Climate change...are plants the answer?

Background

Sixty percent of the photosynthesis on our planet is carried out by a huge variety of water-dwelling plant species. Of these, phytoplankton, which make up less than one percent of the planet's biomass, contribute about fifty percent of its photosynthesis.

Vast populations of ocean dwelling phytoplankton (comprising a diverse group of microscopic algae, photo-synthesising bacteria, cyanobacteria, plant-like diatoms and calcium carbonate-coated coccolithophores) have recently been of interest to climate scientists. There are two main reasons for this:

1. Phytoplankton are responsible for most of the transfer of carbon dioxide from the atmosphere to the ocean. Carbon dioxide used up during photosynthesis is 'fixed' in the phytoplankton, just as carbon is stored in the wood and leaves of a tree. Most of the carbon is returned to near-surface waters when phytoplankton are eaten, or decomposed, but a significant quantity falls to the ocean depths where it can remain for decades. Phytoplankton, therefore, play a crucial role in reducing levels of the atmospheric carbon dioxide which contribute to the greenhouse effect [1].

2. Phytoplankton population growth requires trace amounts of iron as well as the availability of carbon dioxide, water, sunlight, and nutrients (such as nitrate, phosphate and calcium). Iron stimulates growth of cyanobacteria that fix atmospheric nitrogen, and the extra nitrogen stimulates phytoplankton proliferation. In addition, iron is essential for the production of ferredoxin proteins which mediate the transfer of light energy-stimulated electrons in photo-synthetic pathways [2]. In large areas of the ocean where iron concentrations are low, phytoplankton growth is limited.

Enhanced phytoplankton growth occurs where frequent upwelling of cool, deep water carries nutrients, including iron, to the surface. Windblown dust from the land is the main input of iron to the ocean. It has also been observed that where natural iron enrichment of the ocean by iron-rich volcanic ash has occurred, huge phytoplankton population explosions ('blooms') visible by satellite have ensued. [3]

