: Imaginary walkways on a regular plot
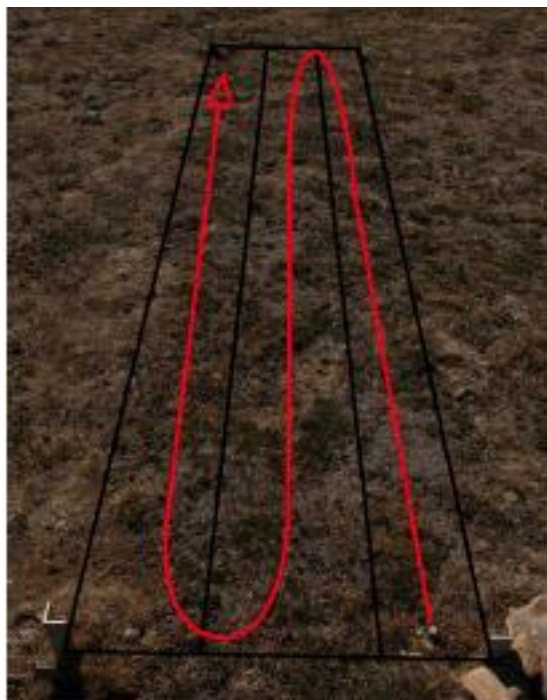
As the technician moves forward inside the imaginary strip, she scans the floor for interesting elements and counts every occurrence. Some elements are going to be in the middle of the imaginary strip, but others are going to be on the sides; close to the adjacent imaginary strip. When the technician sees the elements that are on the side she will decide whether to count

them along with the ones from the current strip, or leave them for when she comes back. It is here that two types of errors can occur: 1. The technician might ignore an element thinking that it will be counted on the way back, only to ignore it again because she did not recognize it as pending or just missed it. We will refer to this error as Missed Counts. And 2. The technician might count an element thinking that it will be ignored on the way back, only to count it once more because she did not recognize it as counted. We will refer to this error as Double Counts.

While all the technicians acknowledge this type of error, they also clarify that there is no way (at the moment) to know the effects it has on the measurements. There is not way to know how often it happens. More importantly, there is no way to recount – as a plot count is an event that occurs in the field at a given point in time. The way this issue is addressed is by trusting the technician on the one hand and the sample size on the other hand. Whether this approach is robust or statistically sound is an open issue. What is sure is that this approach is costly and non-reproducible. This is the problem we aim at addressing with automatic phenology monitoring.

1.2. The Promise of Automatic Phenology Monitoring

This work is based on the insight that redesigning the current process into an image dependent work-flow (that leverages known computer vision methods) could contribute to (i) reducing the cost of phenology monitoring, (ii) making phenology monitoring reproducible, and (iii) effectively eliminating the uncertainty produced by double counts and missed counts in the manual process.

Our original intention was to devise an imager-based infrastructure attached to a given plot. We quickly realized that (i) the resolution of low-cost imagers does not allow today to apply efficient computer visions techniques, and (ii) ecologist much prefer a portable, low-overhead method to an infrastructure that requires maintenance.

We thus decided to reorient our work and devise a new workflow for plant monitoring based on images taken by ecologists with a high resolution camera.

1.3. Homography Aided Plot Based Phenology Measurements

In this document, we describe a new work-flow for plant phenology monitoring and report on the test we conducted in Zackenberg during the summer season 2012. The new workflow replaces the manual counts previously done in the field on physical plots, with counts done on images. It is for this reason that we denominate it photo-plot work-flow.

Much of the photo-plot work-flow relates to images and how these are processed. A main component is an automated image processing algorithm that normalizes pictures from the field into a common format. After execution the images will seem to be taken from the same point. Because of its nature we denominate it normalization algorithm.

Finally we developed graphical user interface (GUI) designed to annotate images. It differentiates itself from other labelers in that it is specifically designed to work with time

series of phenological plot images. Since it is used for annotations we refer to it as the annotation GUI.

