Climate engineering – how could it be regulated?

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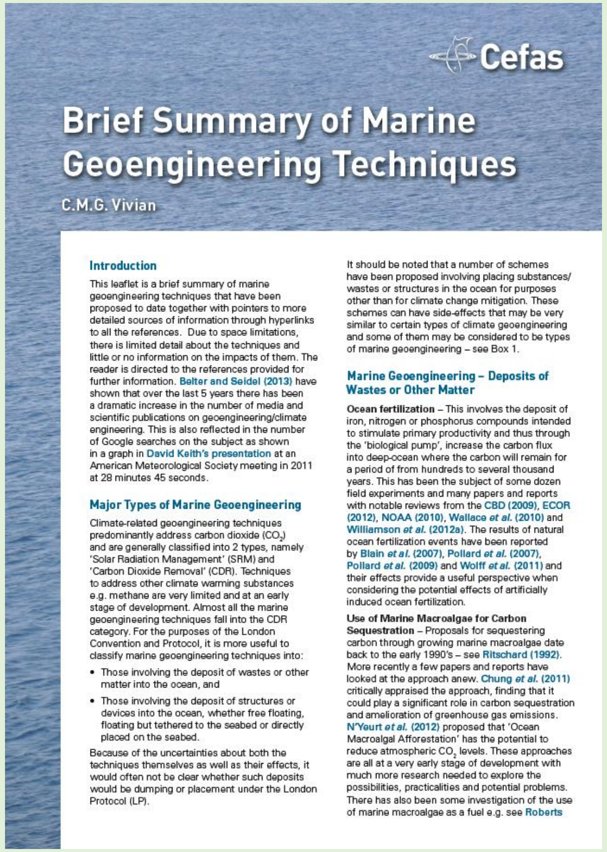
Climate engineering – many things to many people…

- Carbon dioxide removal (CDR) *vs* Solar radiation management (SRM)
- Marine *vs* atmospheric *vs* land-based

- Even within marine CDR techniques…
  - ocean fertilization
  - alkalinity management
  - dumping of crop residues
  - mineralization of seabed rocks
  - enhanced upwelling or downwelling
  - artificial impoundments



Cefas

Brief Summary of Marine Geoengineering Techniques

C.M.G. Vivian

Introduction

This leaflet is a brief summary of marine geoengineering techniques that have been proposed to date together with pointers to more detailed sources of information through hyperlinks to all the references. Due to space limitations, there is limited detail about the techniques and little or no information on the impacts of them. The reader is directed to the references provided for further information. Belter and Seidel (2013) have shown that over the last 5 years there has been a dramatic increase in the number of media and scientific publications on geoengineering/climate engineering. This is also reflected in the number of Google searches on the subject as shown in a graph in David Keith's presentation at an American Meteorological Society meeting in 2011 at 28 minutes 45 seconds.

Major Types of Marine Geoengineering

Climate-related geoengineering techniques predominantly address carbon dioxide (CO_2) and are generally classified into 2 types, namely 'Solar Radiation Management' (SRM) and 'Carbon Dioxide Removal' (CDR). Techniques to address other climate warming substances e.g. methane are very limited and at an early stage of development. Almost all the marine geoengineering techniques fall into the CDR category. For the purposes of the London Convention and Protocol, it is more useful to classify marine geoengineering techniques into:

- Those involving the deposit of wastes or other matter into the ocean, and
- Those involving the deposit of structures or devices into the ocean, whether free floating, floating but tethered to the seabed or directly placed on the seabed.

Because of the uncertainties about both the techniques themselves as well as their effects, it would often not be clear whether such deposits would be dumping or placement under the London Protocol (LP).

It should be noted that a number of schemes have been proposed involving placing substances/ wastes or structures in the ocean for purposes other than for climate change mitigation. These schemes can have side-effects that may be very similar to certain types of climate geoengineering and some of them may be considered to be types of marine geoengineering – see Box 1.

Marine Geoengineering – Deposits of Wastes or Other Matter

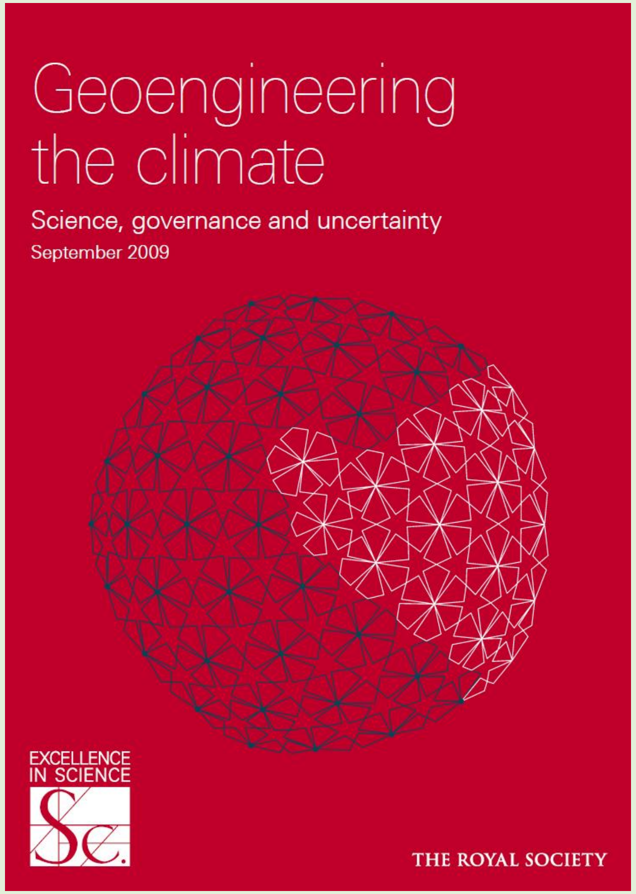
Ocean fertilization – This involves the deposit of iron, nitrogen or phosphorus compounds intended to stimulate primary productivity and thus through the 'biological pump', increase the carbon flux into deep-ocean where the carbon will remain for a period of from hundreds to several thousand years. This has been the subject of some dozen field experiments and many papers and reports with notable reviews from the CBD (2009), ECOR (2012), NOAA (2010), Wallace *et al.* (2010) and Williamson *et al.* (2012a). The results of natural ocean fertilization events have been reported by Blain *et al.* (2007), Pollard *et al.* (2007), Pollard *et al.* (2009) and Wolff *et al.* (2011) and their effects provide a useful perspective when considering the potential effects of artificially induced ocean fertilization.

Use of Marine Macroalgae for Carbon Sequestration – Proposals for sequestering carbon through growing marine macroalgae date back to the early 1990's – see Ritschard (1992). More recently a few papers and reports have looked at the approach anew. Chung *et al.* (2011) critically appraised the approach, finding that it could play a significant role in carbon sequestration and amelioration of greenhouse gas emissions. N'Yeurt *et al.* (2012) proposed that 'Ocean Macroalgal Afforestation' has the potential to reduce atmospheric CO_2 levels. These approaches are all at a very early stage of development with much more research needed to explore the possibilities, practicalities and potential problems. There has also been some investigation of the use of marine macroalgae as a fuel e.g. see Roberts

Climate engineering - how could it be regulated?

