Intended and Unintended Consequences of Large-Scale Ocean Fertilization

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"Exploring Ocean Iron Fertilization: the scientific, economic, legal and political basis"

Woods Hole Oceanographic Institution
September 26, 2007

IMAGE: *NASA Goddard Space Flight Center*

1988

Iron deficiency limits phytoplankton growth in the north-east Pacific subarctic

John H. Martin & Steve E. Fitzwater

Moss Landing Marine Laboratories, Moss Landing, California 95039, USA

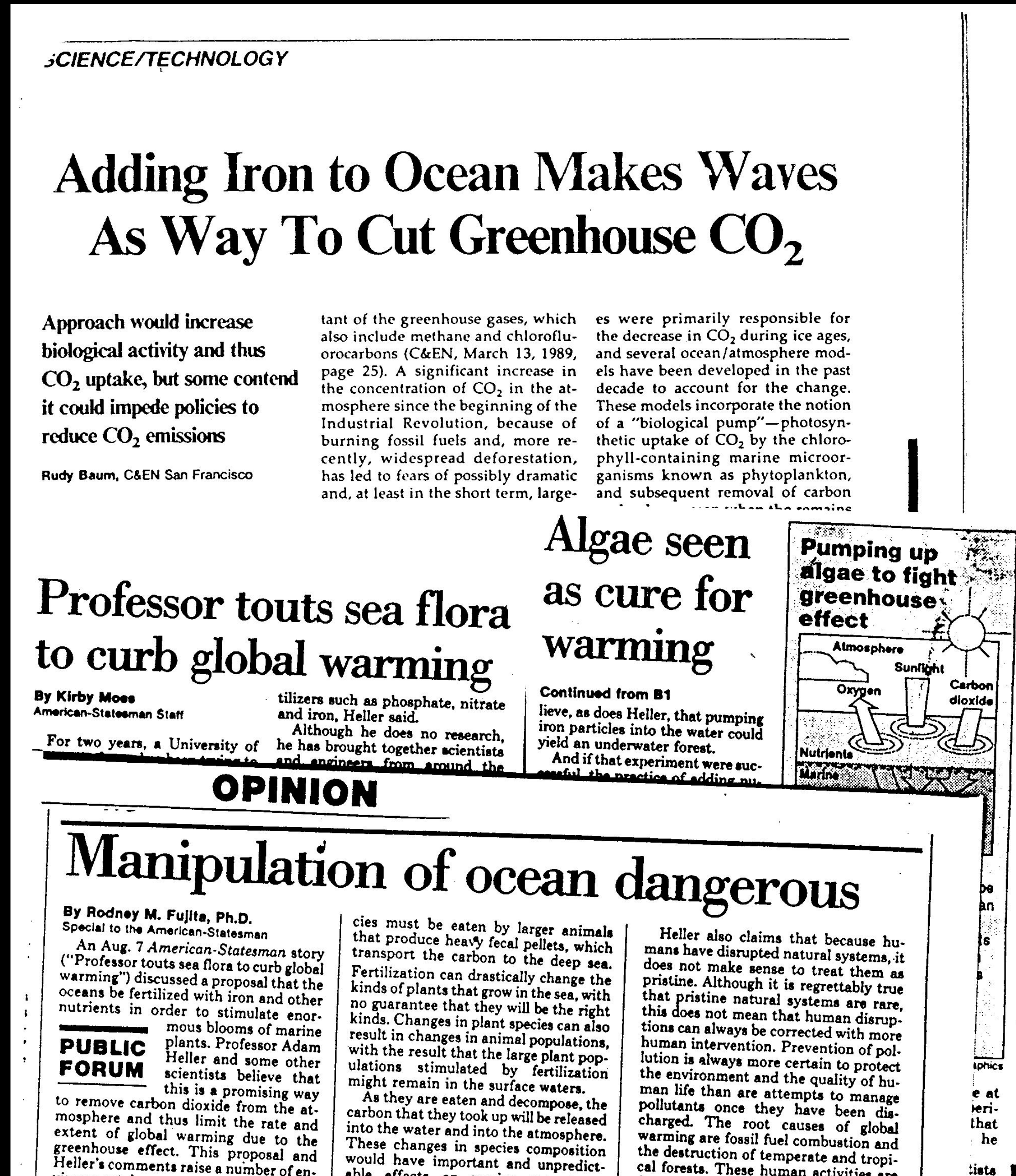
An interesting oceanographic problem concerns the excess major plant nutrients (PO_4, NO_3, SiO_3) occurring in offshore surface waters of the Antarctic[1–3] and north-east Pacific subarctic Oceans[4]. In a previous study[5], we presented indirect evidence suggesting that inadequate Fe input was responsible for this limitation of growth; recently we had the opportunity to seek direct evidence for this hypothesis in the north-east Pacific subarctic. We report here that the addition of nmol amounts of dissolved iron resulted in the nearly complete utilization of excess NO_3, whereas in the controls—without added Fe—only 25% of the available NO_3 was used. We also observed that the amounts of chlorophyll in the phytoplankton increased in proportion to the Fe added. We conclude that Fe deficiency is limiting phytoplankton growth in these major-nutrient-rich waters.