2.   Manual Workflow

For reference, we describe here in detail the manual workflow currently used at Zackenberg for plant phenology monitoring. The current work-flow begins in the field1. The technician has to first decide on a day in which to do the phenology. This will depend on the date in which the previous count was done and on the expected weather conditions. On the selected day all the plots are visited in the order which is thought to require less effort. For each plot the technician will collect two types of measurements: normalized difference vegetation index (NDVI) and phenology measurements. These are expected to be closely related as the amount of green in a plot fluctuates in sync with phenological dates. It would be strange to see very low NDVI numbers in the middle of the season when plots contain plant activity. In the same way it wouldn't be normal to have high NDVI measurements at the beginning of the season, when snow covers most of the plots.

NDVI is related to the characteristic of all green vegetation where chlorophyll doesn't reflect light at red wave lengths (centered 730nm) but scatters the light that is close to the near infrared (NIR) range (centered at 800nm). This difference of reflectance varies with the amount of pigment present in the plants but can be used for long-term monitoring. NDVI is of importance to biologists because it can be correlated with variables like biomass, leaf area index and CO_2 flux.

NDVI is collected with a measuring apparatus which is composed of a logger and the sensor both attached by a tube extension that allows reaching into the plots. The sensor is configured to do ten measurements per second which it sends directly to the logger. The measurements get saved into a file together with its GPS position. The file is later aggregated to phonological data coming from its plot.

NDVI measurements are taken along two of the four sides of the plots. Most of the area is covered by the NDVI measurement unless the plot is large; in this case the sections towards the middle are effectively ignored. The NDVI measurements are kept to a minimum to try to reduce the impact on the plot (by walking inside) and the time spent doing the measurements. The impact on the plots is important. While the biologists want to gather as much information as possible, they would like to avoid influencing the data with the method. It has been found for example that walking both inside and along side the plots creates paths in which the ground is compacted, effectively changing the behavior of the plants in that spot. It is also important to minimize the time spent on a plot. The time allocated for completing extra work could be assigned on more pressing activities like analyzing control plots or creating extra plots that include other diversities in the field. Diversity in this context refers to different environmental metavariables (orthogonal to phenological counts) like soil moisture, soil chemistry and altitude.

The NDVI and the phenological counts are done consecutively for each plot. While the order is not important, it is crucial that the NDVI data is somehow linked with the phenological

counts. The technician carries a personal data assistant (PDA) where all the plant phenology variables are recorded. The PDA runs ArcPad a geographical information system (GIS) software distributed by ESRI that provides a digital field sheet. Besides all the plant phenology data, this sheet must contain the name of the file of the NDVI measurements of the same plot. It is with the file name that the data from the NDVI apparatus gets linked to the phenology counts.

The exact phenological variables that are measured in a given plot depend on the species. Different species have different stages of maturity in their seasonal cycle and therefore have different phenological dates. The *Salix arctica*, for example, has a total of eight phenological dates, while the *Silene acaulis* has only five. This variability among species requires the data to be highly customized when filling out the forms in the PDA. There is a protocol called The International Tundra Experiment (ITEX) that defines various aspects of high arctic monitoring. While it defines what to measure for each species, it is the specific scientific stations (like Zackenberg) that make the final list of variables.

To add to the species variability, not all plots are the same size. In Zackenberg's specific case the sizes range from 2 m^2 to 300 m^2. Though none of the biologists we interviewed were present at the time when the plot sizes were defined, they all agreed that the main decision factor was related to the amount of individuals from a species within a plot (note that "individual" does not necessarily mean flower). In other words, the plots should be big enough to accurately sample the behavior of a species; they would have large plots for sparse species and small ones for dense populations.

