Review of Impacts of Ocean Iron Fertilization on Marine Environment and Biodiversity

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26 Oct. 2010

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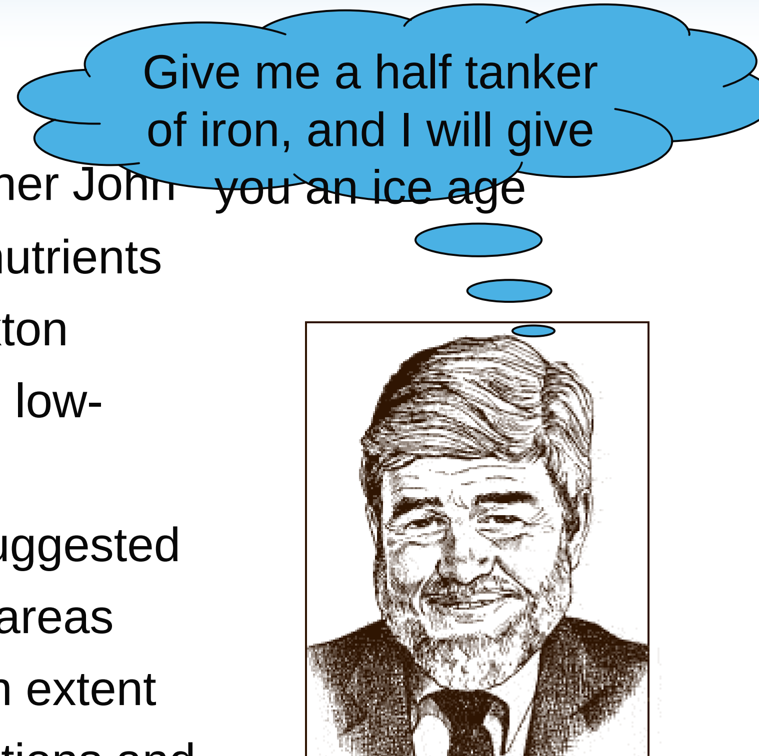
Scientific Research on Ocean Fertilization

1. Background

In the 1980s, the studies of the oceanographer John Martin confirmed that the scarcity of iron micronutrients was indeed a major factor in limiting phytoplankton growth and overall productivity in “high-nutrient, low-chlorophyll” (HNLC) areas of the oceans.

His research, supported by test experiments, suggested that adding iron to the surface waters of HNLC areas would intensify phytoplankton growth to such an extent that it could reduce atmospheric CO_2 concentrations and thereby mitigate climate change.

These results was published in nature.