The "Iron Hypothesis" gains prominence

Nature 331 p341-343 1988

1990

First surge of publicity



SCIENCE/TECHNOLOGY

Adding Iron to Ocean Makes Waves As Way To Cut Greenhouse CO_2

Approach would increase biological activity and thus CO_2 uptake, but some contend it could impede policies to reduce CO_2 emissions

Rudy Baum, C&EN San Francisco

tant of the greenhouse gases, which also include methane and chlorofluorocarbons (C&EN, March 13, 1989, page 25). A significant increase in the concentration of CO_2 in the atmosphere since the beginning of the Industrial Revolution, because of burning fossil fuels and, more recently, widespread deforestation, has led to fears of possibly dramatic and, at least in the short term, large-

es were primarily responsible for the decrease in CO_2 during ice ages, and several ocean/atmosphere models have been developed in the past decade to account for the change. These models incorporate the notion of a "biological pump"—photosynthetic uptake of CO_2 by the chlorophyll-containing marine microorganisms known as phytoplankton, and subsequent removal of carbon

Professor touts sea flora to curb global warming

By Kirby Moss
American-Statesman Staff

For two years, a University of

tilizers such as phosphate, nitrate and iron, Heller said.

Although he does no research, he has brought together scientists

Algae seen as cure for warming

Continued from B1

lieve, as does Heller, that pumping iron particles into the water could yield an underwater forest.

And if that experiment were suc-

Pumping up algae to fight greenhouse effect

Atmosphere
Sunlight
Oxygen
Carbon dioxide
Nutrients

OPINION

Manipulation of ocean dangerous

By Rodney M. Fujita, Ph.D.
Special to the American-Statesman

An Aug. 7 *American-Statesman* story ("Professor touts sea flora to curb global warming") discussed a proposal that the oceans be fertilized with iron and other nutrients in order to stimulate enormous blooms of marine plants. Professor Adam Heller and some other scientists believe that this is a promising way to remove carbon dioxide from the atmosphere and thus limit the rate and extent of global warming due to the greenhouse effect. This proposal and Heller's comments raise a number of environmental concerns.

PUBLIC FORUM

cies must be eaten by larger animals that produce heavy fecal pellets, which transport the carbon to the deep sea. Fertilization can drastically change the kinds of plants that grow in the sea, with no guarantee that they will be the right kinds. Changes in plant species can also result in changes in animal populations, with the result that the large plant populations stimulated by fertilization might remain in the surface waters.

