Chlorophyll Apparitions

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Senescence is a word that has been firmly transplanted into our vocabulary. With its intimations of senility, aging, and mortality in humans, the scientific application of this word describes the process of leaf death and chlorophyll loss in plants.

It is difficult to overstate the crucial role that chlorophyll plays in the greater scheme of things. It is the green pigment responsible for initiating the beautifully orchestrated sequence of events leading to photosynthesis. The term photosynthesis literally means building up or assembling by light, and it could be regarded as the basic alchemy of all life— the gold of the sun transmuting into the green of life. There is poetry and mystery in describing the chemical embrace of light and chlorophyll. Photons of light pierce through the outer layer of the epidermis and enter into the heart of the palisade cells. Drawn irresistibly by the magnesium at the heart of the tiny chlorophyll molecules, the light gives up its energy, and in the process a water molecule is split into hydrogen and oxygen. The plant releases the oxygen, and the hydrogen, with carbon dioxide, is converted into sugar to build new plant tissue. How the chlorophyll molecule achieves this remarkable division of the water molecule, is a bio-chemical enigma, highly researched yet still not fully understood. (1)

The beginning of our artistic collaboration in 1990 was catalyzed by grass, a material we had both been working with individually before we met. At this time, our perceptions of this growing, living agent were inspired more by the philosophy of the arcane arts than the rigors of scientific investigation. Seven years later we embarked on intensive research into a specialized new breed of grass at the Institute of Grassland and Environmental Research (IGER) in Wales, now part of Aberystwyth University's Institute of Biological, Environmental and Rural Sciences (IBERS). Grass may be the material of our investigation but chlorophyll is the primary medium that binds us.

Early in 1997, we approached scientists Howard Thomas and Helen Ougham (2) at IGER in response to an article in the New Scientist (3) journal describing their
pioneering work into a strain of grass. This strain did not senesce in the usual way and lose its green color when under stress. The color green is volatile and the chlorophyll molecule even more, so this ‘‘stay-green’’ grass held promise to an inquiry that we had been pursuing for some years in our artistic work.

Grass grown from seed on vertical surfaces has an extraordinary capacity to record either simple shadows or complex photographic images through the production of chlorophyll. In a sense we have adapted the photographic art of producing pictures on a sensitive film to the light sensitivity of emergent blades of young grass; the equivalent tonal range of black-and-white photographic paper is created within the grass in shades of yellow and green. Each germinating blade of grass produces a concentration of chlorophyll molecules depending on the amount of projected light available to it, and the strength of green produced is determined by the intensity of light received. In complete darkness, the seedling grass grows but no chlorophyll is produced; other, light-independent pigments give the grass a yellow color. But once exposed to light in a gallery environment, the grass in the yellow regions quickly seizes the available light and gradually, over hours, changes color, greening up. Kept in very low light levels in a living state, the green grass begins to dismantle its chlorophyll and, taking on a quality akin to an old tapestry, the image slowly fades away.

The haunting presence of the emergent organic image was and still is a revelation to us. In the greater body of our artwork we play with many materials exploring processes of growth, transformation, and decay, and while we embrace the transience and ephemeral nature of our materials, somehow the fragility of these chlorophyll apparitions urges us to make moves to preserve them for longer. We cannot recall the exact moment when we first articulated this desire to hold the image, although conceptually we can rationalize the move to preserve it for longer by saying that it follows through the established process of photography of exposing, developing, and then fixing the image. To talk about ‘‘fixing’’ an image refers directly to the photographic process of stabilizing the emergent picture. It is a word used as much now as nearly 200 years ago by the early pioneers of photography.

According to historian Malcolm Andrews the widespread use of the word ‘‘fix’’ at this time indicates ‘‘a predatory, acquisitive instinct,’’ a ‘‘figurative sense of appropriation’’ that ‘‘leads in one direction to landscape as a commodity.’’ At the same time, he suggests, such terms represent a prevailing need to give ‘‘stability to new experiences.’’

We recognize these thoughts—a desire to hold onto something, an attachment to visibility, a reluctance to allow an extraordinary elusive presence to depart too soon, a need to stabilize or slow the process of change, allowing more people to
witness the works for longer periods of time.

William Henry Fox Talbot, the English pioneer of photography, received a letter from his sister-in-law in 1834: She wrote, ‘‘Thank you very much for sending me such beautiful shadows. . . . I grieved over the gradual disappearance of those you gave me in the summer.’’(5) Talbot made his first photographs by placing an object on paper sensitized with silver salts and putting both in the sun. When the object was removed, the exposed paper retained the silhouette of the object. The frustration of capturing and then losing the image led Talbot to find ingenious ways to fix the image, and through a seminal art and science collaboration, Talbot’s friendship and working relationship with the eminent scientist John Herschel eventually led to the discovery of hypo, the chemical fixative, in the 1840s.