- Can such a diverse array of concepts be regulated in a consistent and coherent manner?
- For regulatory purposes, can valid distinctions be made between research and deployment of climate engineering techniques?
- Do appropriate regulatory bodies exist to address the diversity of concepts and proposed activities?
- Is our knowledge base on effectiveness and potential adverse impacts developed enough to allow regulated research and deployment?

Royal Society – headline messages

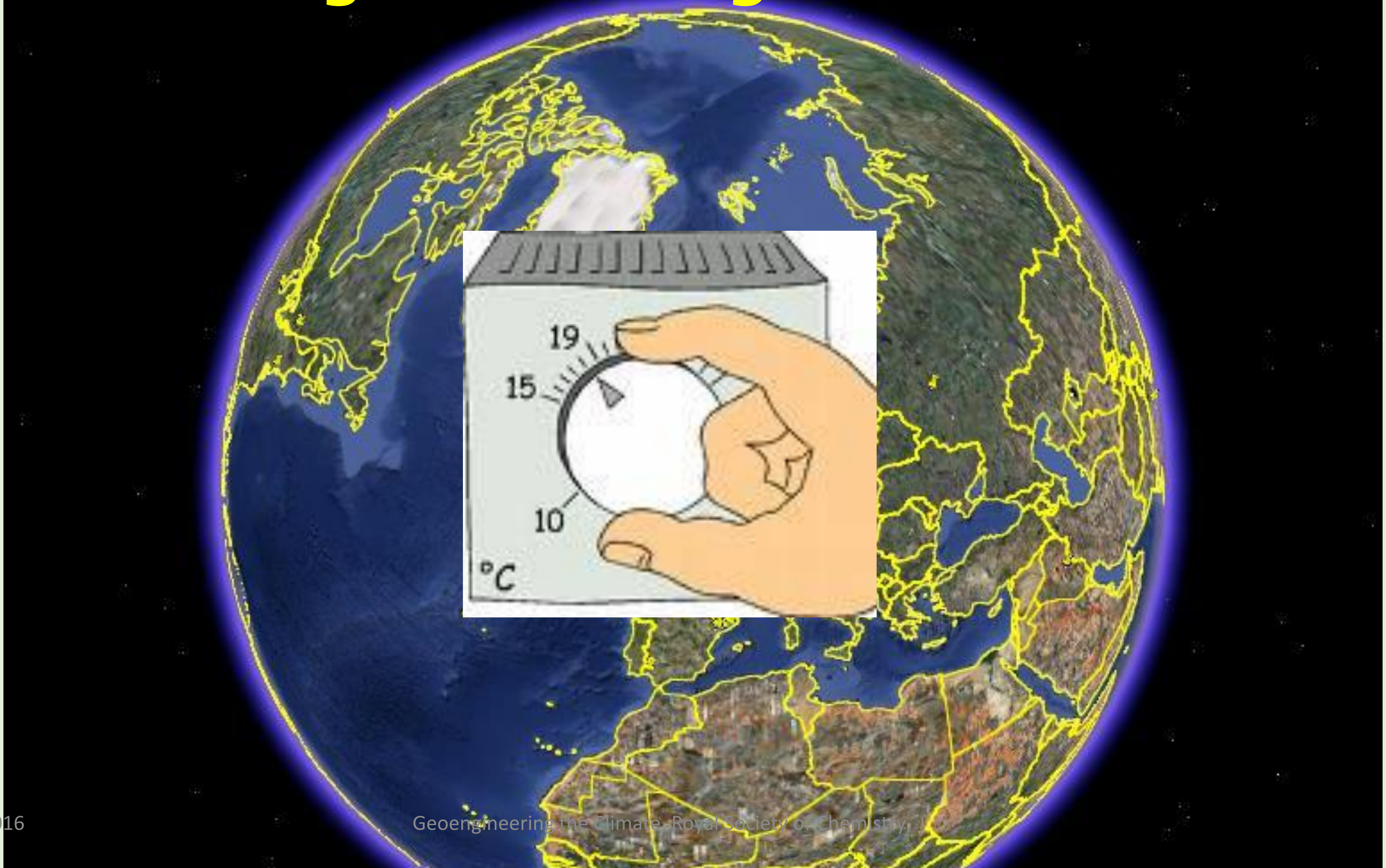


- "Geoengineering of the Earth's climate is very likely to be technically possible. However, the technology to do so is barely formed, and there are major uncertainties regarding its effectiveness, costs, and environmental impacts".

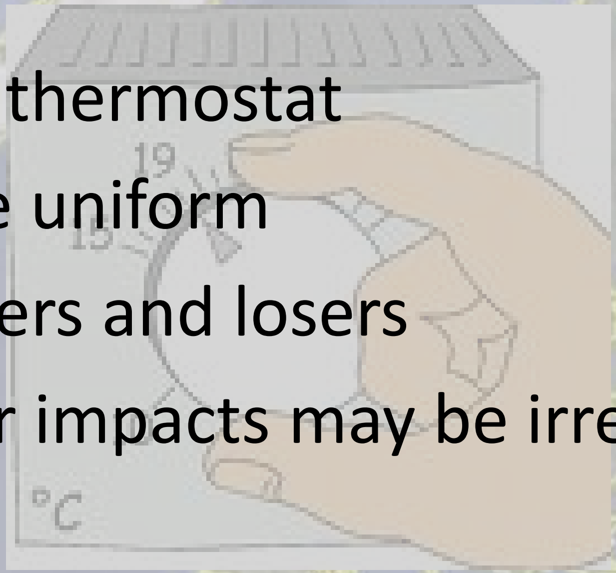
Royal Society – headline messages

- “The safest and most predictable method of moderating climate change is to take early and effective action to reduce emissions of greenhouse gases”.
- “Nothing now known about geoengineering options gives any reason to diminish these efforts”.
- “No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change”.

Turning down 'the global thermostat'?



Turning down 'the global thermostat'?



- There is no simple thermostat
- Impacts will not be uniform
- There will be winners and losers
- Decisions and their impacts may be irreversible
- Who will decide?