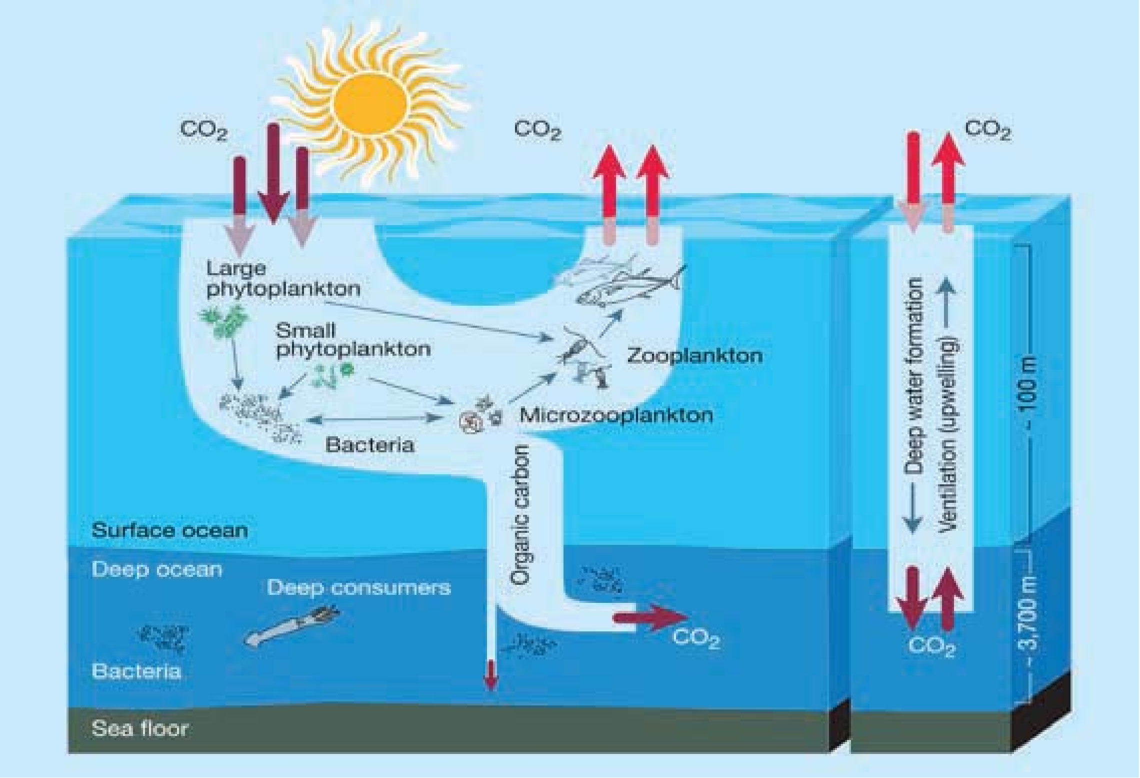
1. Background

In recent years, a number of companies have expressed interest in carrying out large-scale ocean fertilization on a commercial basis. Due to a range of uncertainties and questions, many policy-makers, international organizations and experts have also expressed their concerns about the possible adverse impacts of large-scale ocean fertilization activities.

Despite a wealth of literature, descriptions and statements on ocean fertilization, there are few internationally agreed definitions of ocean fertilization. According to the agreement by the Parties to the London Convention and London Protocol on the regulations of ocean fertilization, this term is defined as：any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans, not including conventional aquaculture, or the creation of artificial reefs.