We were first introduced to Fox Talbot’s extraordinary photographic work, The Pencil of Nature, (6) in 1995, four years after our first experiment of capturing an image in grass. We were both astonished and drawn by his subject material, and one picture in particular sent a shiver of recognition through our spines—a photograph of a ladder leaning against a haystack.(7)

Under the title of The Other Side, we presented our first collaborative artwork in 1990 in the village of Bussana Vecchia in Northern Italy. Here, a vaulted ceiling interior room became the site for an interaction that involved quantities of germinating seeds, volumes of mud and water, and, significantly, a ladder. The space literally became a living chamber, as seed implanted in a clay base and spread over the walls sprouted and grew into a vibrant skin of fresh grass. As part of the installation the ladder was placed leaning against the far wall of growing grass. One day, upon moving the ladder we noticed its faint yellow shadow cast in the grass. To be honest, we were unclear exactly what we were witnessing, terms such as ‘‘chlorophyll’’ and ‘‘photosynthesis’’ were not tripping off our tongues and it would be some time before we would draw the analogy of leaving a deck chair on the lawn and seeing the yellow imprint days later when it was removed. Quite simply, the seed of an idea was sown, and in 1991 we experimented in growing our first living grass photograph.

A ‘‘pencil of nature’’ seems such an apt description of the single living blade of grass present by the thousands in our living photography. In a contemporary echoing of the pioneering work of the proto-photographers, it became apparent to us that should a potential solution exist for arresting the chlorophyll image, it lay within the field of science.

Our earliest forays into science took us superficially into the world of embalming plants. A Swedish company, Evergreen, indicated that the immature root hairs of our seedling grass would be too tiny to absorb the relatively large molecules of
their liquid embalming feed. In pursuit of longevity of the grass photograph, we went one step further, beyond notions of embalming living plant material into the botanically dubious area of rapidly killing it off.

The syndrome of senescence is part of the plant’s natural life cycle and survival strategy in the face of stress. As applied to plants, it can only occur if the tissue is fully viable. That is, green leaves and other organs will not senesce properly if they cannot vigorously accomplish all the essential life processes such as gene expression, energy generation, and maintenance of cell integrity. Plants are tough and adaptable, but even the hardiest plant needs to have a way of resisting or running away from a hostile environment. When a plant is subjected to environmental pressures such as heat, drought, and pollution, the plant selectively kills off bits of itself until it becomes a near-impregnable residual structure. What is seen as yellowing, withering, and death is part of the plant’s survival kit. The disappearance of green color is the visible symptom of a plant under stress.

In 1969, a meadow fescue plant was identified in field tests at IGER, which subsequently led to years of scientific investigation. The favored story goes that a crop of grass plants were plucked from the neighboring hills and brought into the greenhouses at the research station for study. A particularly hot weekend combined with an absent employee resulted in the transplanted plants struggling in a drought-ridden environment. Most succumbed to the state of senescence described above, relinquishing their green and fading into a pallid version of their former selves. But one plant, to all intents and purposes, remained looking green and healthy. Termed a ‘‘stay-green’’, the mutation was at first treated as a scientific curio. Under the observant eye of Howard Thomas and his team, however, the mutant has come to play a critical role in establishing current understanding of the cellular pathway of chlorophyll breakdown and the mechanism by which photosynthetic structures in green cells are taken apart.

To understand the process pursued by Howard Thomas, it is necessary to ask a fundamental question: ‘‘Why is chlorophyll green?’’ The answer to this lies in the structure of the chlorophyll molecule. It is one of a class of compounds known as tetrapyrroles, of which the best known is haem. Haem, as part of the protein haemoglobin, gives blood its red color, and is responsible for blood’s ability to carry oxygen around the body. Although chlorophyll and haemoglobin have evolved separately for hundreds of millions of years, and fulfill very different functions, their structures are remarkably similar. The chemical structures of both haem and chlorophyll, like many other tetrapyrroles, are such that they selectively absorb light in certain parts of the visible spectrum, reflecting the rest back. The chlorophyll molecule absorbs red and blue light and reflects—or rejects—the green light; this is why plants appear green. Absorbing red and blue light is fundamental to the function of chlorophyll, which is to capture light energy from
the sun so that it can be used to turn water and carbon dioxide into sugars and oxygen. This is the process of photosynthesis, which directly or indirectly supports almost all life on earth.

Yet chlorophyll’s ability to absorb light is a mixed blessing. When plant leaves are under stress, or simply at the ends of their lives, chlorophyll becomes potentially very dangerous, because light energy that can no longer be used for photosynthesis may instead be diverted to generating reactive oxygen species (free radicals). These are potentially as dangerous to plants as they are to humans, because they can damage membranes, DNA, and other structures in the plant cell. Although plants have a built-in antioxidant system, it is not always sufficient in times of stress. So they have evolved a method of removing unwanted chlorophyll. This in some ways resembles the way they handle toxic compounds from their environment, and the detoxification process is the reason why plants lose their chlorophyll.

