Spectrophotometric color measurement for early detection and monitoring of greening on granite buildings

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This paper addresses the detection and monitoring of the development of epilithic phototrophic biofilms on the granite façade of an institutional building in Santiago de Compostela (NW Spain), and reports a case study of preventive conservation. The results provide a basis for establishing criteria for the early detection of phototrophic colonization (greening) and for monitoring its development on granite buildings, by use of color changes recorded with a portable spectrophotometer and represented in the CIELAB color space. The results show that parameter b* (associated with changes of yellowness - blueness) provides the earliest indication of colonization and varies most over time, so that it is most important in determining the total color change. The limit of perception of the greening on a granite surface was also established in a psychophysical experiment, as Δb^*: + 0.59 CIELAB units that corresponds, in the present study, to 6.3 μg biomass dry weight cm^{-2} and (8.43 ± 0.24) x 10^{-3} μg extracted chlorophyll *a* cm^{-2}.

Keywords: Preventive conservation; CIELAB color system; biofouling; greening; monitoring; phototrophic colonization.

Introduction

The fouling of stone surfaces by abiotic substances and organisms poses serious problems for the maintenance of all types of buildings. Fouling by microorganisms, known as biofouling, is considered to start with phototrophic organisms (algae and cyanobacteria) conditioning the inert surfaces for subsequent growth of heterotrophic organisms (eg Grant 1982; Albertano 1991; Ortega-Calvo et al. 1993; Saiz-Jimenez and Ariño 1995; Prieto et al. 2005; Miller et al. 2010). However in the absence of a primary colonizing film of phototrophs, heterotrophic bacteria and fungi can grow on building façades, using organic compounds from organic pollutants, painted surfaces or conservation treatments (eg Cappitelli et al. 2005, 2007). Unlike heterotrophic biofilms, phototrophic biofilms have received little attention until recently (Di Pippo et al. 2009, 2011).

Biofilms that grow in areas exposed to light tend to contain photosynthetic organisms (Ramírez et al. 2010). The presence of these pioneer photosynthetic-based microbial communities generally result in the appearance of thin green films, which usually adhere to the stone substrate (ICOMOS-ISCS 2008) in a phenomenon often referred to as greening. The presence of greening depends on a variety of factors, such as a suitable combination of dampness, warmth and light on the stone surface (Tiano 2002) as well as the intrinsic characteristics of stone, such as permeability, porosity and surface roughness, which influence its bioreceptivity (Guillitte 1995; Prieto and Silva 2005; Miller et al. 2006). Factors such as the exposure site (Barberousse et al. 2006), the presence or absence of adjacent vegetation (Smith et al. 2011) and the urban or rural location (Tanaca et al. 2011) also affect the development of biofouling.

The study of greening on building façades deserves considerable attention because pollution-related soiling has been widely superseded by algal growth. Since the beginning of the 20th century, when the first data on the aspect of some important buildings were recorded, there has been an apparent decrease in the occurrence of black deposits (Newby et al. 1991; Davidson et al. 2000; Brimblecombe and Grossi 2009), partly because of the decrease in air pollution resulting from the declining use of coal and the switch to gas and electrical heating

(Brimblecombe 1987; Grossi and Brimblecombe 2008). At the same time, there has been an increase in biological activity, favored by lower concentrations of sulfur dioxide and greater deposition of organic compounds and nitrogen (Grossi and Brimblecombe 2008). Higher humidity caused by climate change also favors the development of greening as it increases the time that stone structures remain wet and possibly the depth of penetration of moisture. This has already been observed on buildings in places such as Northern Ireland and London, as respectively an increased incidence of algal greening (Smith et al. 2011) and decreased incidence of blackening (Brimblecombe and Grossi 2009).