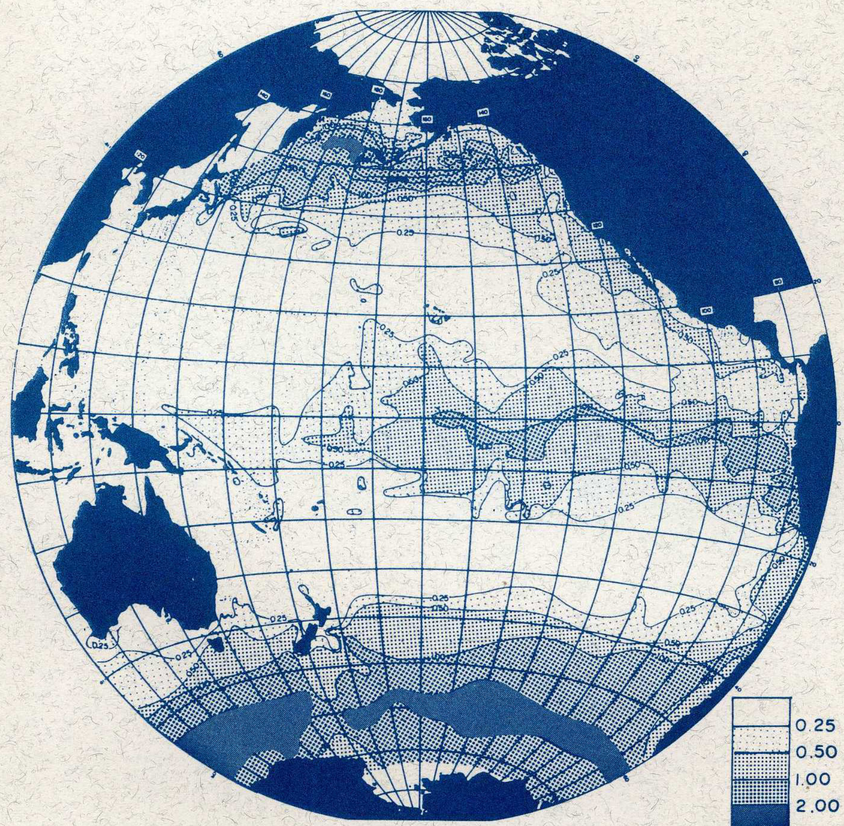
As they are eaten and decompose, the carbon that they took up will be released into the water and into the atmosphere. These changes in species composition would have important and unpredictable effects on marine ecosystems.

Heller also claims that because humans have disrupted natural systems, it does not make sense to treat them as pristine. Although it is regrettably true that pristine natural systems are rare, this does not mean that human disruptions can always be corrected with more human intervention. Prevention of pollution is always more certain to protect the environment and the quality of human life than are attempts to manage pollutants once they have been discharged. The root causes of global warming are fossil fuel combustion and the destruction of temperate and tropical forests. These human activities are

AMERICAN SOCIETY OF LIMNOLOGY AND OCEANOGRAPHY SYMPOSIUM

WHAT CONTROLS PHYTOPLANKTON PRODUCTION IN NUTRIENT-RICH AREAS OF THE OPEN SEA?

February 22-24, 1991
San Marcos, California



Distribution of inorganic phosphate-phosphorus (µg-at/l) at the surface of the Pacific Ocean (Reid, J.L., 1962).

February 1991

Scientists tackle the issue head-on

Plans for commercial fertilization of the ocean were quickly developed

- Patent for fertilization with iron chelate
- May include seeding surface layers with other nutrients, microorganisms, and fish

US005433173A

United States Patent [19] — **Markles, Jr.**

[11] **Patent Number:** **5,433,173**
[45] **Date of Patent:** **Jul. 18, 1995**

[54] **METHOD OF IMPROVING PRODUCTION OF SEAFOOD**

[76] Inventor: **Michael Markles, Jr.**, 1816 Drury La., Alexandria, Va. 22307

[21] Appl. No.: **234,374**

[22] Filed: **Apr. 28, 1994**

[51] **Int. Cl.**[6] **A01K 61/00**
[52] **U.S. Cl.** **119/231**
[58] **Field of Search** .... 119/230, 231, 268, 200, 119/51.04, 212, 235, 242; 47/1.4 R, 1.4 AP, 1.4 SW