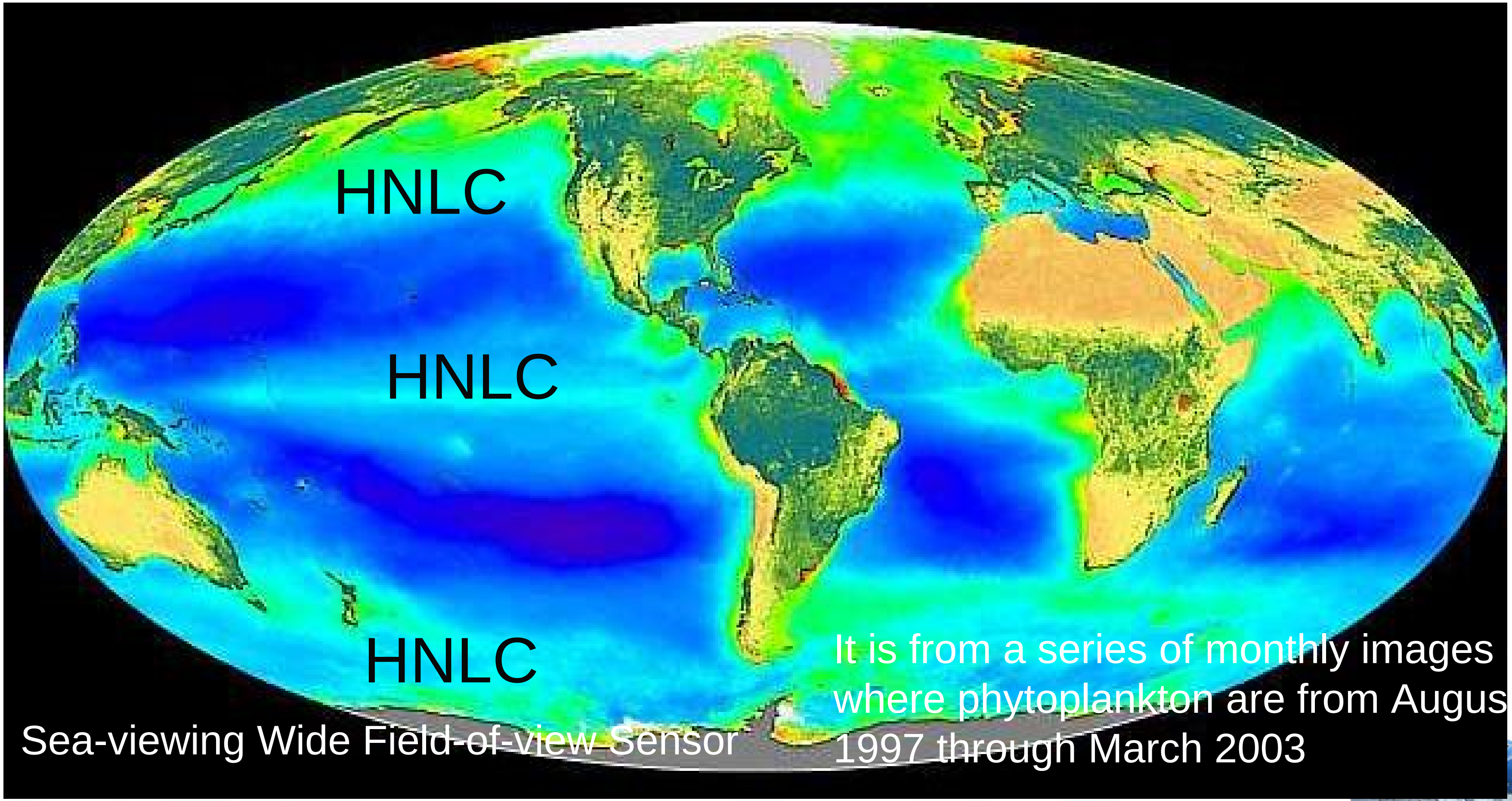
2. Ocean fertilization approaches

- Ion fertilization
- Phosphorus fertilization
- Nitrogen fertilization
- Upwelling of deep sea water



3. Review of potential impacts of ocean iron fertilization on marine biodiversity

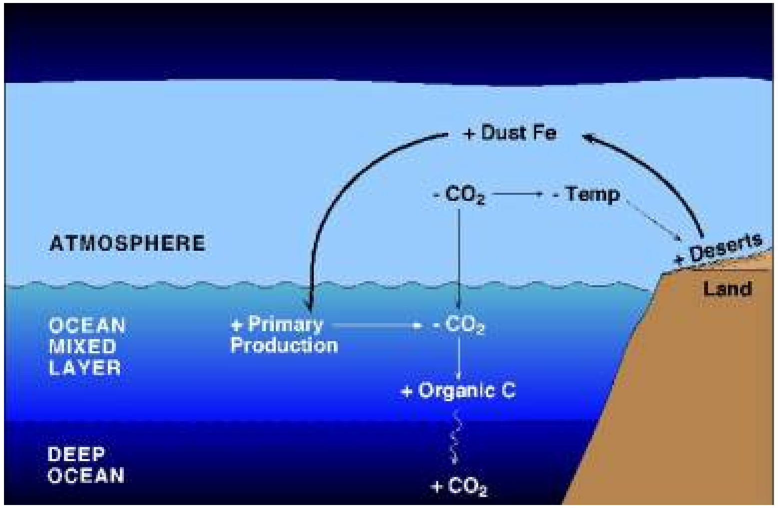
The Global Biosphere
SeaWiFS: August 97 - March 2003



High Nitrate Low Chlorophyll (HNLC)