Several authors have demonstrated that the discoloration of stone caused by the growth of microorganisms can be easily determined by a non-invasive (non-destructive) technique based on measurement of the reflectance by a spectrophotometer or a tristimulus colorimeter. The data are expressed in CIE-L*a*b* color system units (Wyszecki and Stiles 1982; Sanmartín et al. 2010). Using this technique, Urzì and Realini (1998) correlated the orange or grey color of the patina on Noto's calcareous sandstone with the associated microflora; Prieto et al. (2005) quantified the development of biofilm induced on the open rock faces of quartz quarries to reduce the visual impact; De Muynck et al. (2009) evaluated strategies for preventing algal fouling on two types of concrete (man-made stone), and more recently Tanaca et al. (2011) evaluated fungal colonization on three fiber cement (man-made stone) formulations exposed to urban, rural and coastal environments. Nevertheless, to the authors' knowledge, the color measurement technique has not previously been used to study the phototrophic colonization (greening) of granite stone buildings naturally exposed to the outdoor environment.

Apart from the chemical and/or physical deterioration of buildings caused by phototrophic-based microbial communities, greening must be considered as aesthetic damage that depends not only on the general conditions of the local environment, but also on the individual perception by the people involved (Smith et al. 2011). In this respect, green is more easily perceived than other colors, since the differences detected by the human eye are not of the same magnitude in the different parts of the spectrum; wavelengths close to 400 (blues) and 700 nm (reds) are less important from the point of view of perception than those around 500 nm. In fact, 560 nm (corresponding to the green area) is the wavelength at which

75 the human eye is most sensitive (Gescheider 1976; McDonald 1997). Green color had been
76 used for the quantification of biomass of the green alga *Ulva* (syn. *Enteromorpha*) on test
77 panels coated with a range of experimental formulations (Cassé et al. 2007). Knowledge of
78 the threshold of perception of greening by the human eye would be very useful for the
79 effective and sustainable management of stone buildings and monuments. To date, few
80 studies have addressed the human perception of changes in the appearance of stone due to
81 general fouling, and most of the existing studies have investigated the changes in appearance
82 in terms of blackening or darkening (Newby et al. 1991; Andrew 1992; Grossi and
83 Brimblecombe 2004; Brimblecombe and Grossi 2005). As far as the authors are aware, only
84 one laboratory-based study has examined the limits of perception of the phototrophic
85 colonization on building stones (Prieto et al. 2006). In the latter study the qualitative terms,
86 ranging from inappreciable to very intense, referred to the change in appearance caused by
87 the live microorganisms on the surface of granite rock were related to the total color change
88 (ΔE^*_{ab}). However, variations in the three color parameters, lightness-darkness ΔL^*, redness-
89 greenness Δa^* and yellowness-blueness Δb^*, were not analyzed. In the present study, these
90 variations were taken into account with the aim of selecting the parameter that provides most
91 information regarding the detection and monitoring of greening on granite façades.

92 Thus, the overall aim of the study was to demonstrate the suitability of a spectrophotometric
93 measurement technique for detecting phototrophic colonization (greening) and real-time
94 monitoring of the development of the colonization in a real case of a granite building. The
95 specific purposes of the study were as follows: (1) to establish the threshold of human
96 perception of greening on granite rock and its value in terms of partial color differences (ΔL^*,
97 Δa^* and Δb^*), amount of phototrophic biomass (dry weight) and extracted chlorophyll *a*
98 content; (2) to analyze the changes in the L*, a* and b* CIELAB coordinates in a real case
99 involving the cleaning and recolonization of a granite façade, with the aim of determining
100 the parameter or parameters that best indicate the start of the greening process and (3) to
101 describe a methodology that could be used as a tool for making decisions about the required
102 frequency of cleaning and biocide treatment in a real case.

Materials and methods

The perception of color depends on the incident light and variations in illumination, thus changes in the natural light affect the judgment of the observer about the color observed. For this reason, a visual sorting task used to estimate the threshold of perception of greening by the human eye was carried out in a laboratory test, under standard conditions of illumination. Detection and monitoring of greening were performed outside, since measurements made with a portable spectrophotometer are not affected by external light parameters. Psychophysical and monitoring experiments were carried out with granite rocks of similar color characteristics and mineralogical nature in order to obtain comparable results.