Until relatively recently, it was unknown what chemical changes happened to chlorophyll as it disappeared from leaves during senescence. Stay-green grass was the key to unlocking this mystery. The late Philippe Matile, Professor of Plant Biology at the University of Zurich, had long shared the IGER team’s interest in the fate of chlorophyll. During a sabbatical visit to IGER in the mid-1980s, he and Howard Thomas found some chemical constituents of yellowing grass leaves that were absent from the stay-green. After further exchanges, and some state-of-the-art chemistry in Zurich, it was confirmed that these products are indeed the elusive colorless residues left when chlorophyll is broken down. Subsequently many of the intermediate steps in the sequence—the enzymes that bring about the changes, the cellular organization of the process, and some of the genes that specify chlorophyll breakdown—have been discovered. Thomas and Matile learned that one of the steps in the pathway is blocked in stay-green grass because, as the consequence of a defective gene, the corresponding protein is missing. (A deficiency in the same gene is responsible for the difference between green and yellow pea seeds, first described by Gregor Mendel just a few years after Talbot and Herschel had conceived the infant era of photography.)

Searching for stay-greens is in one sense easy, as it requires nothing more complicated than a keen eye. Creating a stay-green in a precisely targeted way is more difficult, but it has been done.

One way of creating a stay-green is to disable pigment degradation. Most of the known mutants of this kind have a genetic lesion that interferes with the same step of chlorophyll breakdown. Since the stay-green trait was first discovered, grass geneticists and breeders have been crossing the gene into different lines. Initially crosses were confined to meadow fescue, the species in which the stay-green
character was originally found. For many purposes, fescue is less useful and versatile than other grass species, notably ryegrass, and stay-green ryegrass has been produced by hybridization with perennial ryegrass. Modern breeding methods use genetic maps of species, such as the grasses, allowing individual traits to be tagged with DNA markers and efficiently traced during a breeding program.

Stay-green perennial ryegrass (10) was the seed in research available to us to experiment with in our photosynthetic photographs. With the support of a Wellcome Trust Sci-Art (11) research award, we set ourselves up in temporary residence at IGER in the summer of 1997. A series of comparative studies between the regular ryegrass and the stay-green ryegrass were made from which it emerged that the stay-green permitted rapid drying of the grass canvas with no loss of the green chlorophyll, in contrast to the regular grass in which many of the green blades senesced. Significantly, it was at this time that we first considered drying the grass photographs as a way of preserving them, and we became aware of the possibility of growing, drying, and framing the photographs in a studio environment and then freighting them off to exhibitions. Independence had been conferred to the photographs through this collaboration; we also had the ability to show these pieces for much longer periods of time. In one respect the work had “come of age.”
Figure 1

However, we had not quite taken into consideration just how influential light would be on the long-term preservation of the images. The ephemeral nature of our creations had been tempered somewhat using the stay-green, so the fading of the work was no longer occurring along the physiological but along the pathological route.

It is a task of museum conservators to anticipate and avoid direct exposure of precious paintings, photographs, textiles, and tapestries to light. The shorter wavelengths present in light are potentially destructive to sensitive pigments and, given the opportunity, will bleach them away. This became the subject of the 2001 exhibition Presence at the Isabella Stewart Gardner Museum in Boston. Alongside the new artworks created in response to the museum’s collection, the first ever Mother and Child grass photograph was brought out of storage and exhibited within view of a freshly grown piece.

Mother and Child was the first artwork presented publicly using the stay-green seed (figure 1). It was developed, grown, and dried in 1998 in response to a California exhibition at the Santa Barbara Museum of Art Out of Sight:
Imaging/Imagining Science. Displayed behind plexiglas, the grass photograph received direct light over the course of the six-week exhibition, resulting in fading in areas of the image subjected to the most intense light.

Figure 3

It became apparent that to conserve the image in the long term, it would be necessary to display the work in a non-direct, subdued light. Helen Ougham and Howard Thomas believe that under the correct conservation conditions, the grass image should retain visibility for many, many years. A grass photograph was taken into the collection at IGER and, under the watchful eye of such chlorophyll experts, the correct lighting conditions can be determined to inhibit the corruption of the image.

It has been argued at times that artists gain more from crossing the cultural divide between art and science than scientists do, yet Helen Ougham has said that some of the new directions for IGER, and subsequently IBERS, research would never have been undertaken without our artistic presence. The subtlety and range of tonal color captured in the grass photographs (figures 2-5) made a deep impression on our science colleagues and, in a remarkable shift in perception, they realized that observations of plant material could occur in very different circumstances.
than the established investigative paths. Grinding up leaves and subjecting them to various kinds of separation was the conventional scientific way to analyze the molecular makeup of plant material. The irony of observing processes of life through dead material had been an accepted collusion of established method and material.