3. Review of potential impacts of ocean iron fertilization on marine biodiversity

HNLC (High-Nutrient, Low-Chlorophyll) Regions

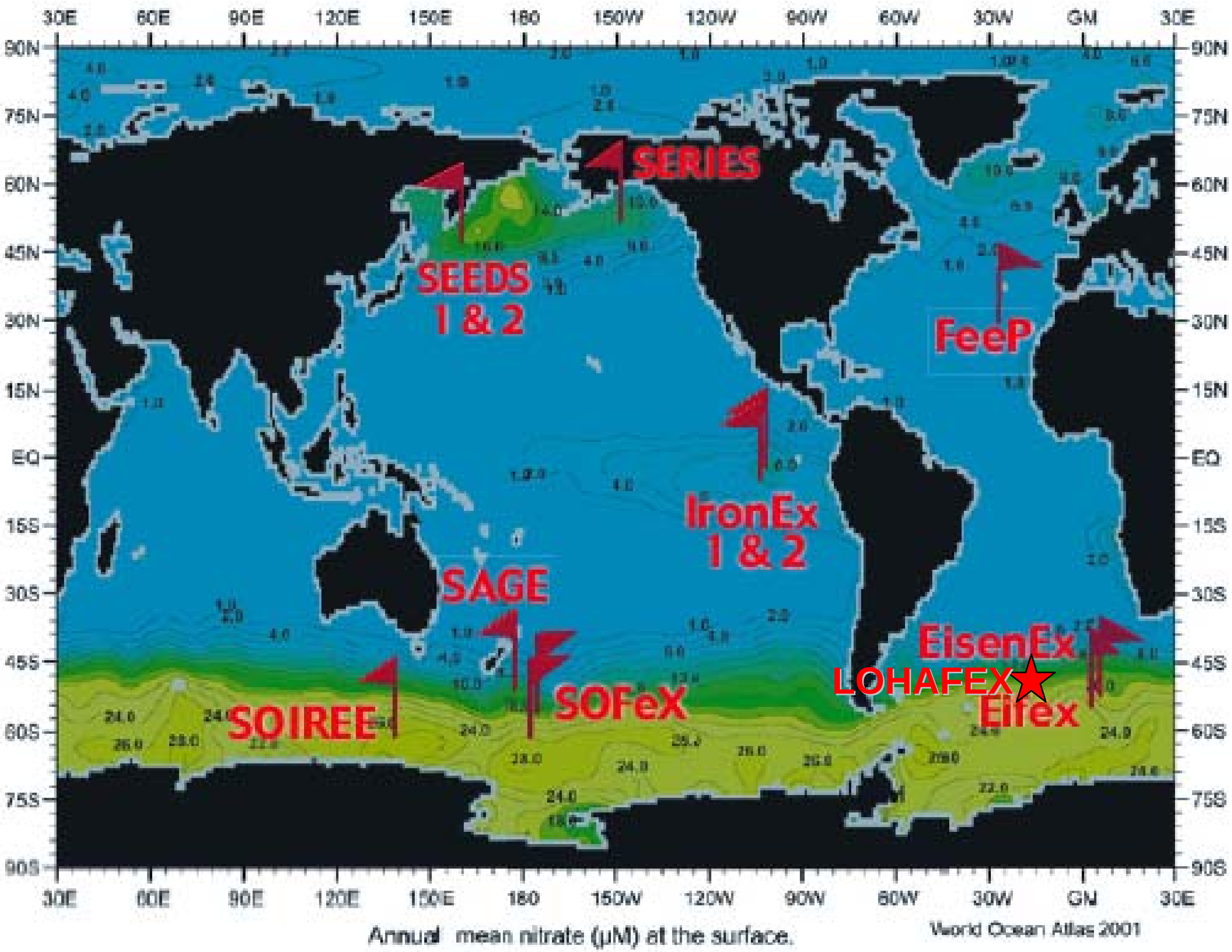


Martin and colleagues predicted and later validated that micronutirents, such as Fe, which are catalytic components in a wide variety of electron transport and enzymatic systems in phytoplankton, are a limiting factor in phytoplankton photosynthesis. It is also supported that iron availability may regulate ocean production in HNLC areas, thus influencing the associated uptake of carbon over large areas of the ocean.