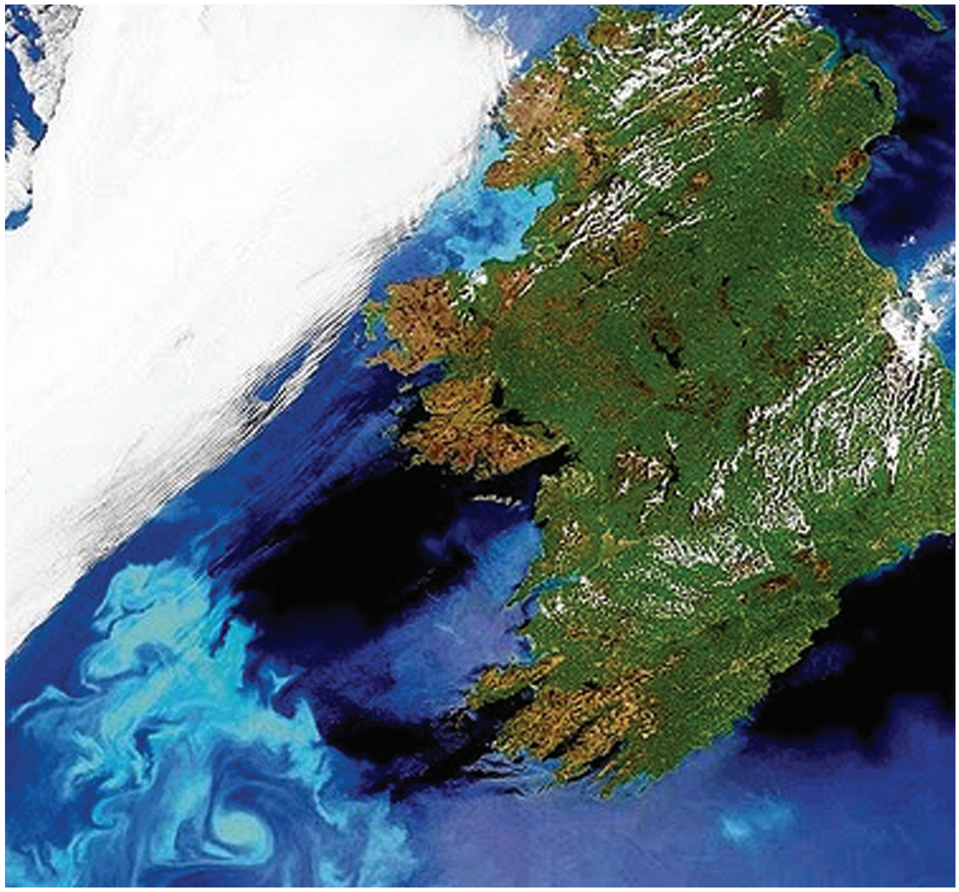

Figure 1 *- Satellite image from the European Space Agency (ESA) showing the swirls of phytoplankton blooms south of a cloud bank off the coast of Ireland (see [3]).*

One particularly striking example of a bloom was spotted off the coast of Ireland in May 2010 and Figure 1 shows a satellite image of the bloom; the large swirls of turquoise water, south of the large cloud mass, are due to the presence of a species of phytoplankton known as *Emiliania huxleyi* (see electron micrograph in Figure 2). This phyto-plankton bloom followed the 2010 volcanic eruptions at *Eyjafjallajökullin*, Iceland.

So, could the growth of phytoplankton blooms be stimulated by artificially 'seeding' the ocean with iron? And would the resulting increase in photosynthesis also result in increased transfer of carbon from the atmosphere to phytoplankton for subsequent deep-ocean storage?

Ocean iron fertilisation (OIF), as it is called, has already been carried out by research groups around the world using iron sulfate. While satellite images confirm the creation of phytoplankton blooms, consequent increased transfer of carbon dioxide from the atmosphere is yet to be proven. Of course the marine

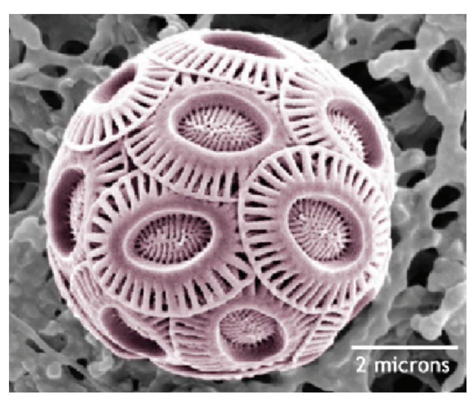

Figure 2 *- Image of Emiliania huxleyi. (Image taken from http://earthguide.ucsd.edu/earthguide/imagelibrary/emilianiahuxleyi.html).*

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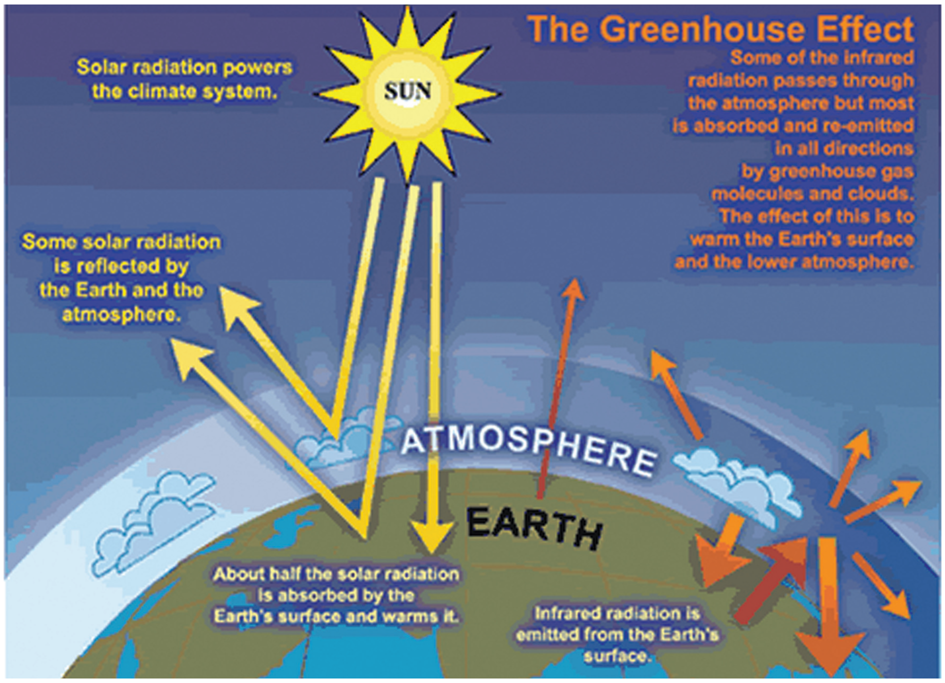

Figure 3 *– Greenhouse effect*

ecosystem is a complex interaction of biological, chemical and physical processes and the potential disruption and knock-on effects of OIF on it are not yet understood. Like many issues related to climate change, OIF is complex and controversial [4].