Currently plots have objects that identify and delimit them. This is important so other scientists don't inadvertently disturb the area of interest. Moreover in winter, when snow covers everything, it is practical to have artificial points of reference. Each plot has a high pole that marks its proximity. This is useful in the snowy part of the season when everything is hidden. Stakes are used to mark the corners as these are low and could get covered by the snow. On one of the corners, a plate contains a code that defines the type of plot (usually depending on the species or type of experiment). For the big plots there is a stake that marks the middle of the plot. This divides the plot in four and serves as a reference when the technician is doing the counts within the sub-plots.

At the moment when the plant population peaks, there could be potentially thousands of individuals to be counted. Therefore the weekly counts stop at one hundred or fifty; depending on the species. This is essentially a trade off between an accurate and extremely time consuming process (counting the whole plot every week) and a fast and "incomplete" one (counting a percentage of the plot every week). There is however one week where they do a total count of the plot. This happens whenever the technician has ascertained that there are no more new flowers emerging. The resulting number is called the total production of the plot.

Before the technician begins counting a plot, she resets the mechanical counters (see Figure 2). One is needed for each variable that is being measured. After everything is set to zero she walks into the plot clicking once for every instance that she sees. When what is seen is

ambiguous, the technician can get closer and even remove occluding material (like debris or scat) to get a better view. This is done while being careful of not stepping over important vegetation. Though special attention is given towards avoiding double counts and avoiding missing instances, these two phenomena are an inevitable presence that adds to the inaccuracy of the process.

Figure 2: Mechanical counters used in the field

The technician stops the count when she has reached the maximum amount of instances that should be counted or when there is no more plots left to cover. The small plots allow for the technician to do the counts without actually stepping into the plot. For the bigger ones the technician has to walk in a specific pattern (zig-zag-like pattern in Figure 1) that facilitates accurate counting while minimizing plot exposure.

When the plots are too big, they are separated into smaller sub-plots. In these cases the process is done in the sub-plots as if they were "complete" plots. Each has an individual phenological count but the NDVI is taken on the periphery of the containing plot. The idea behind the subdivision is to get a sample that is spread out evenly within the plot.

After finishing the counts, the technician feeds the data from the mechanical counters into the PDA being careful to relate it with the NDVI measurement file. The field sheet in the PDA also requires the insertion of additional variables like cloud cover, snow cover (percentage of the plot covered by snow) and precipitation conditions. All these procedures are repeated for all the existing plots in the field. In the case of the normal counts, it takes most part of the day to complete the task. In the case of the total counts, it could take up to two days. In any case the result is multiple files in the PDA that describe the state of the plots.

When the technician returns to the station, these files get automatically synchronized to a

laptop. At this point most of the physical work is done, but there is one last step before the end. Before the technician can consider the phenological counts as done, she must validate the data in the office. There are various mistakes that can be easily detected by just perusing the data. Sometimes a mechanical counter is not reset before a count; this will cause the count to be too large. This is easily detected when a large number is seen in the data sheets. One way of correcting this would be to redo the plot counts or adjust the erroneous value using the surrounding data. Another type of mistake can come from interfacing with the PDA. The technician might have thought that she selected 80% cloud cover, when in reality another value was selected. These types of errors can be easily corrected by little adjustments in the data. Finally, notice that though there is a session of data validation at the end of the process, there is still a possibility of missing some details.

At Zackenberg security copies of the data are constantly made. Besides having the whole season in the PDA and in the main office laptop, backup copies are made to DVD and kept in different locations inside the station. The media is kept until it is possible to send it back to DMU. At the moment, the only way to electronically get data out is through a satellite connection. This is extremely expensive and researchers tend to avoid the unnecessary use of this medium. The only other way to get data out of the station is through the hands of people leaving. During most of the operational season at Zackenberg there is a constant flow of researchers arriving and leaving from the station. When there is a chance of them taking data back, they are given copies to take to DMU in Roskilde. At the end of the Zackenberg season the phenological counts are stopped. The temperature drops to levels below zero which negatively affects most of plants. The snow also begins to cover the plots making phenological counts irrelevant. At this point the final copies of the data are made ready to be shipped out to DMU together with the last remaining scientists. This last shipment represents the data set for the whole season and multiple copies are taken to ensure that no part of it is lost.