3. Review of potential impacts of ocean iron fertilization on marine biodiversity

- The HNLC regions are mainly distributed in the Southern ocean, North Pacific and equatorial Pacific. The southern ocean is the largest HNLC area of the global ocean.
- Approximate site locations of 12 mesoscale Fe fertilization experiments (between 1993 and 2007) have been conducted.
- In Jan. 2009, a larger-scale scientific iron fertilization experiment, LOHAFEX, was conducted in the Southern Ocean, releasing 6 tones of dissolved iron into a 300 km^2 patch. The bloom was followed for a period of 39 days.

Locations of Iron Fertilization Experiments



Location of most of the iron enrichment experiments carried out to date, shown against the global oceanic nitrate distribution.

3. Review of potential impacts of ocean iron fertilization on marine biodiversity

Summary of materials used in iron fertilization

	Typical Sources	Typical physical forms	Typical impurities
Ferrous sulphate	Manufactured	powder	Phosphate Trace elements Trace organics
Fe-chelate (organically complexed)	Manufactured		
Iron sulphide	Manufactured		
Hematite dust	Manufacturing process Naturally occurring	Fine-powder or nano-particle	

3. Review of potential impacts of ocean iron fertilization on marine biodiversity

	Observed or predicted impacts to fertilized area
Organism responses	Diatoms have responded to Fe additions with the greatest increase in biomass in 5 out of 12 experiments. Diatoms have a siliceous shell and a strong tendency to sink out of the surface waters driving sequestration. Diatoms did not proliferate during the LOHAFEX experiment, leading to limited CO_2 drawdown. No evidence of harmful algal bloom (HAB) production in any of the 12 experiments. However, HAB forming phytoplankton were observed in bottle incubations at the SEEDS location.
Nutrient field changes	Fe induced phytoplankton bloom in HNLC surface waters confirmed by high chlorophyll levels. Macro nutrients in the surface layer are depleted by phytoplankton bloom.
Ecosystem considerations	An increase in amphipods-zooplankton predators-was observed during LOHAFEX.

3. Review of potential impacts of ocean iron fertilization on marine biodiversity

- **Depletion of macro nutrients by iron fertilization may cause the change in ecosystem food web;**
- **Red tide blooms may be initiated;**
- **Iron addition may be able to increase some other greenhouse gas, such as N2O and methane;**
- **Effect of chelator and some other ancillary input on marine environment and ecosystem is currently unknown.**

4. Uncertainties and Other Considerations

1. Both of the carbon sequestration efficiency and impacts of ocean fertilization are unclear；
2. How long will the sequestrated carbon from atmospheric stay in biosphere? (Permanency)
3. If the technology accelerate carbon accumulation in biosphere, how long will this acceleration continue? (Saturation)
4. How to measure and estimate the quantity of sequestrated carbon in biosphere resulting from ocean fertilization? (Verification)

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Ocean Iron Fertilization –Moving Forward in a Sea of Uncertainty

It is premature to sell carbon offsets from ocean iron fertilization unless research provides the scientific foundation to evaluate risks and benefits

Ken O. Buesseler,Scott C. Doney,David M. Karl, Philip W. Boyd, Ken Caldeira,Fei Chai,Kenneth H. Coale, Hein J. W. de Baar, Paul G. Falkowski, Kenneth S. Johnson, Richard S.Lampitt, Anthony F. Michaels, S. W. A. Naqvi, Victor Smetacek, Shigenobu Takeda, Andrew J. Watson

5. Conclusions

- The “iron hypothesis” is correct;
- Fe is a limiting factor in phytoplankton photosynthesis in one third of global ocean;

However,

- There is no direct evidence to verify ocean fertilization can be considered as an effective carbon sequestration technology;
- The research focusing on the efficiency estimates of carbon sequestration is lack;
- The key of ocean fertilization is to make sure that a great number of organisms are capable of reaching benthal in deep ocean and stabilizing for a minimum period of 100 years in a verifiable manner.