Psychophysical experiment

A visual sorting task (psychophysical experiment) was conducted to investigate the threshold of perception of greening on granite surfaces. Blanco Cristal, a medium-grain, heterogranular-panallotriomorphic, biotitic adamellitic leucogranite (with dark minerals absent), and feldspar-K, plagioclases, quartz, biotite, chlorite and moscovite as major minerals was selected for the experiments. The petrographic characteristics and mineral composition of this lithotype were described in a previous study (Sanmartín et al. 2011). Twenty-one blocks (6 x 3 x 1 cm) were cut and sterilized before starting the experiments. The upper surface of each granite block (18 cm^2) was inoculated in a laminar flow cabinet with a mixed culture of three isolates of subaerial stone biofilm-forming cyanobacteria grown in $BG11_0$ medium (Rippka et al. 1979), viz. *Nostoc* sp. PCC 9025, *Nostoc* sp. PCC 9104 and *Scytonem*a sp. CCC 9801. The mixed inoculum consisted of 0.21 mg (dry weight) of each strain per ml of medium giving 0.63 mg (dry weight) per ml of mixed inoculum. Distinct volumes from 150 µL (the minimum volume required to fully cover the total area of 18 cm^2 of the surface block) to 540 µL mixed cyanobacteria suspension, were inoculated uniformly with the point of a pipette onto the surface blocks, in order to adjust phototrophic biomass between 0 (to exclude the possibility of an abiotic contribution to the green color) and 18.9 µg biomass (dry weight) per cm^{-2} surface area. Experiments were performed in triplicate.

Each inoculated block was assessed by eight different observers (five females and three males aged from 25 to 60 years) with normal color vision ie normal trichromat observers without color blindness (see Fletcher and Voke (1985) for details of color vision examination). The task of each observer was to decide if the greening due to the presence of organisms was perceptible. The responses reported by the observers (yes/no) were recorded and analyzed. The point at which the observers began to note the green color has been coined as the just noticeable difference (jnd). The conceptualization of the greening threshold has its roots in the study of thresholds for other sensory-related stimuli (Gescheider 1976).

The color of the upper surface of each granite block was measured before and after inoculation, following the methods proposed by Prieto et al. (2010a, b). The CIELAB coordinates (L*, a* and b*) were measured before and after inoculation, with a portable spectrophotometer (Konica Minolta CM-700d/600d) equipped with CM-S100w (SpectraMagicTM NX) software; the measuring conditions were illuminant D65, observer 2º and a 8-mm diameter viewing area. A total of 14 readings were taken at different randomly selected zones on each wet surface block, and the results expressed as the mean values.

To relate the phototrophic biomass (dry weight) to color and extracted chlorophyll *a* content, the concentration of chlorophyll *a* on each block was determined after the visual evaluation and color measurements, following the protocol for the extraction of chlorophyll *a* from microorganisms colonizing rocks, recently proposed by Fernández-Silva et al. (2011). The extracts were measured in a UV–Visible spectrophotometer (UVIKON XS, Bio-Tek), and the equation proposed by Wellburn (1994) was used to calculate the concentration of chlorophyll *a*, expressed as μg chlorophyll *a* per cm^{-2} surface area.

Finally, the thresholds between imperceptible and perceptible greening, in terms of partial color differences (ΔL*, Δa* and Δb*), amount of phototrophic biomass (dry weight) and extracted chlorophyll *a* content, were estimated (Prieto et al. 2006). For this purpose, a data table was built in which for each sample (1-21), including its measured parameters, the eight answers from observers were included (1-8). The whole of cases (1-1, 1-2, (…), 1-8, 2-1, 2-2, (…), 21-8; ie sample-observer) were sorted into two sets, imperceptible and perceptible, and cumulative percentages were calculted for each group using the following

159 equations where n_p represents the number of answers that were "yes, ie perceptible", n_i
160 represents the number of answers that were "no, ie imperceptible", and z represents answer
161 1, 2, …, n_p or n_i:

162 Cumulative $_{\text{perceptible, z}} = 100\ (z/n_p)$;

163 Cumulative $_{\text{imperceptible, z}} = 100 - 100\ (z/n_i)$

164 The greening thresholds on granite were derived by plotting the cumulative percentages,
165 cumulative frequency of answers for each qualitative term (imperceptible and perceptible)
166 versus ordered partial color differences, phototrophic biomass (dry weight) and extracted
167 chlorophyll *a* content. The intersection of the two sets of data defines the just noticeable
168 difference (jnd) in greening (Berns 2000).