[56] **References Cited**

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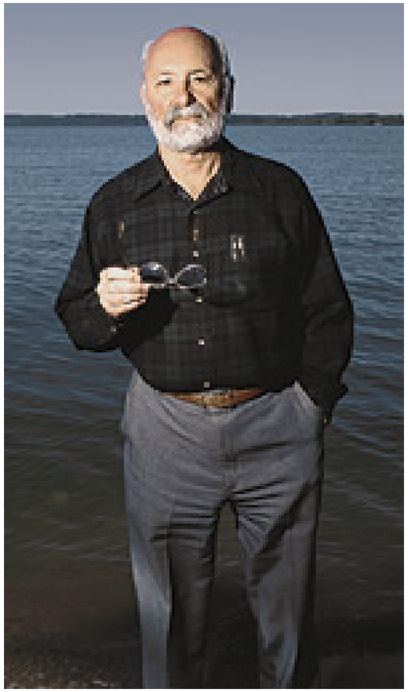


Michael Markels, Jr.

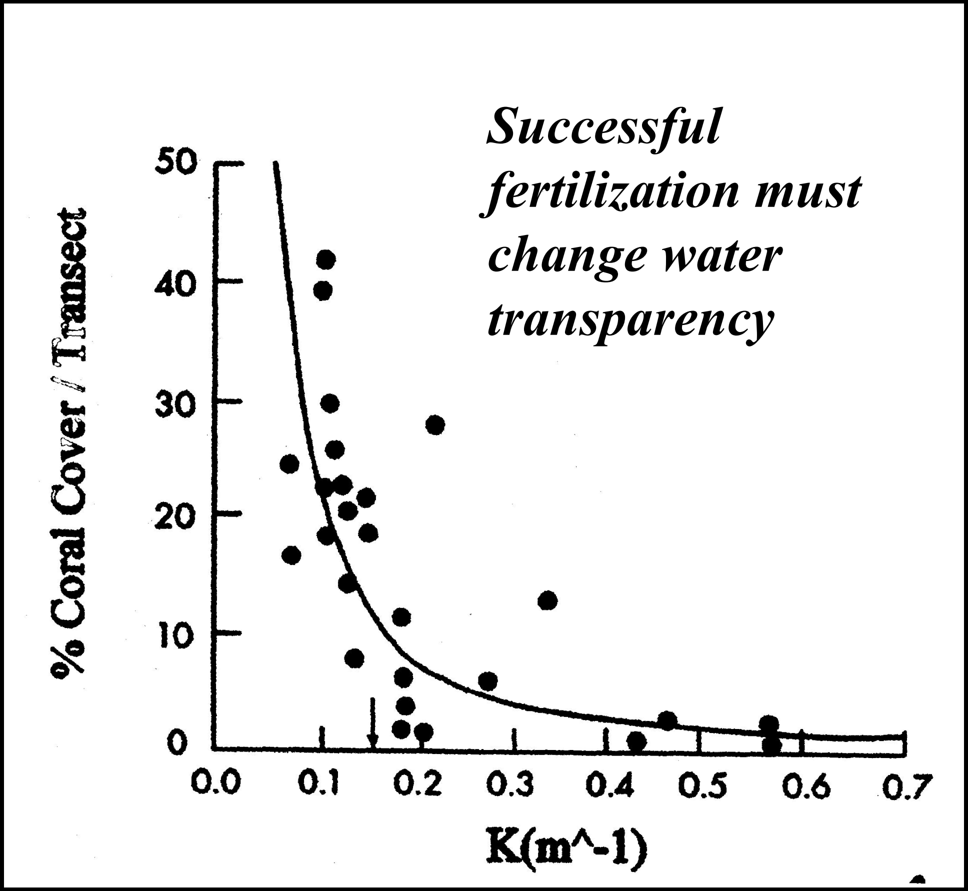
Plans revealed in the media

- 200 boats
- 8.1 million tons of iron
- 16 million square miles of HNLC ocean
- $16 billion
- Sequestration of 8 gigatons of CO_2 ***per year***