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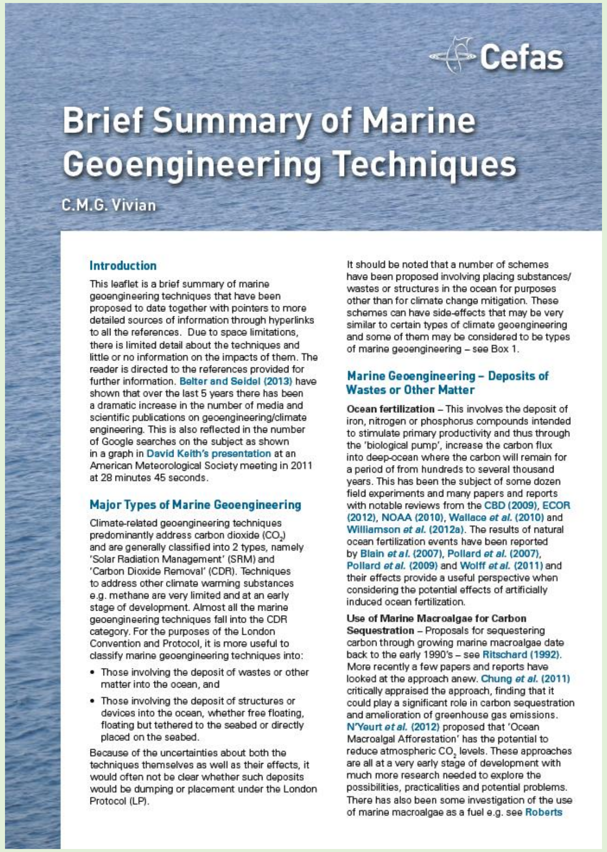

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Case example:
regulation of marine geoengineering under the London Convention – London Protocol

- Legal amendments to London Protocol in 2013 to enable regulation of marine geoengineering activities listed on an Annex
- So far Annex includes only ocean fertilization (with potential to add other activities on a case-by-case basis)
- Has yet to be used in action

What is ocean fertilisation?

- Some ocean regions support lower plankton productivity than predicted – ‘high nitrate, low chlorophyll’ (HNLC) regions
- Adding nutrients, especially iron, stimulates phytoplankton blooms
- Phytoplankton fix carbon, resulting in localised drawdown of CO_2

15 years of laboratory and field research…

- have confirmed that adding iron to HNLC regions can stimulate phytoplankton blooms (commonly associated with a shift in species composition)
- have led to increased understanding of the cycling of iron and other nutrients in ocean ecosystems
- have contributed to understanding of the linkages between ocean productivity and climate
- BUT many uncertainties remain

Some historical context

- Continued research interest (1960s onwards, but especially 1990s-2000s)
- Greatly increased commercial interest (2007 onwards)
- Rapidly increasing policy interest (2007 onwards)
  - is it an effective option for climate change mitigation?
  - what are the likely nature, scale and acceptability of the consequences (both intended and unintended) for marine ecosystems?
  - should commercial ocean fertilization developments be allowed?

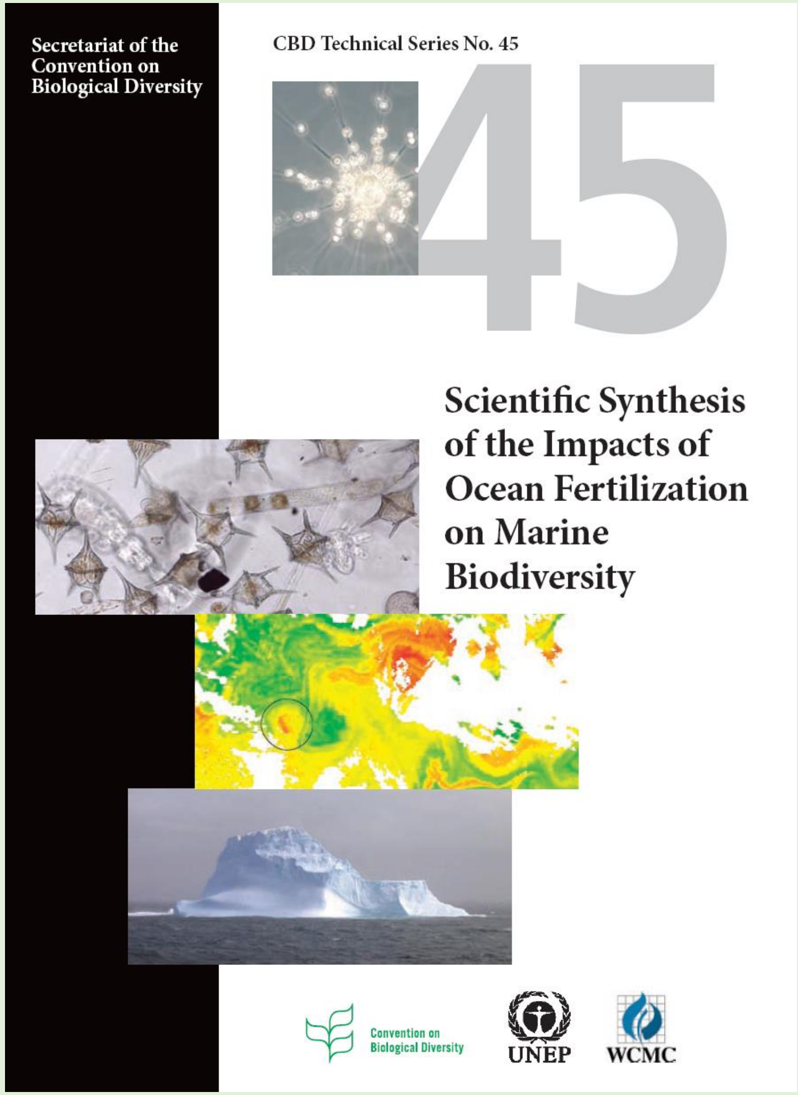
Key international treaties and conventions

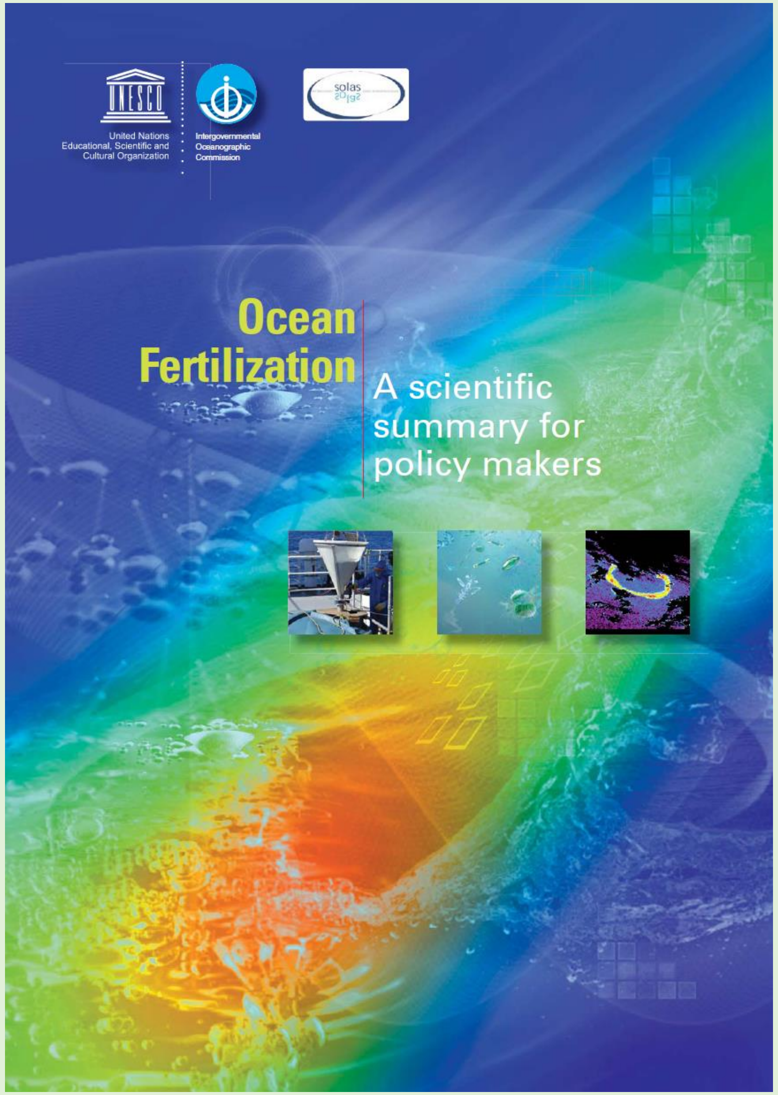
- London Convention (1972)
- London Protocol (1996)
- United Nations Convention on Law of the Sea (UNCLOS)
- UN Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol
- UN Convention on Biological Diversity (CBD)
- Regional seas conventions (e.g. OSPAR and many others)