Back at the DMU offices, after the last bit of the data arrives, the scientists need to consolidate everything into a consistent set. There are three processes involved in this: the first has to do with putting together data that is kept in multiple storage mediums. Data from all the DVDs that were brought during the season are put in one place. The second is related to data presentation which involves transforming the data into text files for uploading to the web server. The third is a final check of the data before publication. The data is finally uploaded onto servers hosted by DMU where researchers can gain access to it for free.
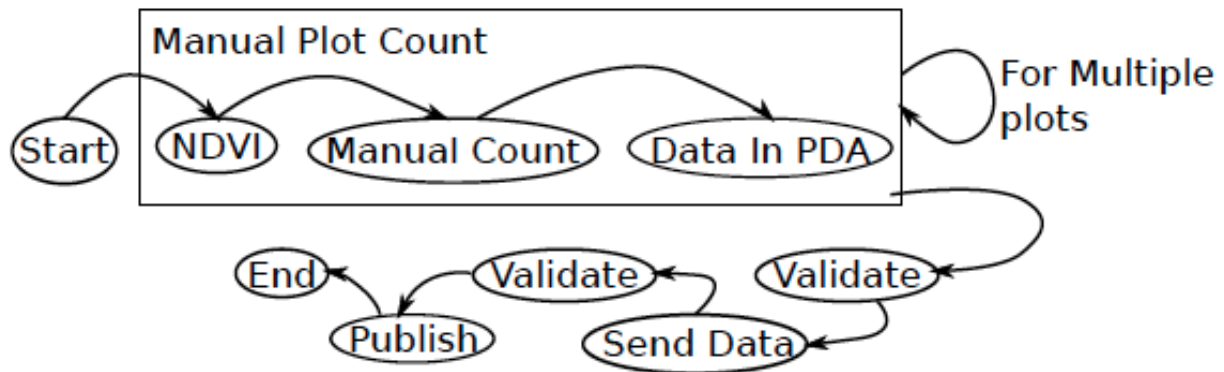
Figure 3: Manual workflow

3. Photo-Plot Workflow

In general the Photo-plot work-flow will focus on changing what is currently done in the field. All the stages that occur after the digitalization of the plant counts are the same. Though parallel measurements (NDVI, cloud cover and precipitation) will be associated with plant counts in a different way, the process of extracting them is unchanged. Moreover, the format of the data at its final resting place is also untouched. This means that the new process will be transparent for scientists that currently use the data.

3.1.Taking photographs

To implement the new workflow the plots need to be fitted with new markers hat subdivide the plot further (see Figure 4). For the smaller plots there would be no additional subdivision as the new process works well with areas that are under 4 m^2. The bigger plots however, need to be subdivided in sections that are equal or less than 4 m^2. In any case the plots need to be delimited by an ID marker (see 3.2) and three corner reference markers. To differentiate the plots from their subdivisions we will refer to the latter as photo-plots (note that there is a difference between the plot corners and the photo-plot corners). Each of the elements delimiting the photo-plots shall be waterproof and sturdy to withstand the elements. Also, they shall be positioned close to the ground to reduce the effects on plants.

The manual counts are replaced with pictures. Instead of the technician walking inside the plots with the physical counters, she only needs to take pictures of the photo-plots. She will collect various pictures of one photoplot and do this for all the photo-plots in the field. The pictures will then be stored (as with the original workflow) in different mediums at different locations in the station. From this point the photo-plot workflow is highly customizable because the post-processing does not depend on the technician in the field. It could be considered important to do an initial validation before the images are shipped back to DMU; in this case the post-processing should begin at Zackenberg. On the other hand, if this is deemed unnecessary, the rest of the process can be moved out of Zackenberg (into DMU offices) effectively freeing valuable and expensive technician hours. In any case, the decision of where and when to do the rest of the photo-plot work-flow depends on specific

implementation. Note that the rest of the process will now be centred in some form of image handling.