![Figure 5](image)


The potential to investigate molecular indices of leaf death through a noninvasive high-resolution imaging technique was recognized in 1999 with the help of a Pioneer Art and Science award from the National Endowment of Science, Technology and Art. (12) Using digital cameras able to resolve minute differences on a grey scale at many orders of magnitude greater than the human eye, the IGER team pioneered a technique for searching out and recording the hidden information that emerges when the color spectrum of light reflected from plants is examined. This approach draws on tools used in remote satellite sensing, producing hyperspectral (13) images of color, which influence, in turn, the artistic vision of a grass photograph (figure 6).

Research into imaging first carried out at IGER is now part of ongoing studies at IBERS being funded by the British government, the European Union, and industry, involving a range of applications of the technique including studies of flower petals, plant diseases, crop genetic variation, and the composition of complex plant communities. An internationally significant development of these
lines of research was the opening in May 2012 of the National Plant Phenomics Centre at Aberystwyth University. This facility provides 3D images of the plants and monitors their growth on a daily basis, using large-scale application of fluorescence, infra-red and near infra-red, laser and root imaging combined with advanced robotics and computing technology.

Figure 6

Seductions of time and visibility are at the heart of our artistic work with photosynthesis (figure 7). A grass photograph has the power to elicit strong emotional responses in the viewer, and it is undeniable that the beauty of the freshly grown grass canvas suggests all that is fertile and life-enhancing. Our desire to alleviate the process of decay has encouraged us to journey into the world of science and genetics, and has opened our work to a greater number of people throughout the world. There seems little doubt that that which survives turning to dust or fading is potentially conferred prestige.

We cannot at this time truly say how long our chlorophyll apparitions will be visible, but we can suggest how best to conserve them and note that the negative is held for future reprints or ‘regrows’. For further inspiration, we can refer interested parties to Sigmund Freud’s thought-provoking paper “On Transience”: “‘Nor can I understand any better why the beauty and perfection of a work of art or of an intellectual achievement should lose its worth because of its temporal limitation.’” (14)
Notes


2. Howard Thomas and Helen Ougham worked at the Institute of Grassland and Environmental Research, a leading agricultural research institute based in Aberystwyth, Wales, UK. Howard ‘Sid’ Thomas is Emeritus Professor in Aberystwyth University and has held visiting professorships at Universities in Switzerland and the United States. His research interests include genetics, evolution and uses of food plants. He also has a special interest in the cultural significance of scientific research and promotion of links between science and the arts. He is the author of over one hundred refereed publications numerous conference proceedings, published abstracts and other written contributions. Helen Ougham is an independent scientist associated with the Institute of Biological, Environmental and Rural Sciences at Aberystwyth University and a consultant to several institutions in the UK and Europe. She specializes in research and teaching in the areas of gene expression during leaf senescence and growth, interaction between chlorophyll synthesis and catabolism, regulation of plant development, bioinformatics and the biological applications of computing methodologies, the art-science interface, and science in society. She is also the author of numerous refereed papers.


6. The Pencil of Nature by William Henry Fox Talbot was published between 1844 and 1846.


8. The protein is essential for the correct function of the chlorophyll-degrading enzymes. The stay-green gene has recently been isolated and sequenced: New Phytologist 172, no. 4 (December 2006): 592–597, and is a continued focus of work in China (Plant Physiology 144, no. 3 (July 2007): 1429-1441), Switzerland (Plant Molecular Biology
67, no. 3 (February 2008), 243-256) and elsewhere.


10. The stay-green Lolium perenne (perennial ryegrass) for turf was developed at IGER, and subsequently IBERS, by plant breeder Dr. Danny Thorogood supported by the seed company Germinal Holdings. The variety AberNile is now available worldwide in the lawn seed mix So-Green.

11. The Wellcome Trust SCI-ART initiative was set up in 1997 to engage collaborative work between artists and scientists.

12. NESTA (The National Endowment of Science, Technology and the Arts) was set up by an act of British Parliament in 1998. Its aims are “to seek out creative people and innovative ideas that can bring social, economic and cultural benefits to society.” http://www.nesta.org.uk/home1

13. Hyperspectral imaging enables extraction of high-resolution color and texture information from leaves. IGER, and now IBERS, scientists do this by fitting a liquid crystal tunable filter to a cooled, CCD camera. The system’s 400–720 nm range tracks the interplay among the dozens of pigments in living grass, including carotenoids (responsible for yellows, oranges, and some reds) and anthocyanins (reds and purples), as well as chlorophyll.