Ocean fertilization research is essential whether it can be considered as a carbon sequestration tool because the results will better understand the biochemical processes in the marine environment and the role of oceans in the global carbon cycle.

6. Issues to be further researched on

- Recent experiment is mainly limited to a relatively small scale (64-1,000km^2). Whether the results is difficult to extrapolate to broader spatial scales/time-frames or not needs to further verify;
- Carbon export efficiency determination method would be further improved in terms of carbon export flux and timescales of carbon sequestration;
- Large scale monitoring is necessary for allowing it to usefully distinguish between ocean fertilization activities that would and would not damage the ocean environment;
- More extensive and targeted field work on carbon sequestration efficiency would be required to determine whether significant sequestration has taken place;
- Available iron for plankton but not the total iron as the main factor limiting plankton growth would be further researched detailedly;

Ocean Fertilization and International Convention

1. London Convention and Protocol

The convention on the prevention of marine pollution by dumping of wastes and other matter (London Convention) is a global framework that contributes to the international control and prevention of marine pollution by prohibiting the dumping of certain hazardous materials and providing permits for the dumping of some wastes and matter. The convention was modernized in 1996 by the more elaborate London Protocol, under which all dumping is prohibited, with exception of a restricted range of acceptable wastes.

1. London Convention and Protocol

As a large scale iron input activity was not included and regulated in any recent laws or regulations, at the meeting of London Convention iron fertilization was discussed for the first time. Meanwhile the special scientific group was established to better understand impacts of ocean fertilization on marine environment and to further provide scientific support for the impact assessment.

1. London Convention and Protocol

The 29th Consultative Meeting of Contracting Parties to the London Convention agreed that,

1 The scope of work of the London Convention and Protocol included ocean fertilization, as well as iron fertilization;

2 The London Convention and Protocol were competent to address this issue due to their general objective to protect and preserve the marine environment from all sources of pollution;

3 They would further study the issue from the scientific and legal perspectives with a view to its regulation;

4 Every contracting party should be highly cautious for large-scale ocean iron fertilization.

Resolution LC-LP.1 (2008)

By this resolution Contracting Parties have declared, *inter alia*, that, "given the present state of knowledge, ocean fertilization activities other than legitimate scientific research should not be allowed."

The meeting agreed that in the next meeting whether to move an amendment or legal resolution or not will be discussed.

2. Convention on Biological Diversity decision IX/16 in 9th meeting(2008.5.30)

…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.

3. Oceans and the law of the sea in the general assembly of the united nations

Resolution 62/215 (2007.12.22)

"… encourages states to support the further study and enhance understanding of ocean iron fertilization"。

Resolution 63/111 (2008.12.5)

- **"…welcomes the resolution of the consultative meeting of contracting parties to the London Convention and London Protocol in 2008"**

4. Others

Greenpeace International:
They doubt that iron fertilization is effective to reduce climate change rate. This tool is expensive in price. Large-scale iron fertilization will badly disturb the Balance of marine ecosystem.

Intergovenmental Panel on Climate Change (IPCC):
Iron fertilization of the oceans may offer a potential strategy for removing CO_2 from the atmosphere by stimulating the growth Of phytoplankton and thereby sequestering CO_2 in the form of particulate organic carbon. However, commercial ocean iron fertilization remains largely speculative, and many of the environmental side effects have yet to be assessed.

Future of Ocean Iron Fertilization

- **Ocean fertilization carried out as scientific research will be conducted under the necessary risk assessment and supervision by the government;**
- **Attention on the ocean fertilization would decrease with the increased doubt of international organization and supervision by the government；**
- **Commercial ocean fertilization is forbidden. Companies turned to cooperation with government and research institution. It is expected that restart commercial ocean fertilization based on an adequate scientific research.**

Thank you for your attention!