Figure 4: Photo-plot workflow

3.2. Normalization

Image files contain meta-data with information about the camera settings; things like the date, what aperture was used and the ISO setting are examples of this. Even with all this, we are still missing two essential elements for the photo-plot work-flow: (1) A way to uniquely distinguish the images of the photo-plots, and (2) A way to work with pictures that have the same image plane coordinates These two elements are added by the image normalizing algorithm. The photo-plot ID value is calculated from the ID marker (see Figure 5).

Figure 5: ID Markers (colour vs. black/white)

The ID number is then added to the image meta-data which should enable the system to answer questions about the place where the pictures were taken. The normalization algorithm also modifies the image. It uses Homography, algebraic transforms and pattern recognition to go from the original image matrix to one that is common for all the images. At the end of this second process elements in pictures taken of the same place at different times and from different perspectives will coincide when superimposed. It would be as if all pictures were taken from the same spot. We refer interested readers to Joel Granados thesis for more details on the normalization algorithm and on markers[1].

3.3. Annotation GUI

Once the automatic normalization has taken place, the phenological counts can start. Notice that the product of the Normalization is an image time series. The counts are done through an annotation GUI application that aids in identifying elements of interest in images. A useful feature in the GUI application is that it is able to show a photo-plot at any point in time. The counts can actually begin at a point where it is easier to detect the phenological dates. This would probably be when the plots peak in production. The idea is for the GUI to propagate the annotations through the image time series (both forward in time, and back in time). Therefore an annotation done in one image (corresponding at one point in time) will show up in the images that come before and after.

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[1] http://joelgranados.wordpress.com/2011/11/19/masters-document-prezi-presentation/
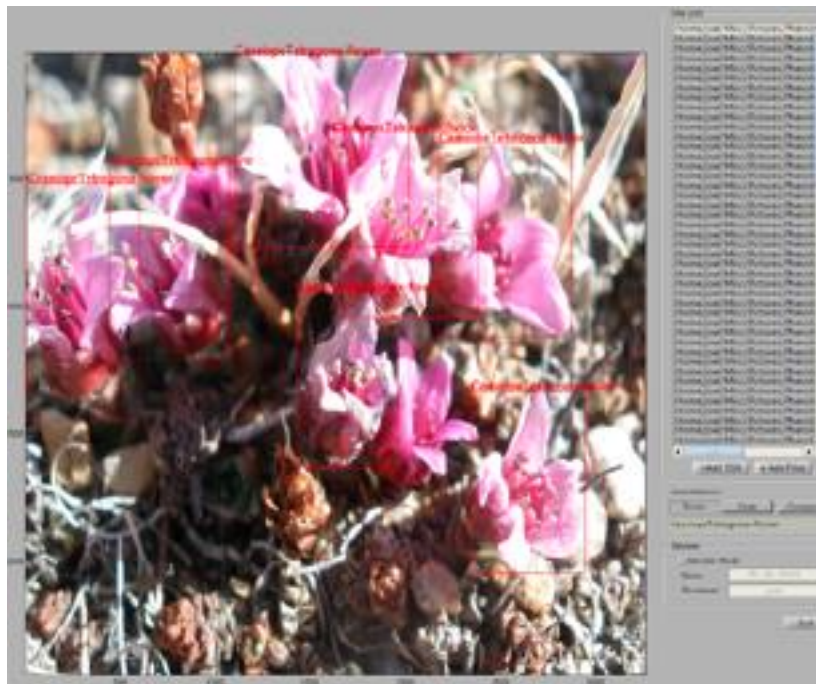
Figure 6: Annotation GUI

As the photo-plot counts advance, the application will create an annotation file for every group of pictures of a photo-plot taken on a particular date. The final data will be a transformation of these annotation text files into the format used in the Zackenberg GIS data repository. The transformation from one format to the other can be done by means of a script. Having the raw data in form of images might change the way it is published. At the moment Zackenberg data is distributed as flat text files that contain all the phenological counts in a season. This distribution method has positive characteristics like the small file size (making download fast and reliable) together with low complexity. Though this would still be the case with the photo-plot counts, there could be gain in publishing the images where the data was extracted from. This could be useful in one of two ways: (1) It can serve as material for further validation of the data and (2) It can be used for other purposes.

