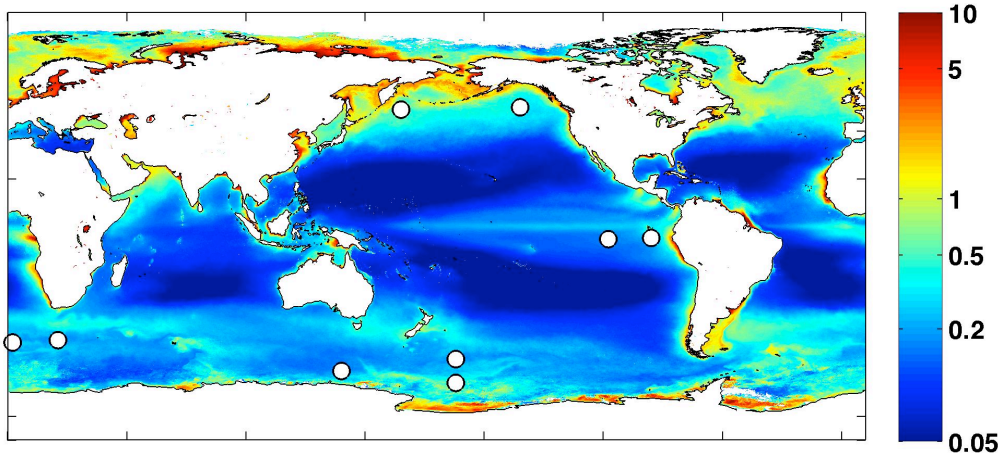
Mixing iron into the north Pacific stirs controversy

A story has recently broken in the Guardian, the New York Times, CBC, Nature and Science about a community from British Columbia that fertilised the ocean with iron in order to stimulate a plankton bloom and restore the salmon fishery. This idea has drawn almost universal condemnation for violation of international protocols and potential deleterious effects on the ecosystem. But it's possible that the bloom occurred naturally. What is the science behind iron fertilisation and why is this recent event causing so much controversy?

The process by which atmospheric CO_2 enters the surface ocean, is packaged into planktonic biomass and exported to the deep ocean is known as the *biological pump*. In vast areas of the global ocean – the north Pacific, equatorial Pacific and Southern Ocean – the efficiency of the biological pump is limited by the bio-availability of dissolved iron. Iron is an important micro-nutrient, almost like a vitamin for ocean productivity, yet it is extremely scarce in much of the modern ocean. Oceanic iron fertilisation (OIF) has been suggested as a climate change mitigation mechanism to enhance the sequestration of anthropogenic CO_2 into the deep ocean. It has also been discussed and even patented in the context of increasing the productivity of ocean fisheries. That is, by increasing the productivity of the base of the marine food chain, it might be possible to enhance fish yields.



A map of satellite-derived mean annual chlorophyll concentration (units are mg chl m^{-3}). Phytoplankton contain chlorophyll, so these maps are used as an indicator of ocean productivity. The white circles are the locations of nine OIF experiments performed since 1993.