169 ***Monitoring experiment***

170 The progress of recolonization of the granite façade of the Supercomputing Centre of Galicia
171 (CESGA, www.cesga.es), a centre par excellence in research and high-performance
172 computing services built in 1993 in Santiago de Compostela (Galicia, NW Spain), was
173 monitored fortnightly for a period of ten months (289 days, March/2009-January/2010),
174 using a spectrophotometer for instrumental color measurements. Three target areas (1, 2, 3)
175 of the south facing wall, each of which was divided in two subareas, upper (A) and lower
176 (B), were selected and cleaned mechanically with distilled water and a brush to remove the
177 existing phototrophic colonization (Figure 1). The six study areas (1A, 1B, 2A, 2B, 3A and
178 3B), each of 21.5 cm x 31.0 cm, do not receive direct sunlight because of the proximity of
179 the neighboring buildings. They are also very damp due to water run-off. The weather
180 conditions in Santiago de Compostela during the experiment (according to data from the
181 Galician regional meteorological office: MeteoGalicia, www.meteogalicia.es) are shown in
182 Table 1.

183 Following the methodology proposed by Prieto et al. (2010b), a total of 234 readings
184 were taken fortnightly at random points in the six study areas. A portable reflection
185 spectrophotometer (CE-XTH) equipped with OptiviewSilver/i QC Basic software, was used

under the following conditions: illuminant D65; observer 2º and a 10-mm diameter viewing area. Color measurements were analyzed by considering the CIELAB color system (CIE Publication 15–2, 1986), taking into account the mean values of CIELAB coordinates (L*, a* and b*). Variations in the three color parameters (partial color differences), lightness-darkness ΔL*, redness-greenness Δa* and yellowness-blueness Δb*, were calculated as follows:

$$\Delta L^* = L^*_t - L^*_0;$$

$$\Delta a^* = a^*_t - a^*_0;$$

$$\Delta b^* = b^*_t - b^*_0,$$

where L^*_0, a^*_0, b^*_0 = mean value of CIELAB color parameter at the study area after cleaning, and L^*_t, a^*_t, b^*_t = mean value of CIELAB color parameter at the study area after a period of exposure (t).

Results and Discussion

The laboratory-induced epilithic cyanobacterial biofilms on granite blocks served to emulate the presence of initial green fouling. Photographs of the granite blocks inoculated for the psychophysical experiment, along with the data for the amount of phototrophic biomass (dry weight) and the concentration of chlorophyll *a* extracted are shown in Table 2.

On the basis of the visual evaluation, the threshold of human perception between imperceptible and perceptible greening in terms of the partial color differences (ΔL*, Δa* and Δb*), biomass (dry weight) and extracted chlorophyll *a* content, were calculated by plotting the cumulative frequency of answers given by each observer (Figure 2). The visual perception of the color difference differed with each observer, and the point at which individuals began to note the greening on the surface due to phototrophic biomass also differed among the different observers. From the results summarized in Figure 2, it was concluded that greening became perceptible when colonization resulted in a decrease of 4.37 CIELAB units in parameter L*, or when the values of parameters a* and b*decreased and increased, respectively, by only 0.41 and 0.59 CIELAB units. In terms of μg biomass (dry

213 weight) and extracted chlorophyll *a* content, a lower abundance of phototrophic biomass was
214 required to reach the greening threshold or just noticeable difference (jnd) in greening in
215 terms of yellowness-blueness variations, Δb* (6.3 μg biomass dry weight cm^{-2} and (8.43 ±
216 0.24) x 10^{-3} μg extracted chlorophyll *a* cm^{-2}) and a larger quantity was required for the other
217 two color parameters, lightness-darkness, ΔL*, and redness-greenness, Δa* (12.6 μg biomass
218 dry weight cm^{-2} and (20.33 ± 1.60) x 10^{-3} μg extracted chlorophyll *a* cm^{-2}). This indicates
219 that of the CIELAB color parameters, parameter b* provides the earliest indication of the
220 presence of phototrophic microorganisms.