Given that the photo-plot work-flow relies on images, resolution is an important factor. With low resolution the markers will not be detected consistently and the flowers would be increasingly difficult to annotate. To avoid these pitfalls the technician taking the pictures should be careful to get as close as possible to the photo-plot.

Occlusion on the other hand is something that might be unavoidable. It is equally as important as resolution because it affects the accuracy of the photo-plot work-flow. It occurs when there is something between the object of interest and the camera. To avoid the occluding object it is sometimes enough to just change the position of the camera. We will mitigate it by taking various pictures from different positions but understand that it is unavoidable. We expect the effects of occlusion in a time series to be minimal because of the type of vegetation at Zackenberg, the existence of multiple shots and the natural movement of the growing vegetation

4. Zackenberg Field Test

In this Section, we report on the field test we conducted at Zackenberg in the summer 2012. Note that our original intention was to experiment at Abisko as well. However, such an experiment was not possible within the budget of WP5.

4.1. Protocol

Here is the protocol that was prepared by Joel Granados and used by the technicians at Zackenberg during the field test conduced in August 2012.

How to setup the photo-plots:

We are going to start off with 4 or 5 photo-plots. They should be located wherever it is most convenient for the technician (Was thinking of the wet land adjacent to the runway). Once a patch of land has been selected, the photo-plots can be placed in any required position. Be cautious to not have any overlap between photo-plots; this is important so there are only markers from **ONE** photo-plot in an image.

The size of the plots depends on the type of camera and lens that is being used. The rule of thumb is for the pictures to contain all 4 corners of the photo-plot. I successfully tested with 1 meter square regions.

The species contained within the photo-plots can be whatever the technician deems convenient. Please notice that color **IS** important for proper detection. If you choose a species that is yellow, then you should use a marker of a different color. I'll provide red and yellow markers.

A photo-plot consists of 4 markers: 1 Chessboard marker and 3 sphere markers. To create a photo-plot you must place each element in a corner of the plot. Each sphere has a steak that is to be used to fasten it to the ground. The chessboard is similar to the ones we deployed last year. It connects to a stake that is used to fasten it to the ground. Please use the stakes that are already in Zackenberg.

Try to make the photo-plots as square as possible.

Be sure that all the corner elements (spheres and chessboard marker) can be seen by a camera. Try to place them in places that don't have obstructions. Make sure the chessboard is facing upward. Remember that the picture will be taken from above the photo-plot.

How to picture the photo-plots:

One of the most important things when taking the picture is to try to fill the picture space with the plot. To achieve this the picture should be taken from above and **as close to the plot as possible**. Try to align the photo-plot corners with the image corners.

Take more than one picture of a plot. Sometimes the auto-focus is slow, or the lighting might change a bit due to clouds. Taking at least 3 pictures is a good idea. Taking more is encouraged.

Be careful with the position of your shadow. Try not to take a picture of a photo-plot that contains the shadow of the photographer.

In the best case scenario the pictures will be taken from above the midpoint of the photo-plot. If the photo-plot is too big, it can be managed with an extension to the centre (camera attached to a tripod or stick). If this is not possible, get as close to the centre as possible. Notice that all the pictures are to be with a hand held camera.

How often pictures are taken is dependent on the workload of the technician. We want to do two measurements per week. We hope that choosing photo-plot close the the station will make this possible.

Image format is not extremely important. JPG is preferred, but the algorithm can also work with PNG and TIFF. No Raw format please (They will be turned into JPGS anyway). No compression for JPGS. No lossy compression of any kind.