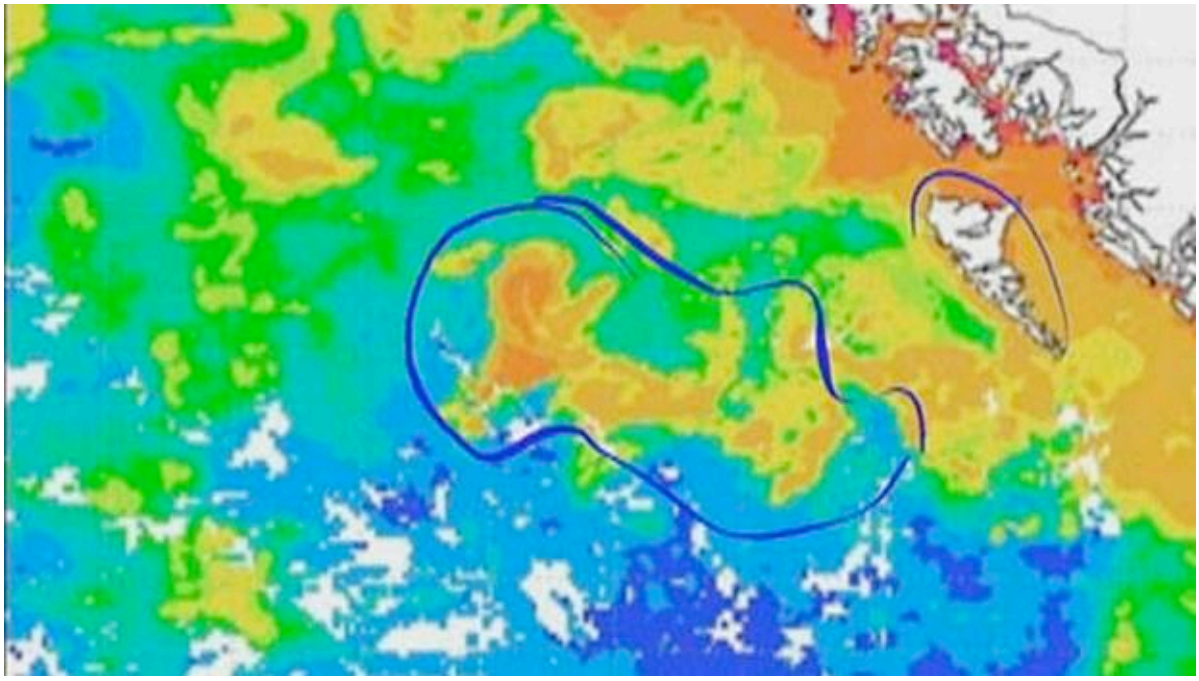
At least nine OIF experiments have been performed since 1993 in each of the major iron-limited regions of the global ocean, mostly in the context of understanding changes in ocean productivity and atmospheric CO_2 concentrations that have occurred over

glacial-interglacial cycles (~20,000 years). These experiments have demonstrated increases in chlorophyll (phytoplankton biomass), changes in the type of phytoplankton (usually more diatoms), and consumption of other nutrients and CO_2. Until recently, export of carbon into the deep ocean had been confirmed in only two of the OIF experiments, and even then, the efficiency of the transport had been far less than expected. But in 2004, an export efficiency (beyond 1000m depth) of greater than 50% was measured for an iron-fertilised bloom in a clockwise-rotating eddy in the Southern Ocean. This result has to some extent revived the debate surrounding iron fertilisation as a geo-engineering technique.

Concerns have been raised about the impact of OIF on several aspects of ocean health. Fertilising with one nutrient will undoubtedly cause scarcity of the next least-available nutrient, probably phosphorous or nitrogen. The blooms generated by iron fertlisation, when they die and decompose, consume oxygen and may lead to larger oxygen deficient zones. It's also possible that the phytoplankton that are favored by iron addition will be the kind that produce potent neurotoxins, which accumulate up the food chain and cause illness in marine mammals and humans. Concern surrounding these potential impacts has in part led to the establishment of moratoria on OIF. But it's also important to realise that these are only potential impacts. With the possible exception of depletion of other nutrients, none of these processes have been observed in any OIF experiments to date.