Potential adverse effects

- Toxic phytoplankton blooms (algae)
- Lack of oxygen in oceanic waters
- Increased emissions of other important climate gases, e.g. DMS and nitrous oxide
- Alter food web structure
- Effects on ecosystem scale
- Ocean ecosystems already stressed. Extra stress? Possible collapse??

Scientific synopses of ocean fertilization





IOC-UNESCO Ocean fertilization:
scientific summary for policy makers*

Recognises three proposed justifications for ocean fertilization:

1. for scientific research
2. for deliberate carbon sequestration
3. for fisheries enhancement

(*Wallace *et al.* 2010)

IOC-UNESCO Ocean fertilization:
scientific summary for policy makers

- "…chlorophyll increased in all [iron] experiments, by 2-25 times, with associated increases in carbon fixation."
- ***BUT*** …
  - "… biological and chemical responses to nutrient fertilization are variable and difficult to predict."
  - "…adequate verification cannot yet be achieved with currently available observing capabilities."
  - "…we have insufficient knowledge, let alone technique…to reverse any large scale, long term changes to ecosystems"

Summary of reports from US National Academy of Sciences

- Climate intervention is no substitute for reductions in GHG or for adaptation
- If deployed, carbon dioxide removal techniques (BECCS, DACS) could be most predictable
- Attempts to modify albedo (SRM) pose poorly understood risks (especially to precipitation and stratospheric ozone) and would not address ocean acidification
- SRM would have unique legal, ethical, social, political and economic implications

Summary of reports from US National Academy of Sciences

- Nevertheless, research should continue…
  - For CDR techniques, research & development at scale
  - For SRM techniques…
    - More modelling
    - Small scale atmospheric experiments (under normal research controls)
    - Large-scale atmospheric experiments (only under new governance systems for research)
    - Deployment – not in the foreseeable future

CBD developments (November 2015)

UNEP

CBD

Convention on Biological Diversity

Distr.
GENERAL

UNEP/CBD/SBSTTA/19/INF/2
5 October 2015

ENGLISH ONLY

SUBSIDIARY BODY ON SCIENTIFIC,
TECHNICAL AND TECHNOLOGICAL ADVICE
Nineteenth meeting
Montreal, 2-5 November 2015
Item 4.2 of the provisional agenda*

UPDATE ON CLIMATE GEOENGINEERING IN RELATION TO THE CONVENTION ON BIOLOGICAL DIVERSITY: POTENTIAL IMPACTS AND REGULATORY FRAMEWORK

Note by the Executive Secretary

1. In response to decision X/33, the Secretariat published, in 2012, CBD Technical Series No. 66: *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters* (http://www.cbd.int/doc/publications/cbd-ts-66-en.pdf). The study provided a scientific reference basis for the decision adopted at the eleventh meeting of the Conference of the Parties.

2. In decision XI/20, paragraph 16(a), the Conference of the Parties requested the Executive Secretary, subject to the availability of financial resources and at the appropriate time, to prepare, provide for peer-review and submit for consideration by a future meeting of the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), an update on the potential impacts of geoengineering techniques on biodiversity, and on the regulatory framework of climate-related geoengineering relevant to the Convention on Biological Diversity, drawing upon all relevant scientific reports such as the Fifth Assessment Report of the Intergovernmental Panel on Climate Change and discussions under the Environment Management Group.

3. An interim update of information on the potential impacts of climate geoengineering on biodiversity and the regulatory framework relevant to the Convention on Biological Diversity was made available in June 2014 for the eighteenth meeting of SBSTTA (UNEP/CBD/SBSTTA/18/INF/5). The Synthesis Report of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change now having been published, the update requested by the Conference of the Parties has been prepared for consideration by SBSTTA at its nineteenth meeting.

4. The present note expands on the interim update prepared for SBSTTA-18, with the inclusion of additional information from the Synthesis Report of the Fifth Assessment of the Intergovernmental Panel on Climate Change, and other more recent publications. This report has been prepared by the Secretariat of the Convention on Biological Diversity with the assistance of the lead authors[1] of Parts I and II of CBD Technical Series No. 66.

5. A draft of this note has been made available widely for peer-review, including to the authors of and contributors to the earlier studies, and the experts nominated as reviewers through notification 2015-016 of 12 February 2015.

6. The key messages of this note have been reproduced in document UNEP/CBD/SBSTTA/19/7.

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* UNEP/CBD/SBSTTA/19/1.

[1] Chapters 1-5: Phillip Williamson, acting in an independent capacity with support from the UK Natural Environment Research Council, and with assistance on BECCS-related text by Naomi Vaughan (University of East Anglia) and Clair Gough (University of Manchester). Chapter 6: Ralph Bodle, Ecologic Institute, Berlin, Germany.

UNEP

CBD

Convention on Biological Diversity

Distr.
GENERAL

UNEP/CBD/SBSTTA/REC/XIX/7
4 November 2015

ORIGINAL: ENGLISH

SUBSIDIARY BODY ON SCIENTIFIC,
TECHNICAL AND TECHNOLOGICAL ADVICE
Nineteenth meeting
Montreal, Canada, 2–5 November 2015
Agenda item 4.2

RECOMMENDATION ADOPTED BY THE SUBSIDIARY BODY ON SCIENTIFIC, TECHNICAL AND TECHNOLOGICAL ADVICE

XIX/7. Climate-related geoengineering

The Subsidiary Body on Scientific, Technical and Technological Advice,

Recalling decisions X/33 and XI/20 and the information contained in Technical Series No. 66 of the Convention on Biological Diversity,[1]

Noting that the Intergovernmental Panel on Climate Change in its Fifth Assessment Report has not addressed, in detail, the impacts of climate-related geoengineering techniques on biodiversity and ecosystems,

1. *Takes note* of the updated report on climate-related geoengineering in relation to the Convention on Biological Diversity[2] and the information contained in the note by the Executive Secretary on climate-related geoengineering,[3]

2. *Recommends* that the Conference of the Parties at its thirteenth meeting adopt a decision along the following lines:

The Conference of the Parties

(a) *Reaffirms* paragraph 8, in particular its subparagraph (w), of decision X/33, and decision XI/20;

(b) *Recalls* paragraph 11 of decision XI/20, in which the Conference of the Parties noted that the application of the precautionary approach as well as customary international law, including the general obligations of States with regard to activities within their jurisdiction or control and with regard to possible consequences of those activities, and requirements with regard to environmental impact assessment, may be relevant for geoengineering activities but would still form an incomplete basis for global regulation;

(c) *Recalling* paragraph 4 of decision XI/20, in which the Conference of the Parties emphasized that climate change should primarily be addressed by reducing anthropogenic emissions by sources and by increasing removals by sinks of greenhouse gases under the United

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[1] *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters*, available at www.cbd.int/doc/publications/cbd-ts-66-en.pdf.