Work with the maximum resolution of the camera.

Please work with the automatic settings on the camera. This could mean a lot of things for different cameras. In the cases where the camera has more than one automatic setting, choose one and stick to that one throughout the whole experiment.

Avoid the use of flash. This would mean that the pictures should be taken during the day (don't think this will be a problem for the arctic during mid year:)

Normal Work-flow:
Remember that we are comparing two ways of doing phenology. Each time phenology is done on the photo-plots, both work-flows must be performed. This means that for every photographed plot, the technician needs to do a "manual" phenology count. We hope that having only 4 to 5 plots will make this task possible.

Remember that normal work-flow includes everything related to the data acquisition: plant count, picture of the plot, resetting the counters, putting the data in the PDA....

How to Document normal and photo-plot phenology:
The objective for this year's deployment is to gather enough information to compare the normal work-flow and the new photo-plot work-flow. With this in mind we would like to gather as much information as possible. One important variable is work-flow time (both photo-plot and old). I see two possibilities here:

1. Filming the process: If all the created photo-plots are in the same area, the technicians can setup a camera before the whole process and film themselves doing both the normal and the photo-plot measurements. After both measurements are done, the recording can be stopped. There is no need for High def video, I think a 2megapixel resolution is more than enough. For this approach to work, the photo-plots should be located within a small geographical area; the camera is then placed in a strategic location that will record activity in all the plots. Remember, there is no need to see little details of the process, the important thing is to see what process is being done (photo-plot or normal) and how long it took.

2. Creating a diary of start/stop times. The technician would record start stop times for normal work-flows and start stop times for photo-plot work-flow.

3. A third option might be to work with both these systems. Use the camera when possible, but prefer the diary when its raining, windy, snowing or otherwise not possible.

Other comments

These are the things I had on my mind regarding the process to follow in Zackenberg. I could have missed some things and will update the document if needed. If you have any questions please contact me at jogr@itu.dk.

4.2. Results

4.2.1. Field Report

Here is the field report completed by Lars Holst Hansen.

Quadratic plots measuring 80 by 80 cm were marked in areas with Mountain avens (*Dryas sp.*) with 3 spherical coloured markers and one checkerboard marker with coloured ID pattern (see photo 1). Phenology was then monitored weekly by counting the number of buds, flowers and senescent flowers using mechanical tally counters (photo 2). All buds, flowers and senescent flowers within the 80 by 80 cm were counted every time. Also, the number of flowers showing signs of herbivory by moth larvae (*Sympistis zetterstedtii*) was counted. In addition, at least 4 photos covering the whole plot including markers were taken from above and from each side at each count. A total of 9 plots were marked out and a total of 69 counts and photo registrations were made during the season by 3 different field workers (Lars Holst Hansen, Palle Smedegaard Nielsen and Jannik Hansen) from 2012-06-15 to 2012-08-06.

Figure 7: Plot showing spherical and and checkerboard markers (Photo: Lars Holst Hansen).

4.2.2. Workflow evaluation

Table 1 summarizes the volume of data that was obtained during the field test.

Plot #	Nb Pics	Missing	Date missing
16	4	1	12-07-29
20	4	1	12-07-29
59	4	0	
0	8	1	12-06-25
24	8	1	12-07-15

35	8	1	12-06-25
4	8	0	
47	8	2	12-07-{2,29}
63	8	2	12-06-25,12-07-2

Table 1: Volume of data collected during the field test

Joel Granados conducted the plot count on the available pictures for plot 59 and plot 4 using the annotation GUI. He timed himself doing the counts for each. He then compared the counts that he got with the counts that were obtained in the field. The results are summarized in table 2 for plot 59.