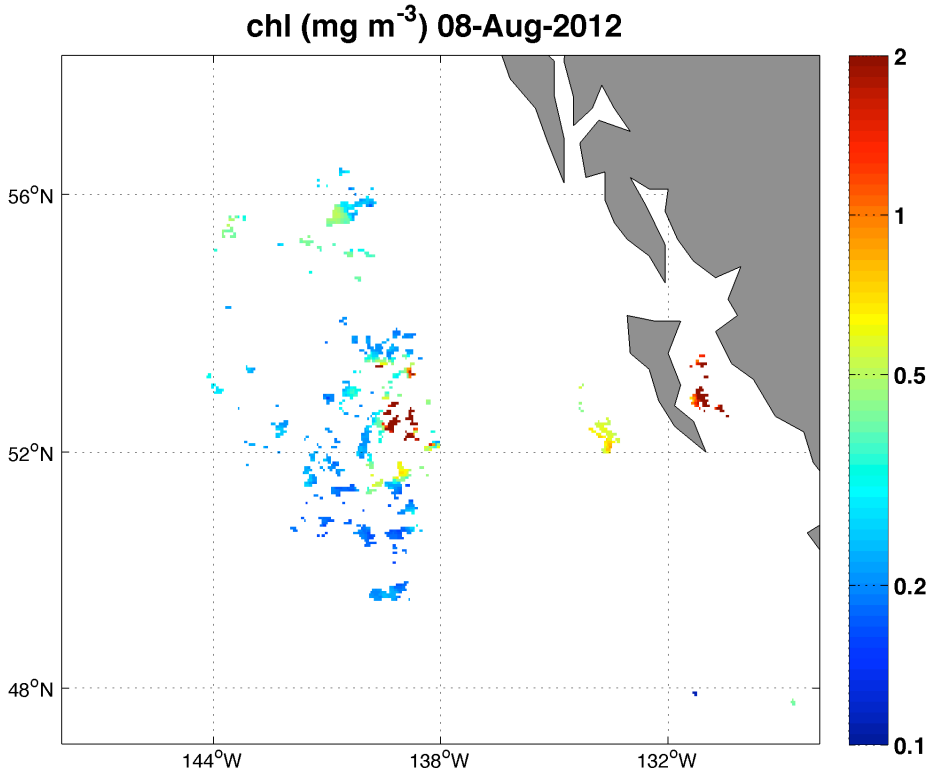
So when it was announced that the Haida Salmon Restoration Corporation (HSRC) had dumped 100 tonnes of iron-rich dirt into the north Pacific from the fishing vessel *Ocean Pearl*, concerns were raised because of the potential violation of the international moratoria, the scale of the experiment and the potential for unintended negative environmental impacts. All of the previous experiments deployed about 1 tonne of iron as iron sulphate solution, so if the dirt used by the HSRC was any more than 1% iron by weight (it was likely more than 5%), this would qualify as the largest deliberate iron addition ever performed. The HSRC claim that they have followed the spirit and the letter of the law, and because the iron addition took place outside of Canada's exclusive economic zone (EEZ, >200 nautical miles, or 370 km from shore), the HSRC were not subject to Canadian law. Leaving aside the legal issues, what evidence is there that a phytoplankton bloom was created?

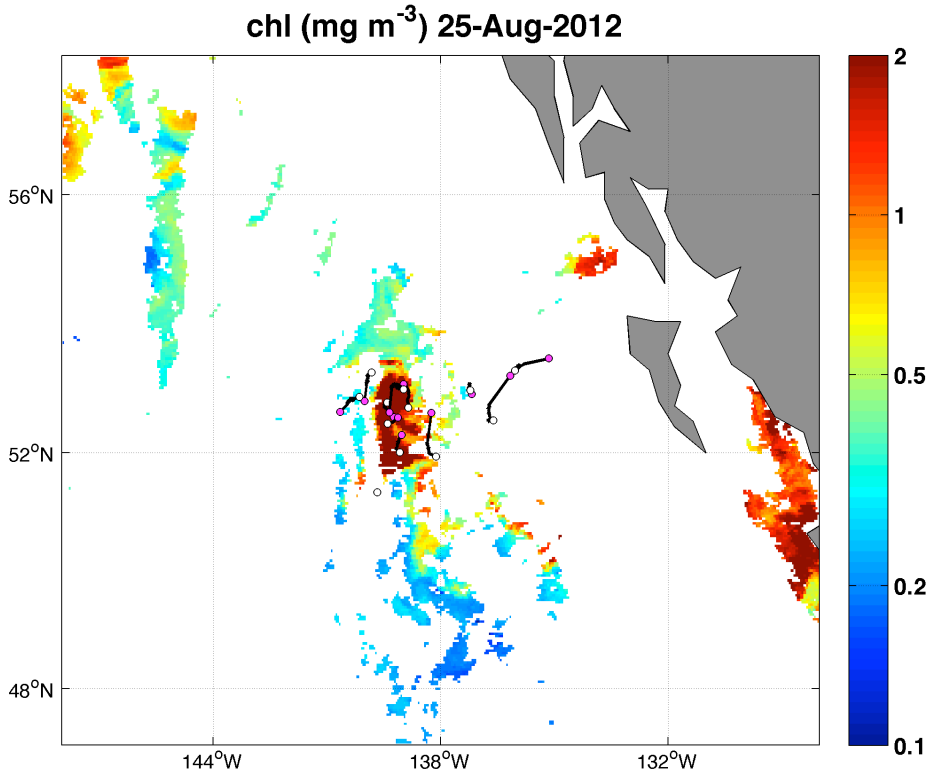
Some news reports of the iron addition have shown a satellite chlorophyll image, with a hand-drawn circle indicating what appears to be a bloom. However, this region of the ocean is known to be populated by eddies (called Haida eddies because of where they are generated) that move productive, iron-rich coastal waters into the low-productivity open north Pacific. Is it possible to determine whether the bloom in the satellite image below was due entirely to deliberate iron fertilisation by the HSRC?



