The oresmen

Some US organizations claim that fertilizing the oceans with iron could both help to tackle climate change, and make money. But marine researchers warn of unpredictable side effects. Quirin Schiermeier reports.

Red trails in the sunset: Russ George (inset) hopes to tackle climate change using iron fertilizer at sea.

PLANKTOS FOUNDATION

The *Ragland* does not look like a research vessel. The 100-year-old wooden Baltic schooner belongs to the Canadian rock star Neil Young who, between tours and recording sessions, relaxes on board the historic boat, which is usually anchored in San Francisco.

But last June, the *Ragland* was chartered for an unusual scientific mission. Young lent the boat to his Bay Area friend Russ George, a business consultant, amateur researcher and founder of the California-based Planktos Foundation. The foundation is one of several US organizations promoting what they say is an innovative method for tackling climate change, and George needed a boat to test his ideas.

After sailing to the Hawaiian Islands, George and his small crew dribbled a deep-red liquid — dissolved iron ore — into the sea. A few days later, the iron prompted a short-lived bloom of phytoplankton, single-celled algae that live at the ocean's surface. The algae absorb carbon dioxide, so fertilizing the sea to encourage their growth should increase the amount of CO_2 removed from the atmosphere, and hence help to tackle climate change. George and others reason that companies and governments that want to cut greenhouse-gas emissions will pay them to fertilize the oceans with iron.

As these groups begin to explore such ideas, ocean researchers are warning that the schemes could disrupt marine ecology and produce harmful gases. But despite their concerns, international law seems to be stacked against the dissenting researchers. As matters stand, there is little scientists can do to make companies perform thorough risk assessments on their fertilization plans.

George's idea is workable in theory. Phytoplanktonic algae are responsible for about half of all of the biological absorption of CO_2. Most of the organisms pass through the marine food web and the CO_2 they have absorbed is returned to the atmosphere by respiration. But some will eventually sink to the ocean floor and remain there for hundreds of years, preventing the CO_2 from causing greenhouse warming.

Food for thought

The link between iron and phytoplankton was first highlighted by John Martin, formerly director of the Moss Landing Marine Laboratories in California. In 1988, Martin published a hypothesis suggesting that iron is the missing factor that limits phytoplankton growth in some ocean waters[1]. The seas between Antarctica and the southern tips of the Americas and Africa, for example, contain plenty of some nutrients, such as nitrates and phosphates. But they don't contain much iron, or much phytoplankton.

Since Martin's death in 1993, several expeditions have shown that a lack of iron does indeed limit phytoplankton growth in these regions[2–5]. One such study — EISENEX — set sail from Cape Town in October 2000. More than 50 physicists, chemists and biologists travelled to the southern Atlantic on the German research vessel *Polarstern*, aiming to distribute iron in the eye of a 150-kilometre-wide eddy current.

Despite extreme weather conditions — the first gale hit the *Polarstern* five days after the iron solution was dissolved — the expedition was a scientific success. By monitoring the amount of phytoplankton in water samples taken before and after fertilization, the team backed up previous experiments that had shown that iron fertilization boosts phytoplankton growth. And by measuring phytoplankton concentrations at different depths, the researchers estimated how much carbon was transported to the deep ocean. They have yet to publish their results, but similar estimates by other teams suggest that the fraction of carbon transported is much lower than theory had predicted[6].

Despite the uncertainty, these experiments have attracted the interest of entrepreneurs. The international effort to limit greenhouse-gas emissions, enshrined in the Kyoto Protocol, is based on a system of emission credits. Each country is assigned an emissions limit, but nations can exceed their target if they counteract their actions by financing measures that absorb carbon from the atmosphere, such as planting forests. Countries that have ratified the Kyoto Protocol are likely to impose emission limits on individual companies and run similar trading systems at the national level. And as projects such as planting new forests are costly, companies such as Planktos want to sell emission credits by running iron-fertilization projects. Although the United States has not ratified Kyoto, it may yet set its own mandatory emission targets, or choose to sign up to the protocol at a later date.

Ulf Riebesell, a marine biologist at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, has compared studies of different methods for removing carbon dioxide from the atmosphere and says that iron fertilization would be 10–100 times cheaper than forestation, the next cheapest option. Riebesell also believes that large-scale, continuous fertilization of suitable areas of the oceans could allow between three billion and five billion tonnes of CO_2 to be drawn down per year — 10–20% of annual synthetic emissions.

J. HAWKES/CORBIS

Steamed up: power generators may be interested in iron fertilization as a balance to their CO_2 emissions.