Date	Type	Buds	Flowers	Senescent	Larvae	Eaten	Total
6/15/2012	field	75	0	0	0	0	75
6/15/2012	photo	85	0	0	0	0	85
6/17/2012	field	93	2	0	0	0	95
6/17/2012	photo	114	2	0	0	0	116
6/25/2012	field	3	105	4	0	3	115
6/25/2012	photo	37	96	0	0	0	133
7/2/2012	field	0	22	91	0	0	113
7/2/2012	photo	0	36	97	0	0	113
7/8/2012	field	0	1	70	0	0	71
7/8/2012	photo	0	1	126	0	0	127
7/15/2012	field	0	0	105	0	0	105
7/15/2012	photo	0	0	108	0	0	108

Table 2: Comparison of manual count (field) and photo-plot count (photo) on 10 images

When analyzing the differences between Joel's photo counts and the one obtained in the field, we should keep in mind that Joel is a computer scientist who had never seen a *Dryas* prior to this count. With that in mind, these initial results are impressive. What is more relevant is that these counts can be reproduced, in parallel, by many different persons. So, we can for example try to have an ecologist perform the count to see how accurate Joel's count is. In terms of time spent, Joel worked on a total of 10 images and spent 106 minutes in total. That would give an average of 10 minutes per image. This, of course, is a preliminary result, but it gives a general idea of how effective this process could become.

4.2.3. Lessons Learned

Here are some of the lessons we learned while preparing for the field test. One of the unexpected issues that we had was related to the camera settings[2]. All the pictures of the first day were useless due to the ISO of the camera being too high. Unfortunately the solution was not as simple as setting the camera to automatic. Doing this brought additional issues like automatically focusing on something that was not of interest or considering unimportant sections for light balancing. At the end it was decided to control the camera setting manually to try to avoid these issues.

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[2] The camera used for these initial experiments was a Panasonic Lumix DMC-FZ50

Something that was clear from the onset is that some plots were too big for the lens that we were using[3]. It was challenging to get the whole plot on the picture and the pictures had to be taken from far to be able to include the four markers. This decreased the resolution of the elements of interest. However, the flowers were not the only ones with bad resolution, the markers also lacked sharpness. In one of the worst pictures, the farthest marker from the camera was represented in thirty pixels; clearly not enough to make positive identification. In fact the normalization algorithm wasn't able to analyse any of these large plots. While it was able to identify some of the markers, there were no images where it was able to identify all of them. While resolution issues prevented us from analysing the female plot, the small plots gave us positive results. Its reduced size allowed us to get relatively close to take the pictures. This in turn was reflected in the resolution of the markers and of the flowers. This time the algorithm was able to normalize most of the pictures.

In the current photo-plot deployment we used four chessboard markers to point to the four plot corners. This meant that for each image we had to run the chessboard detection algorithm four times. Though this overhead is not immediately noticeable when calculating one image, the times add up when analysing a group of images. In general it takes four times more with four chessboard markers than if we would just had to detect one. A possible solution for this inconvenience is to implement corner markers of a different shape that will be easier to detect.

Perspective is something that also has an influence on the quality of the resulting image time series. When pictures from the male plot that were taken from the side were superimposed with pictures taken from above, the picture elements (flowers, rocks and others) moved considerable from picture to picture. This did not happen when two pictures where taken from similar perspectives. That is, if two pictures are taken from above14 the elements in the superimposed images will be proximate to each other.

After our initial fifteen day deployment in Greenland, it was clear that we should prefer smaller plots (with sides close to one meter) rather than big. The pictures should be taken as close to the plot as possible and the camera should be facing the plot in such a way that the image plane is parallel to the plot surface.

5.   Conclusion

We devised a new workflow for phenology monitoring based on pictures taken in the field. This allows for an offline, reproducible counting of plants at various stages of their development. The image time series thus acquired in the field can be reused for other purposes or distributed as raw data for documentation. The field test we conducted at Zackenberg shows very promising results. Future work includes the application of advanced computer vision techniques to automatize (part of) the phenology monitoring process based on images collected from cameras carried by technicians, from fixed location cameras, or from cameras embedded on drones that fly over large sections (instead of plots).

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[3] Panasonic calls it 35mm EQUIV