[2] UNEP/CBD/SBSTTA/19/INF/2.

[3] UNEP/CBD/SBSTTA/19/7.

CBD developments (November 2015)

- Biodiversity is affected by a number of drivers of change that will themselves be impacted by proposed CDR and SRM geoengineering techniques.
- If effective, geoengineering would reduce the impacts of climate change on biodiversity at the global level.
- However, in the case of SRM under conditions of high CO_2 this would not necessarily be the case at local levels, due to an inherently unpredictable distribution of temperature and precipitation effects.
- Benefits for biodiversity of reducing climate change impacts through large-scale biomass-based CO_2 removal seem likely to be offset and possibly outweighed, by land use change.

CBD developments (November 2015)

- Changes in ocean productivity through large-scale fertilization would necessarily involve major changes to marine ecosystems, with associated risks to biodiversity.
- In general, technique-specific side effects that may be detrimental for biodiversity are not well understood.
- Assessment of the direct and indirect impacts (each of which may be positive or negative) of climate geoengineering is not straightforward.
- Further research, with appropriate safeguards, could help to reduce some of these knowledge gaps and uncertainties.

Duprat *et al.* (2016) [Nature Geoscience] & Costa *et al.* (2016) [Nature]

nature geoscience

LETTERS

PUBLISHED ONLINE: 11 JANUARY 2016 | DOI: 10.1038/NGEO2633

Enhanced Southern Ocean marine productivity due to fertilization by giant icebergs

Luis P. A. M. Duprat, Grant R. Bigg* and David J. Wilton

Primary productivity is enhanced within a few kilometres of icebergs in the Weddell Sea[1,2] owing to the input of terrigeneous nutrients and trace elements during iceberg melting. However, the influence of giant icebergs, over 18 km in length, on marine primary production in the Southern Ocean is less well studied[1,2]. Here we present an analysis of 175 satellite images of open ocean colour before and after the passage of 17 giant icebergs between 2003 and 2013. We detect substantially enhanced chlorophyll levels, typically over a radius of at least 4–10 times the iceberg's length, that can persist for more than a month following passage of a giant iceberg. This area of influence is more than an order of magnitude larger than that found for sub-kilometre scale icebergs[2] or in ship-based surveys of giant icebergs[1]. Assuming that carbon export increases by a factor of 5–10 over the area of influence, we estimate that up to a fifth of the Southern Ocean's downward carbon flux originates with giant iceberg fertilization. We suggest that, if giant iceberg calving increases this century as expected[4], this negative feedback on the carbon cycle may become more important.

The Southern Ocean is a significant sink in the ocean component of the global carbon cycle, contributing ~10% of the ocean's total carbon sequestration through a mixture of chemical and biologically driven processes[5]. However, its contribution is at a lower level than that of the smaller South Pacific and Indian Oceans[5], owing to its low concentration of dissolved iron, an important trace nutrient for primary production[6]. Atmospheric dust is a major background source of iron to the region[7], but iron-rich sediment fluxes from islands[8], continental shelves[9], ice sheet meltwater[10] and melting icebergs[1] are known to be other, locally much more important, sources of iron. There are a few large-scale estimates of the contribution of icebergs to the Southern Ocean iron flux, derived from modelling studies of typical sub-kilometre sized icebergs[11,12] scaling up of observational studies[13,14] or remote sensing studies[2]. However, these assume iceberg inputs are well represented by those from the smaller, sub-kilometre, peak in the very bimodal size distribution[15]. In fact about half the total iceberg discharge volume is made up of giant icebergs[15]—those exceeding 18 km in horizontal dimension—and there have at present been only two observational studies of the phytoplankton blooms close to individual giant icebergs, both in conditions within or near sea-ice cover in the Weddell Sea[1,3]. Such areas may be subject to enhanced productivity due to the impact of sea-ice fertilization[16]. Although the calving of giant icebergs is very episodic[15], they derive from a range of geographical and geologic environments around Antarctica, and are thus likely to have different iron and nutrient characteristics. Several dozen such icebergs are present in the Southern Ocean at any one time[15], and they can survive for many years. Even when in areas of open water, giant icebergs can survive for longer than a year[17]. Here we examine the chlorophyll signature from a range of giant icebergs in the open Southern Ocean using remote sensing, to show that ocean fertilization from such icebergs is much larger than previously suspected.

Chlorophyll levels are well known to be raised near icebergs[1,2,18]. This derives from the meltwater plumes from icebergs containing significant concentrations of iron, but also a range of other nutrients[14]. As the Southern Ocean is a high-nutrient low-chlorophyll (HNLC) region[6], it is the bioavailable iron known to be in nanoparticle aggregates of ferrihydrite and goethite in iceberg sediments[13] that is the key nutrient within this meltwater. Dissolution of these particles leads to enriched concentrations of dissolved iron in the meltwater plume at levels 10–1,000 times those due to atmospheric dust[19]. Ship-based studies have demonstrated that, for an iceberg of maximum horizontal size L_1, chlorophyll levels are enhanced downstream over a distance of $\sim L_1$ (ref. 20). Similarly, it has been shown using SeaWiFS ocean colour that the probability of chlorophyll being enhanced six days after an iceberg with a L_1 of ~1 km has passed over a location is a third higher than from chance alone[2]. However, the inherent practical limitations of these studies mean that an accurate picture of the chlorophyll enhancement in waters surrounding a giant iceberg is not known.

The potential for major enhanced production around giant icebergs is shown in Fig. 1, where chlorophyll levels in excess of ten times background extend in plumes at least 3–4 L_1 both upstream and downstream of iceberg C16. Examining the chlorophyll signal of a range of giant icebergs calved from around Antarctica over a ten-year period (see Supplementary Methods and Supplementary Table 1), it is found that such an enhancement is ubiquitous and long lasting. A chlorophyll enhancement by a factor of ten is found at least a month following passage of a giant iceberg (Fig. 2a). This order of magnitude enhancement peaks 50–200 km from the giant iceberg, but some enhancement typically extends for over 500 km from the iceberg (Fig. 2b), and occasionally for over 1,000 km. Note that Fig. 2b also implies that measurements taken near a giant iceberg, as has normally been necessary in field campaigns, will significantly underestimate the fertilization peak. This lower production near the iceberg, and the unexpected enhancement of production ahead of the iceberg, are probably due to the buoyant plume associated with the basal melting of the iceberg. The buoyant meltwater plume takes a little time to rise to the surface ahead of the iceberg[20]. This displacement, coupled with the need for time for the enhanced production to develop and possible increased phytoplankton predation close to the iceberg[20], means that the fertilization near the iceberg is lower than further afield. It then spreads out near the surface, transporting dissolved material, allowing this fertilizing material to move ahead of the iceberg, driven by the surface ocean current. Figure 1 shows that this forward fertilization can be substantial.