Depth charges

No wonder, then, that the fight for pole position in a future ocean-engineering business has already begun. As well as the non-profit Planktos Foundation, which is financed by donations from energy companies and individuals, GreenSea Venture, based in Springfield, Virginia, says that it is planning large-scale commercial fertilization experiments. GreenSea's Michael Markels, a 76-year-old retired environmental engineer, has already obtained US patents on techniques for discharging iron fertilizers from floating buoys or commercial cargo ships.

"Until now, the number of field experiments has been restricted to those with major research budgets," says George. "By using an old sailing vessel, we were able to show that useful ocean research is not the exclusive domain of the richest researchers."

Although George's spirit of adventure may have caught the attention of the media, marine scientists are less enamoured by his ideas. They point out that there are no reliable tools for verifying the amount of carbon taken up by the phytoplankton. More importantly, they worry about the impact of the fertilization on other marine life. "People like George and Markels claim that they can make the oceans green and solve all our problems, but it's not that easy," says Paul Falkowski, a marine biologist at Rutgers University in New Brunswick, New Jersey.

Sallie Chisholm fears that boosting algal growth may disrupt the oceans' ecology.

"There is no free lunch," agrees Sallie Chisholm, a marine biologist at the Massachusetts Institute of Technology who is at the forefront of attempts to resist the iron-fertilization plans. She fears that altering natural carbon fluxes could trigger a cascade of unwanted side effects. The iron could, for example, prompt the growth of toxic algae, which could kill other marine life or change water chemistry by removing oxygen. "The oceans are a tightly linked system, one part of which cannot be changed without it resonating through the whole system," says Chisholm.

Delicate balance

Riebesell adds that gaps in our knowledge about phytoplankton make it difficult to know which of the possible side effects will occur. "The life cycle of plankton and the evolutionary trends it has followed are completely different from those of terrestrial organisms," he says. "As long as our understanding of marine ecosystems is still in its infancy there is a great danger of abuse."

George counters such fears by pointing out that the input of iron into the ocean fluctuates with changes in the vegetation and farming activities on nearby land. Phytoplankton levels in the north Pacific have, for example, declined over the past 30 years. This seems to be linked to increased winter planting of wheat in China, which has limited the amount of iron-containing dust blown from fields into the sea[7].

But there may be more at stake than marine ecology. Mark Lawrence, an atmospheric chemist at the Max Planck Institute for Chemistry in Mainz, Germany, has looked at the possible disruption to climate that the fertilization could cause[8]. Phytoplanktonic algae produce dimethylsulphide, which influences cloud formation. The organisms are also believed to increase the amount of sunlight absorbed by the oceans. And they produce compounds such as methyl halides, which cause ozone depletion.

Lawrence doubts whether the developers of iron fertilization will voluntarily assess such possible environmental side effects. But currently there is no legal framework to demand a full environmental-impact assessment. International maritime law covers issues such as the dumping of waste material at sea, but contains nothing to prohibit commercial ocean fertilization.

And private groups such as the Planktos Foundation are not forced to use the same standards as academic researchers when experimenting on the open seas, points out John Cullen, a physical and biological oceanographer at Dalhousie University in Halifax, Canada. "Before any large-scale projects start, responsibilities, risks and possible benefits need to be addressed at an international level, with inclusion of all interested parties and stakeholders," says Cullen, who suggests that international bodies such as the United Nations Environment Programme should oversee all work on iron fertilization. But so far, politicians seem to have been deaf to such warnings, leaving organizations such as Planktos and GreenSea free to pursue their experiments in climate engineering. ■

Quirin Schiermeier is *Nature*'s German correspondent.

1. Martin, J. H. & Fitzwater, S. E. *Nature* **331,** 341–343 (1988).
2. Martin, J. H. *et al. Nature* **371,** 123–129 (1994).
3. Coale, K. H. *et al. Nature* **383,** 495–501 (1996).
4. Boyd, P. W. *et al. Nature* **407,** 695–702 (2000).
5. Watson, A. J., Bakker, D. C. E., Ridgwell, A. J., Boyd, P. W. & Law, C. S. *Nature* **407,** 730–733 (2000).
6. Dalton, R. *Nature* **420,** 722 (2002).
7. Gregg, W. W. & Conkright, M. E. *Geophys. Res. Lett.* doi:10.1029/2002GL014689 (2002).
8. Lawrence, M. G. *Science* **297,** 1993 (2002).

Planktos Foundation
www.planktos.com
GreenSea Ventures
www.greenseaventure.com