Developing global citizens through sciences, social studies and technologies

The complex global issue of climate change was the focus of three regional Learning and Teaching Scotland events held in November 2010. These events aimed to demonstrate how climate change provides a rich context for learning and for promoting global citizenship within the curriculum. SSERC's Biology Team was pleased to be asked to contribute a workshop at each of these events.

A major focus of our workshop, *Are plants the answer?*, was to present some simple activities which might support the learning and teaching of photosynthesis and its role in sustaining life and maintaining the atmospheric gas balance of our planet. By thinking about photosynthesis on a global scale, pupils can begin to explore ideas relating plants to possible climate change solutions. In light of positive feedback from workshop participants, we thought our ideas and activities would be interesting and useful to science departments delivering aspects of the *Curriculum for Excellence* Sciences Experiences and Outcomes [5] related to climate change.

Through the workshop we sought to:

(i) consider the role of phytoplankton in the gas balance of the atmosphere
(ii) establish curricular links to the wider topic of climate change
(iii) carry out practical activities to support the learning and teaching of photosynthesis
(iv) suggest activities which will allow young people to engage in the discussion of the science and controversy around climate change.

In the sections which follow we give a flavour of the activities used and highlight their availability on the Science 3-18 website [6].

Misconceptions and prior learning

Workshop delegates agreed that many pupils, while having some knowledge of photosynthesis, fail to grasp the idea that plants also carry out respiration. Another commonly held belief is that plants photosynthesise in light and only carry out respiration in darkness. By arranging statements relating to photosynthesis and respiration on a simple 'T chart' (The animal-plant game) [6], pupils and teachers can establish what is already known, or misunderstood.
Discussing carbon dioxide as a 'greenhouse gas' can often point up misunderstandings about the green-house effect. Again, teachers noted that pupils have some knowledge of this but commonly fail to realise that the greenhouse effect is necessary to maintain our planet's temperature at life-supporting levels. Many simple, colourful illustrations of the greenhouse effect are available on line (Figure 3).

Practical Activities

Since we wanted to encourage thinking and learning about the role of phytoplankton in global photosynthesis we decided to use unicellular algae in SSERC's Practical Activities 1 & 2 [6].

1. A relatively straightforward activity demonstrates the effect of photo-synthesis in *Scenedesmus quadricauda* on hydrogencarbonate indicator. We found that a small quantity (1 cm^3) of algal suspension added to indicator (6 cm^3) in a small container, such as a Bijou bottle , brings about a colour change (orange → purple) within 20-30 minutes when placed in bright light. The rate of photosynthesis in bright light far exceeds the rate of respiration. So, although both photosynthesis and respiration are taking place, there is a nett consumption of carbon dioxide by the algae. The resultant increase in pH causes the hydrogencarbonate indicator to change colour from orange to purple. The colour change will take place within a normal

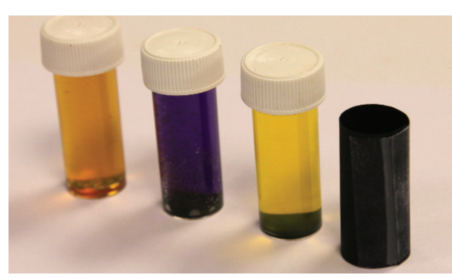

Figure 4 *- Bijou bottles showing results of activities 1 and 2 (see [6]).*

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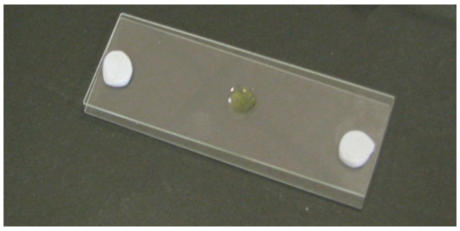

Figure 5 *- Hanging drop using two microscope slides (see Practical Activities [6]).*

teaching period, providing almost instant evidence that the algae have removed carbon dioxide from the surrounding solution.