221 The thresholds calculated for the partial color differences were used in the outdoor
222 experiment, in which the rate of greening on building granite was monitored for ten months
223 after cleaning, by changes in L*, a* and b*. The results are shown in Figure 3 as a summary
224 of the variations in L*, a* and b* values in the six study areas after the exposure period; the
225 point at which the observers began to note the greening. This corresponds to $\Delta L^* < -4.37$;
226 $\Delta a^* < -0.41$ and $\Delta b^* > +0.59$ CIELAB units, and is indicated by a shaded circle in the
227 figure. Thus, the first bar of the histograms (BC) represents the color difference before and
228 after cleaning the colonised surface, and was used as a reference. Subsequent bars reflect the
229 development of the recolonization process, ie the difference between the value on the first
230 day after cleaning and the subsequent values. In all cases, the trends were all in the same
231 direction as the value of the difference between the colonized and the clean rock (BC) (Figure
232 3), thus indicating that the color change was due to recolonization. Thus, during the
233 recolonization process a decrease in the ΔL* and Δa* values and an increase in the Δb* value
234 were observed, indicating that the façade became darker and more yellow-greenish color.

235 One important aspect of the results obtained is that analysis of the Δa* and Δb*
236 parameters enabled identification of the point at which recolonization began, as in both cases
237 the difference (Δ) remained constant for a certain period of time and then increased gradually.
238 The moment at which the difference (Δ) began to increase also coincided with the moment
239 at which the value of the increase changed direction towards the reference value (BC), thus
240 indicating the start of colonization. Analysis of the values in Figure 3 shows that
241 recolonization began at between 80 and 129 days (marked with an arrow in the Figure 3).

242 However, analysis of the ΔL* values was not as useful for identifying the moment at which
243 recolonization began as the variations were more erratic (Figure 3).

244 Comparison of the day on which recolonization began, determined by analysis of the
245 trends (direction changes towards reference value) in the Δa* and Δb* values, and the
246 moment at which greening is considered perceptible in terms of the Δa* and Δb* values (both
247 indicated in Figure 3), revealed that in all cases, the earliest detection of recolonization was
248 by analysis of the trends. Thus monitoring the color of granite façades using a portable
249 spectrophotometer enables early detection of the appearance of greening, even before it is
250 perceptible to the human eye. As in most cases, the greening threshold was reached several
251 days after the value at which colonization was considered to begin, building managers
252 therefore have a period of time in which to decide when cleaning or treatment should be
253 applied.

254 Another aspect to take into account is that when biological colonization develops, the
255 Δb* values, which tend to more positive values, underwent a faster change than the Δa*
256 values, which tend to more negative values. This is consistent with the previous finding that
257 Δb* provides the earliest indication of perceptible greening due to the presence of
258 phototrophic microorganisms. In addition, if the magnitude of the change caused by
259 colonization is taken into account, it was found that, taking into account the 6 plots, parameter
260 L* varied on average by 6.12 ± 1.78 CIELAB units, a* by 3.40 ± 0.24 CIELAB units and b*
261 by 9.82 ± 1.42 CIELAB units. Therefore parameter b* varied most and thus contributed most
262 to the total variation in color ($\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, Wyszecki and Stiles
263 1982). This is consistent with previous observations for other stone materials such as quartz
264 (Prieto et al. 2005) and concrete (De Muynck et al. 2009) and shows that parameter b* is the
265 most informative for detecting phototrophic colonization. This finding suggests that the
266 technique proposed here can be extrapolated to buildings other than those built from granite.

267 For maintenance of granite buildings affected by greening, decisions about the
268 required frequency of cleaning and biocide treatment should therefore take into account the
269 time at which greening becomes perceptible, as well as the time at which colonization is
270 present but not perceived; both parameters are easily determined by use of a portable

spectrophotometer. If the cleaning and/or treatment processes are carried out when colonization exists but is not yet perceptible, it would be easier to establish a target level of color of the original surface (Doehne and Price 2010). Moreover, cleaning when greening is marked can led to the use of chemicals or excessive quantities of water, which may also cause damage (Maxwell 1992).