A satellite chlorophyll image from the Haida Gwaii region, purporting to show the bloom generated by the HSRC iron addition. Image from the CBC.

The image above is likely an average of about 2 weeks of satellite data in order to remove persistent cloudiness. But individual daily images may be more useful for determining whether the circled bloom was natural or iron-fertilised. Many of the news reports say the iron fertilisation occurred in July, but this does not seem to be true. The *Ocean Pearl* deployed 20 drifters provided by the National Oceanic and Atmospheric Administration (NOAA). The deployment information for these drifters gives a fix on the ship. The two images below tell us a little about the pre-existing chlorophyll concentrations in this region of the North Pacific and the *Ocean Pearl's* expedition. The first is a snapshot from August 8th that is significantly cloud-contaminated but does show some high chlorophyll near 139°W, 53°N, where the bloom was eventually seen in the first relatively clear satellite image, the second of the two images below, on August 25th.


chl (mg m-3) 08-Aug-2012
56°N
52°N
48°N
144°W
138°W
132°W
2
1
0.5
0.2
0.1


chl (mg m-3) 25-Aug-2012
56°N
52°N
48°N
144°W
138°W
132°W
2
1
0.5
0.2
0.1

In the August 25th image the magenta circles are the deployment locations of the drifters (*ie* the ship's track), the white circles are the location of the drifters on August 25th and the black lines are the drifter trajectories. There was a delay between the deployment of the drifters and the first data received by the NOAA lab in Miami, hence the initial straight line in each drifter track. Based on the drifter data and some images from August 14th and 17th (not shown here for brevity), the *Ocean Pearl* arrived in the location of the bloom on August 14th at the earliest but probably started fertilising no earlier than August 16 or 17th. The high chlorophyll observed on August 25th (no more than 9 days after fertilisation) is approximately 4.5 mg m^{-3} and is probably an underestimate because of known problems with satellite chlorophyll retrievals at high latitudes. In the Subarctic Ecosystem Response to Iron Enrichment Study (SERIES) experiment in 2002, chlorophyll concentrations of this magnitude were not observed until about 14 days after fertilisation.

All of this evidence strongly suggests that the *Ocean Pearl*/HSRC did not solely generate the bloom observed on August 25th and highlighted in news reports. At best they may have slightly enhanced an already high chlorophyll area, as suggested in an article in the Vancouver Sun, but they did not create a bloom in an ocean desert. Furthermore, if it is their intention to sell carbon credits to help offset the cost of the experiment, how will they document the amount of carbon sequestered (one of the biggest measurement challenges from every OIF so far) and how will they demonstrate how much of that carbon sequestration was due to the addition of iron?

This experiment has drawn almost universal condemnation, with inflammatory language such as 'rogue climate hacker' being used in the media. The scientific community, in its concern to show respect for international rules, should, in my opinion, be careful to avoid hyperbole regarding the risks. No deleterious impacts have been observed for any OIFs thus far. Risks may well be minimal and mitigated by good project design. Further research to understand these issues is urgently needed.

Pete Strutton is an Associate Professor and ARC Future Fellow at the Institute for Marine and Antarctic Studies, University of Tasmania. He is also a Chief Investigator with the ARC Centre of Excellence for Climate System Science. His expertise in this area includes participation in the Southern Ocean Iron Experiment (SOFeX), 2002.