2. In a similar set-up, from which light is excluded by covering the Bijou bottle with a tube of black paper, the colour change (orange → yellow) occurs. In this case, because no light is available to the algae, only respiration is taking place. Since the rate of respiration is slower than the rate of photosynthesis in bright light, the release of carbon dioxide and consequent indicator colour change is also slower. This set-up would have to be left until the next lesson to see the result. However this affords another opportunity for discussion of the two processes.

3. In another activity a 'hanging drop' of mixed algae [6] is prepared for microscopic examination. The protocol for this activity describes a method of making the hanging drop using two microscope slides. This avoids the use of fragile coverslips and has the added advantage that standard microscope slides are significantly cheaper than cavity slides.

Since most of the algae in the mixed algae sample are larger than *Scenedesmus quadricauda* they are easier to see. The use of mixed algae also underlines the fact that 'phytoplankton' is a term that describes a diverse group of organisms. We believe young learners will find the beautiful and diverse forms of the algae fascinating.

Other learning activities

One of the questions asked of pupils by the worksheet which accompanies the practical activity *Observing unicellular algae* [6] is, 'How can such tiny organisms be important to global photosynthesis?'

The fact that scientists study phytoplankton both 'macroscopically' and 'microscopically' is thus introduced. Water containing phytoplankton can be examined in the laboratory under a microscope. The formation and health of phytoplankton blooms can be studied by examining images from space.

The *Background information* sheet [6] describes how climate scientists use satellite images to monitor activity and health of phytoplankton blooms.

There is also scope for pupils to carry out their own research into the idea that phytoplankton are a potential solution to the climate change problems associated with imbalance in the greenhouse gases. The controversies surrounding OIF provide further scope for research, discussion and debate.

The suite of activities related to this article, which can be found on the *Science education 3-18* website, includes some suggested active learning and research tasks (based on the work of Petty [9]) together with a table outlining *Curriculum for Excellence* contexts.

Figure 6 *- Mixed algae available from Sciento (see [8]).*

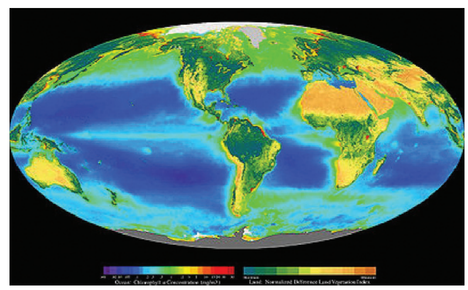

Figure 7 *- Composite image showing the global distribution of photosynthesis, including both oceanic phytoplankton and land vegetation. [10].*

References

[1] http://en.wikipedia.org/wiki/Phytoplankton

[2] Rayner-Canham, G and Flynn, C (2010) Iron ocean seeding. *Education in Chemistry*, **47**, 140-143.

[3] Marine Institute (2010), Giant Bloom of Harmless Plankton Visible from Space – available at http://www.marine.ie/home/aboutus/newsroom/news/GiantBloomofHarmlessPlankton.htm.

[4] Lichten, C. (2010) Ocean iron fertilisation: capturing carbon to slow climate change. *Catalyst*, **21**, 1-3. *Catalyst* is published by the Gatsby Science Enhancement Programme (see www.sep.org.uk/catalyst).

[5] Curriculum for Excellence: Sciences - Experiences and outcomes – available at http://www.ltscotland.org.uk/learningteachingandassessment/curriculumareas/sciences/eandos/index.asp

[6] http://www.tinyurl.com/climate-change-SSERC (*Climate Change Resources* on www.science3-18.org)

[7] Image - Source IPCC, 2007: Climate Change 2007: *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge.

[8] A culture of mixed algae can be purchased from Sciento, 61 Bury Old Road, Whitefield, Manchester M45 6TB - see http://www.sciento.co.uk/.

[9] Petty, G. (2006), *Evidence Based teaching – A Practical Approach.*

[10] Provided by the *SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE.*