There is no statistically significant difference between the magnitude of fertilization effects in spring and summer.

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LETTER

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No iron fertilization in the equatorial Pacific Ocean during the last ice age

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The equatorial Pacific Ocean is one of the major high-nutrient, low-chlorophyll regions in the global ocean. In such regions, the consumption of the available macro-nutrients such as nitrate and phosphate is thought to be limited in part by the low abundance of the critical micro-nutrient iron[1]. Greater atmospheric dust deposition[2] could have fertilized the equatorial Pacific with iron during the last ice age—the Last Glacial Period (LGP)—but the effect of increased ice-age dust fluxes on primary productivity in the equatorial Pacific remains uncertain[3–6]. Here we present meridional transects of dust (derived from the ^{232}Th proxy), phytoplankton productivity (using opal, ^{231}Pa/^{230}Th and excess Ba), and the degree of nitrate consumption (using foraminifera-bound δ^{15}N) from six cores in the central equatorial Pacific for the Holocene (0–10,000 years ago) and the LGP (17,000–27,000 years ago). We find that, although dust deposition in the central equatorial Pacific was two to three times greater in the LGP than in the Holocene, productivity was the same or lower, and the degree of nitrate consumption was the same. These biogeochemical findings suggest that the relatively greater ice-age dust fluxes were not large enough to provide substantial iron fertilization to the central equatorial Pacific. This may have been because the absolute rate of dust deposition in the LGP (although greater than the Holocene rate) was very low. The lower productivity coupled with unchanged nitrate consumption suggests that the subsurface major nutrient concentrations were lower in the central equatorial Pacific during the LGP. As these nutrients are today dominantly sourced from the Subantarctic Zone of the Southern Ocean, we propose that the central equatorial Pacific data are consistent with more nutrient consumption in the Subantarctic Zone, possibly owing to iron fertilization as a result of higher absolute dust fluxes in this region[7,8]. Thus, ice-age iron fertilization in the Subantarctic Zone would have ultimately worked to lower, not raise, equatorial Pacific productivity.

The major nutrients for phytoplankton growth (nitrogen, phosphorus and silicon) are supplied to the surface waters of the equatorial Pacific by wind-driven upwelling along the Equator. Their consumption by phytoplankton is thought to be limited in part by the low concentrations of the critical micro-nutrient iron[1]. Successful iron fertilization experiments in the modern ocean[9] have demonstrated the sensitivity of these regions to changes in the micro-nutrient supply. Dust dissolution is one source of iron to the ocean, and globally increased dust fluxes[2] may have caused natural iron fertilization during the peak of the LGP. There is evidence for iron fertilization[8] in the Subantarctic Zone of the Southern Ocean, and the associated carbon storage in the deep ocean may have been responsible for almost half of the carbon dioxide drawdown during the LGP[10]. However, the effects of increased ice-age dust fluxes on the equatorial Pacific are debated[3–6], with arguments both for and against iron fertilization, particularly in the eastern equatorial Pacific.

Here we present new proxy data on dust flux (^{232}Th flux, see Methods), biological productivity ('export production', the export of organic matter out of surface water, as reconstructed from the opal flux, excess barium flux, and ^{231}Pa/^{230}Th, for which ^{230}Th and ^{231}Pa represent excess initial ^{230}Th and ^{231}Pa, respectively) and the degree of nitrate consumption (foraminifera-bound δ^{15}N) from a north–south transect of six cores from the central equatorial Pacific (0.22° S to 6.83° N, 156°–161° W; Extended Data Fig. 1) at two time slices: the Holocene (0–10,000 years ago) and the LGP (17,000–27,000 years ago). The relatively shallow water depths (average ~3,000 m) result in low rates of carbonate dissolution and permit the development of robust foraminifera-based radiocarbon age models (Extended Data Fig. 2, Extended Data Table 1). Furthermore, these core sites are far from the eastern continental margins, and so ^{232}Th at these sites predominantly reflects the flux of airborne dust particles[2]. Central equatorial Pacific surface waters are dominantly sourced with nitrate from the Equatorial Undercurrent, which originates in the west[11]. Thus, relative to the tropical Pacific as whole, the δ^{15}N of the nitrate supply in the central equatorial Pacific is unlikely to be particularly sensitive to changes in eastern Pacific denitrification (see Methods).

Because the central equatorial Pacific is far from dust sources, reconstructed dust fluxes are among the lowest ever measured[12]. Core-top dust fluxes along the 160° W transect average 11.0 mg cm^{-2} kyr^{-1}, with a maximum of 12.8 mg cm^{-2} kyr^{-1} at 2.46° N (Fig. 1a). There is a weak decline in dust flux with increasing latitude ($r^2 = 0.42$, $P = 0.88$), with the lowest dust flux (8.8 mg cm^{-2} kyr^{-1}) at the most northerly core. This negative correlation is in contrast to more easterly (110° W, 140° W) meridional transects, where the highest dust fluxes occur at the more northerly cores[13]. Relative to the Holocene, ice-age dust fluxes are two to three times greater along the 160° W transect, averaging 28.6 mg cm^{-2} kyr^{-1}, with a maximum of 32.2 mg cm^{-2} kyr^{-1}, at 2.46° N. The dust fluxes are remarkably constant as a function of latitude. Overall, the greater dust fluxes during the LGP are consistent with other reconstructions across the equatorial Pacific, which find glacial dust fluxes 0.7 to 3.4 times those of the Holocene (Fig. 2).

However, the expectations of ice-age iron fertilization do not correspond with the observed changes in surface productivity (as determined from opal flux, excess barium flux, ^{231}Pa/^{230}Th; see Methods). Core-top opal fluxes along the transect at 160° W average 47 mg cm^{-2} kyr^{-1} and are negatively correlated with latitude ($r^2 = 0.90$, $P = 0.31$) (Fig. 1b). The maximum opal flux (70 mg cm^{-2} kyr^{-1}) occurs at the Equator, which is consistent with higher surface productivity within the equatorial upwelling zone. Compared to the core-top fluxes, glacial opal fluxes are mostly lower, averaging 37 mg cm^{-2} kyr^{-1}, a finding that is inconsistent with the expectations of local iron fertilization. Glacial fluxes also diminish northward from the Equator, consistent with a stable position for the upwelling.