According to Escadeillas et al. (2007), it generally takes a year for stains to appear on walls, although under favorable growth conditions, development may be extremely rapid. In practice, and under favorable growth conditions (porous support such as concrete walls), it takes one year before the first greening is visible and 2–5 years for intense greening to develop. Thornbush and Viles (2006) showed that biological colonization of stonework by fungi was evident after just 2 years. Smith et al. (2004) demonstrated the rapid surface colonization (less than 2 years) of sandstone by algae in exposure trials in Belfast. In the present case, recolonization (greening) of the granite façade was apparent within a much shorter time. Recolonization took no more than 129 days (just over 4 months), and greening due to the phototrophic microorganisms was perceptible after approximately 178 days (almost 6 months). This rapid biological colonization was undoubtedly favored by the mild wet climate of Santiago de Compostela, especially the microclimate affecting the most shaded walls of the buildings, as also occurs in other buildings in the city (Silva et al. 1997).

Conclusions

This study demonstrated that measurement of color changes with a portable spectrophotometer was a reliable method for the early detection and real-time monitoring of phototrophic growth (greening) on granite façades, even when it is not perceptible to the human eye. In this sense changes in parameter b* were demonstrated to be the most informative. Thus, Δb^*: + 0.59 CIELAB units, that correspond in this study to 6.3 μg biomass dry weight cm^{-2} and (8.43 ± 0.24) x 10^{-3} μg extracted chlorophyll *a* cm^{-2}, was established as the greening threshold.

Cleaning and/or treatment should be carried out taking into account both the greening threshold in terms of Δb^* and the moment that the trend in the value of Δb^* changes and becomes positive ie indicates the occurrence of phototrophic colonization. In this sense,

monitoring changes in b* of a cleaned granite façade exposed to the natural environment in Santiago de Compostela (NW Spain) revealed that recolonization by phototrophic microorganisms (greening) took no more than 129 days (just over 4 months), and greening was perceptible after approximately 178 days (almost 6 months).

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Figure captures

Figure 1. Granite façade of the Supercomputing Centre of Galicia (CESGA), showing extensive phototrophic colonization (greening) developed as streaks following the path of water run-off. (a) On site measurement of the color on the façade; (b) overview of the façade with perceptible colored stains (greening) in humid zones; (c) location of the six study areas before cleaning; (d) location of the six study areas after cleaning. Six study areas: three target areas (1, 2, 3) each of which was divided in two subareas, upper (A) and lower (B).

Figure 2. Results of the psychophysical experiment. Top: lightness-darkness ΔL*, middle: redness-greenness Δa*, and bottom: yellowness-blueness Δb*. Partial color diferences CIELAB units (on the bottom x-axis) and μg biomass (dry weight) per cm^{-2} surface area and μg extracted chlorophyll *a* per cm^{-2} surface area (in italics) (on the top x-axis) plotted against the cumulative frequency of answers for perceptible and imperceptible qualitative term (%). The values of the greening threshold in terms of these parameters are shown in a box in the figures.

Figure 3. Results of the monitoring experiment. Color changes (top: ΔL*, middle: Δa* and bottom: Δb*) during the period of exposure period (289 days) at the six study areas (1A, 1B, 2A, 2B, 3A and 3B, see Figure 1). $\Delta L^* = L^*_t - L^*_0$; $\Delta a^* = a^*_t - a^*_0$; $\Delta b^* = b^*_t - b^*_0$, where L^*_0, a^*_0, b^*_0 = mean value of CIELAB color parameter at the study area after cleaning with water and a brush, and L^*_t, a^*_t, b^*_t = mean value of CIELAB color parameter at the study area after a period of exposure (t). For comparison, the color change before and after cleaning is shown as BC (Before Cleaning). The change in the direction of the partial color difference

451 is indicated by an arrow, and the time when colonization becomes perceptible by a shaded
452 circle ($\Delta L^* < -4.37$; $\Delta a^* < -0.41$ and $\Delta b^* > +0.59$ CIELAB units).

453

454 **Table legends**

455 Table 1. Climatic data: temperature, humidity, sunshine duration and daily global radiation,
456 during the exposure period (March 2009 to January 2010), recorded at the Santiago_EOAS
457 meteorological station (Santiago de Compostela) and captured by Meteogalicia.

458 Table 2. Blanco Cristal granite specimens inoculated with mixed cyanobacterial culture and
459 used in the psychophysical experiment. Scale = 3.5 cm.

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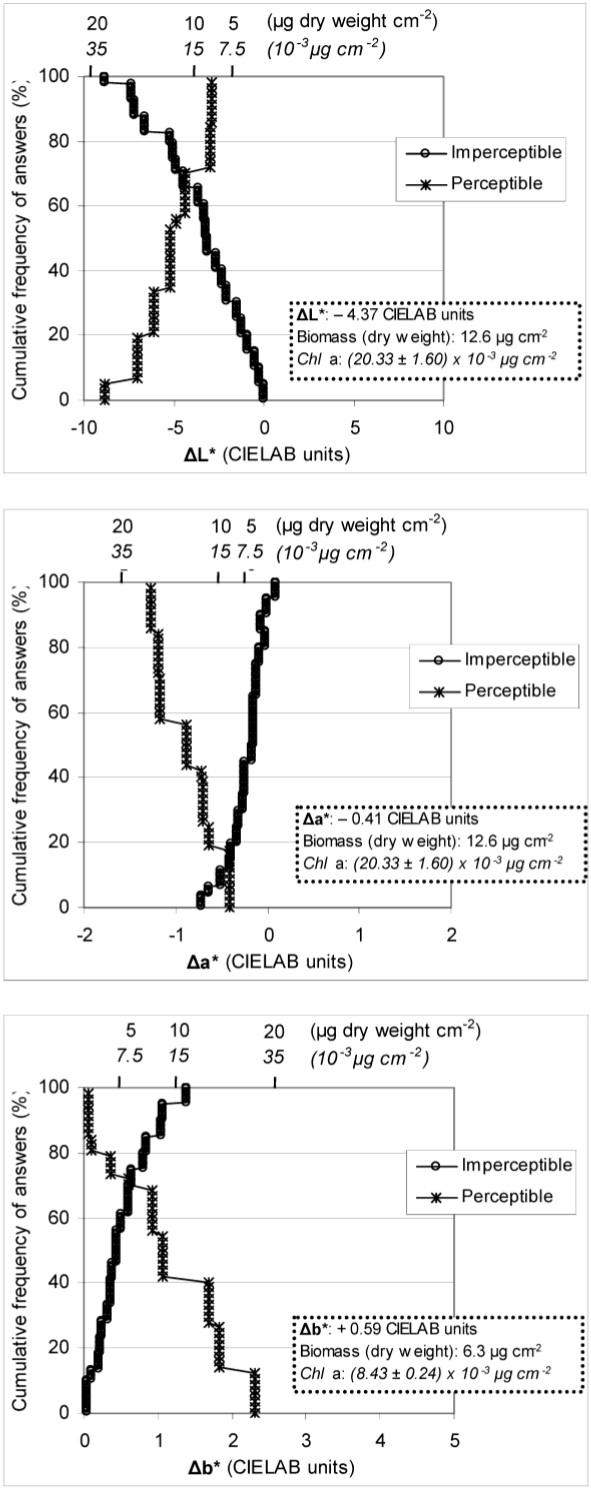
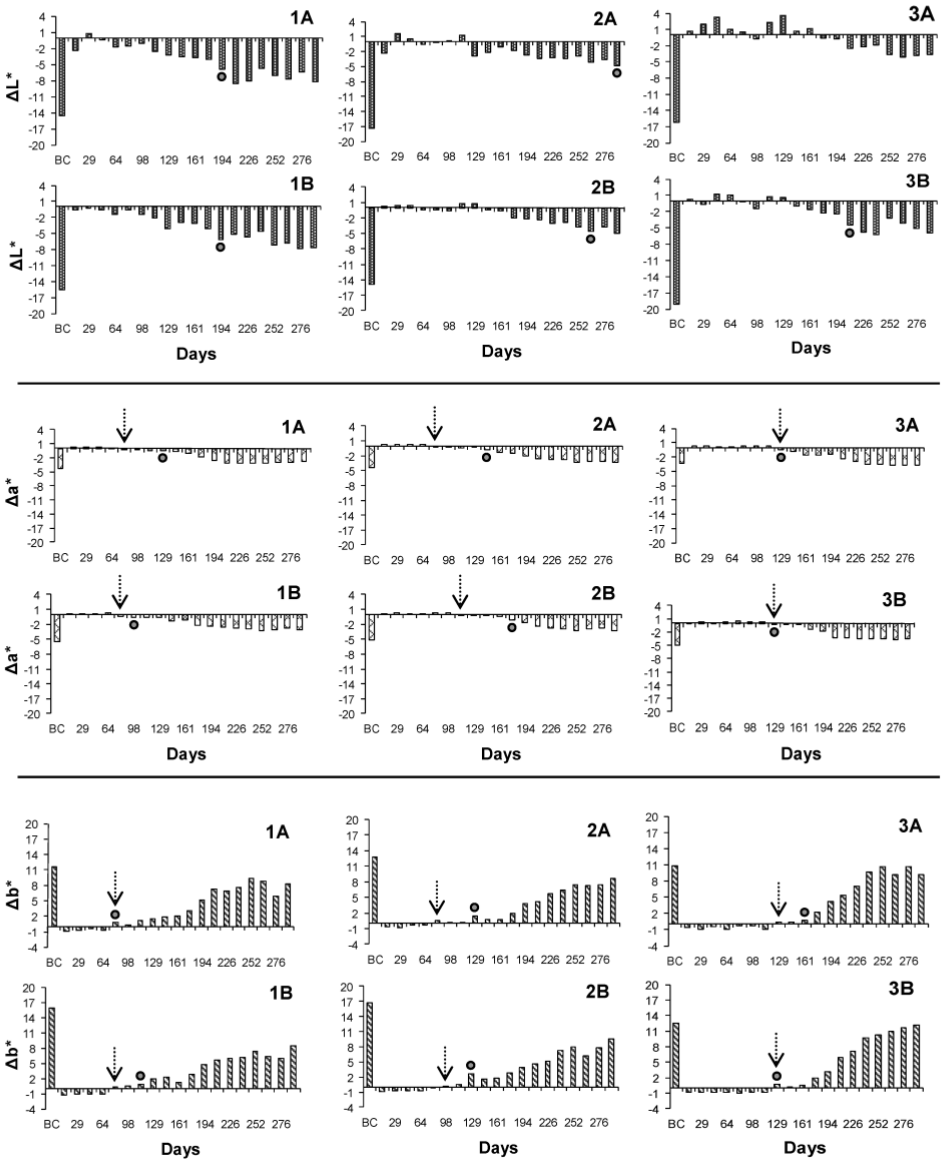
463 Figure 1