[1]Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York 10964, USA. [2]Department of Earth and Environmental Sciences, Columbia University, New York, New York 10027, USA. [3]Department of Geosciences, National Taiwan University, Taipei 106, Taiwan. [4]Department of Geosciences, Princeton University, Princeton, New Jersey 08544, USA. [5]Department of Geology and Geophysics, Texas A&M University, College Station, Texas 77843, USA. [6]Ocean Sciences Department, University of California, Santa Cruz, California 95064, USA.

Policy & regulatory developments…

- London Convention/London Protocol
  - May 2007 – statement of concern
  - November 2007 – intention to regulate
  - May 2008 – preparation of technical background
  - October 2008 – Resolution LC-LP.1

  "…given the present state of knowledge, ocean fertilization activities other than legitimate scientific research should not be allowed"
  - February 2009 – start of assessment framework

Policy & regulatory developments…

- UN Convention on Biological Diversity
  - CBD Decision IX/16 (May 2008)

"… requests Parties and urges other Governments, in accordance with the precautionary approach, to ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities, including assessing associated risks, and a global, transparent and effective control and regulatory mechanism is in place for these activities; with the exception of small scale scientific research studies within coastal waters."

Policy & regulatory developments…

- London Convention/London Protocol
  - October 2009 – first attempts to reach legally-binding agreement to prohibit all ocean fertilization activities other than legitimate scientific research (LSR-OF)
  - March 2010 – intersessional legal working group to explore options further
  - April 2010 – Scientific Group completes assessment framework for LSR-OF
  - October 2010 – final agreement on assessment framework but still no legally-binding measures

Ocean Fertilization Assessment Framework (OFAF)

ANNEX 6

ASSESSMENT FRAMEWORK FOR SCIENTIFIC RESEARCH INVOLVING OCEAN FERTILIZATION

(Adopted on 14 October 2010)

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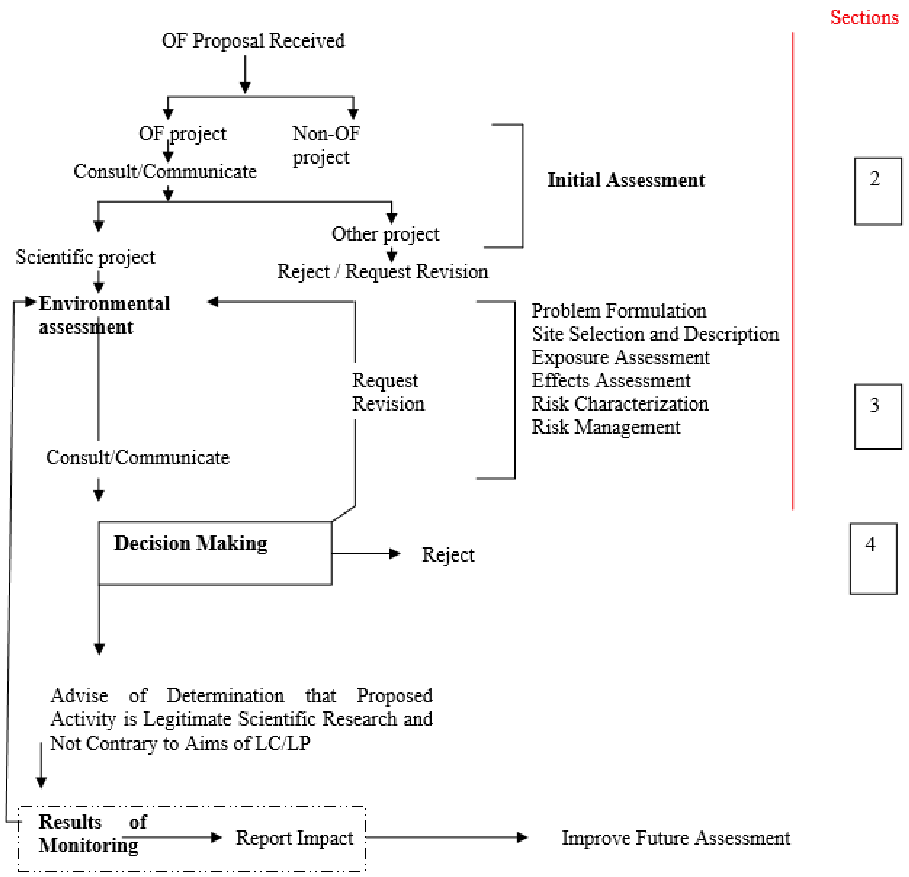
Figure 1: Assessment Framework for Scientific Research Involving Ocean Fertilization



The OFAF (2010) in operation

1 INTRODUCTION AND SUMMARY

1.1 Ocean fertilization is defined as any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans. Ocean fertilization does not include conventional aquaculture, or mariculture, or the creation of artificial reefs.

…

2 INITIAL ASSESSMENT

2.1 The received proposal should include a description of the activity falling within the definition of ocean fertilization in paragraph 1.1 above.

The OFAF (2010) in operation

2.2 In order to determine if a proposed activity has proper scientific attributes, it should meet the following criteria:

.1 the proposed activity should be designed to answer questions that will add to the body of scientific knowledge.

- Proposals should state their rationale, research goals, scientific hypotheses and methods, scale, timings and locations with clear justification for why the expected outcomes cannot reasonably be achieved by other methods

The OFAF (2010) in operation

2.2 In order to determine if a proposed activity has proper scientific attributes, it should meet the following criteria:

.2 economic interests should not influence the design, conduct and/or outcomes of the proposed activity.

- There should not be any financial and/or economic gain arising directly from the experiment or its outcomes. This should not preclude payment for services rendered in support of the experiment or future financial impacts of patented technology

The OFAF (2010) in operation

2.2 In order to determine if a proposed activity has proper scientific attributes, it should meet the following criteria:

.3 the proposed activity should be subject to scientific peer review at appropriate stages in the assessment process.

- The outcome of the scientific peer review should be taken into consideration by the Contracting Parties. The peer review methodology should be stated and the outcomes of the peer review of successful proposals should be made publicly available together with the details of the project. Where appropriate, it would be beneficial to involve expert scientists from other countries

The OFAF (2010) in operation

2.2 In order to determine if a proposed activity has proper scientific attributes, it should meet the following criteria:

.4 the proponents of the proposed activity should make a commitment to publish the results in peer reviewed scientific publications

- …and include a plan in the proposal to make the data and outcomes publicly available in a specified time-frame.

The OFAF (2010) in operation

2.3 Proposed activities that do not meet the above criteria cannot proceed through subsequent stages of the Framework without revision. Only proposed activities meeting these criteria should proceed through subsequent stages of assessment.

Policy & regulatory developments…

- UN Convention on Biological Diversity
  - CBD Decision at COP 10 (October 2010)
- "(w) Ensure, … in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, that no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment;
-

Policy & regulatory developments…

- London Convention/London Protocol
  - April 2011 – Scientific Group considers implications of new studies and reports
  - June 2011 – intersessional legal working group to discuss specific legal proposals
  - October 2011 – final agreement on legally-binding measure expected…but not reached
  - October 2012 – new approaches proposed to try to reach agreement…but still ongoing

Policy & regulatory developments…

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Marine geoengineering including ocean fertilization to be regulated under amendments to international treaty

35th Consultative Meeting of Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Convention) 8th meeting of Contracting Parties to the 1996 Protocol thereto (London Protocol)

Briefing: 45, October 18, 2013

Like 122 Tweet 22 Share 28

Marine geoengineering, including ocean fertilization, will be regulated under amendments to the 1996 Protocol to the international treaty which regulates the dumping of wastes and other matter at sea.

The amendments, adopted on Friday (18 October) by Parties to the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, add a new article 6bis which states that "Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in Annex 4, unless the listing provides that the activity or the sub-category of an activity may be authorized under a permit".

Marine geoengineering is defined as "a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long-lasting or severe".

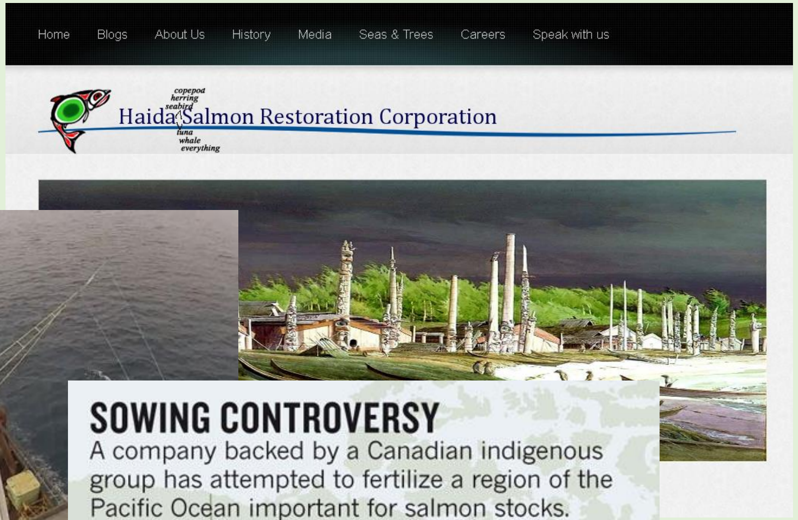
A new Annex 4 on "Marine geoengineering" lists "Ocean fertilization", defined as "any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans. Ocean fertilization does not include conventional aquaculture, or mariculture, or the creation of artificial reefs."

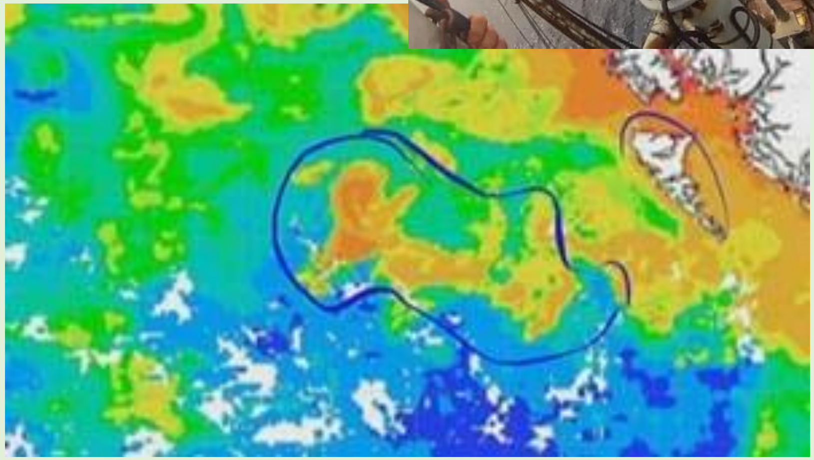
The Annex provides that all ocean fertilization activities other than those referred to above shall not be permitted. An ocean fertilization activity may only be considered for a permit if it is assessed as constituting legitimate scientific research taking into account any specific placement assessment framework.

October 2013…

first international legally-binding regulation of a geoengineering technique

2012: Haida Salmon Restoration Corporation





Haida Salmon case response: November 2012

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Parties to international dumping treaties express concern regarding reported iron fertilization incident

34th Consultative Meeting of Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Convention) and 7th meeting of Contracting Parties to 1996 Protocol thereto (London Protocol)

Briefing: 47, November 2, 2012 — Like 48 | Tweet 23 | Share 11

Parties to the international treaties which regulate the dumping of wastes and other matter at sea have issued a statement of concern regarding the deliberate ocean fertilization activity that was recently reported to have been carried out in July of 2012 in waters off the west coast of Canada.

The Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Convention) and to the 1996 Protocol thereto (London Protocol), meeting in London from 29 October to 2 November 2012, expressed "grave concern" regarding this activity, reportedly conducted by the Haida Salmon Restoration Corporation, and which involved the deliberate introduction into surface waters of 100 metric tonnes of iron sulfate.

The statement refers to an agreement made in 2008 that ocean fertilization activities, other than legitimate scientific research, should not be allowed. It goes on to point out that legitimate scientific research is defined as those proposals that have been assessed and found acceptable under the 2010 "Assessment Framework for Scientific Research Involving Ocean Fertilization." This, it says, should be used to determine, with utmost caution, whether a proposed ocean fertilization activity constitutes legitimate scientific research or is contrary to the aims of the Protocol or Convention. The statement also strongly re-emphasises the point that economic interests should not influence the design, conduct and/or outcomes of any proposed ocean fertilization activity.

In the statement, the Parties recognized the actions of the Government of Canada in investigating this incident and stressed that ocean fertilization has the potential to have widespread, long-lasting, and severe impacts on the marine environment, with implications for human health.

The full text of the statement can be found on the IMO website.

- **The Parties to the London Convention and London Protocol (LC/LP) express grave concern regarding the deliberate ocean fertilization activity that was recently reported to have been carried out in July of 2012 in waters off the Canadian west coast.**

- **The Parties to the London Convention and London Protocol reiterate, as agreed in 2008, that ocean fertilization activities, other than legitimate scientific research, should not be allowed.**

Solar radiation (albedo) management

Candidate particles for SRM

- Sulphate/Sulphuric Acid/Sulphur Dioxide
- Titania (TiO_2) (rutile or anatase)
- Silicon Carbide (SiC)
- Diamond (C)
- Dust (either Arizona test dust of NX-illite)
- Calcium Carbonate
- Alumina (alpha-Al_2O_3)
- Silica (SiO_2)
- Zinc Oxide

The Oxford Principles

...a proposed set of initial guiding principles for the governance of geoengineering...

- Principle 1: *Geoengineering to be regulated as a public good.*
- Principle 2: *Public participation in geoengineering decision-making*
- Principle 3: *Disclosure of geoengineering research and open publication of results*
- Principle 4: *Independent assessment of impacts*
- Principle 5: *Governance before deployment*

Are such principles enough…?

- Will the LC-LP approach to regulation of ocean fertilisation be sufficient and effective?
- How readily can it be adapted to include regulation of other marine climate engineering-related activities?
- Could a similar model be developed to regulate other proposed climate engineering activities?
- If so, where could that happen…?