464

465 Figure 2



466

467 Figure 3

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469

470 **Table 1.**

471

Date	Average air temperature (ºC)	Dew point temperature (ºC)	Mean relative humidity (%)	Rain (L/m^2)	Sunshine duration (hours)	Daily global radiation ($10KJ/m^2/day$)
March 2009	11.1	4.5	68	30.4	246.6	1617
April 2009	10.3	6.2	79	106.2	177.6	1581
May 2009	14.5	8.9	73	55	241.6	1932
June 2009	17.2	12.9	78	106.6	218.4	1942
July 2009	17.1	13.1	80	105.2	211.4	1917
August 2009	18.8	14.4	78	24.5	236.9	1917
September 2009	18.0	13.5	78	13.5	248.6	1691
October 2009	16.2	13.4	86	189	149.0	935
November 2009	11.7	9.9	92	272.2	60.1	433
December 2009	8.1	5.9	89	424.5	96.6	434
January 2010	7.6	5.6	91	200.2	85.4	489

472

Table 2.

Photograph of the granite block surface										
Phototrophic biomass (µg dry weight cm^{-2})	0.0	0.4	0.7	1.1	1.4	2.1	3.2	6.3	12.6	18.9
Chlorophyll *a* extracted(*) (10^{-3}µg cm^{-2})	0.0	1.65 ± 0.12	2.49 ± 0.21	4.04 ± 0.08	4.49 ± 0.20	5.74 ± 0.02	4.95 ± 0.91	8.43 ± 0.24	20.33 ± 1.60	31.50 ± 2.47

(*)mean value of three replicates ± SD.