WIRED - November 2000

Recurring theme:

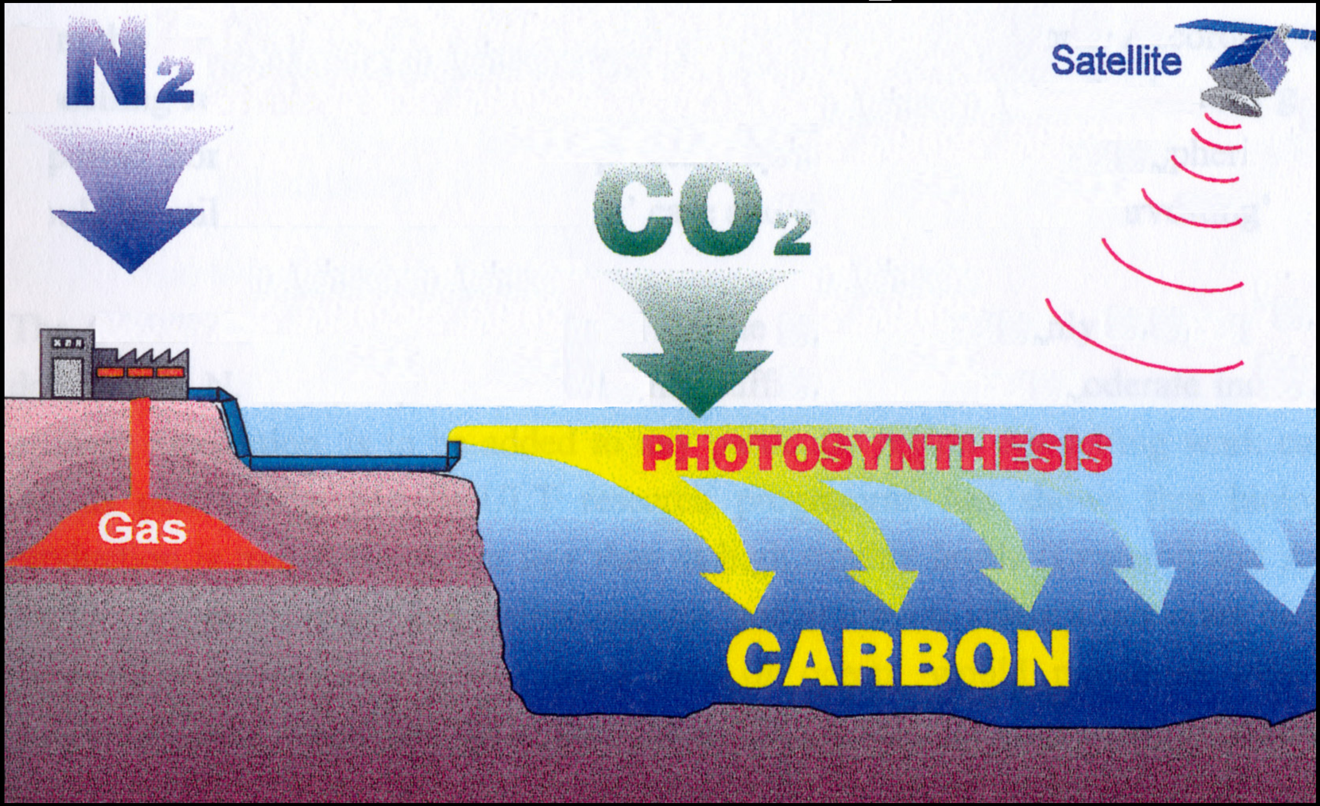
Unrecognized Potential Side Effects



Tomascik et al. 1993

Another idea

Fertilization of Ocean Waters with Nitrogen will Provide Food and Sequester Carbon



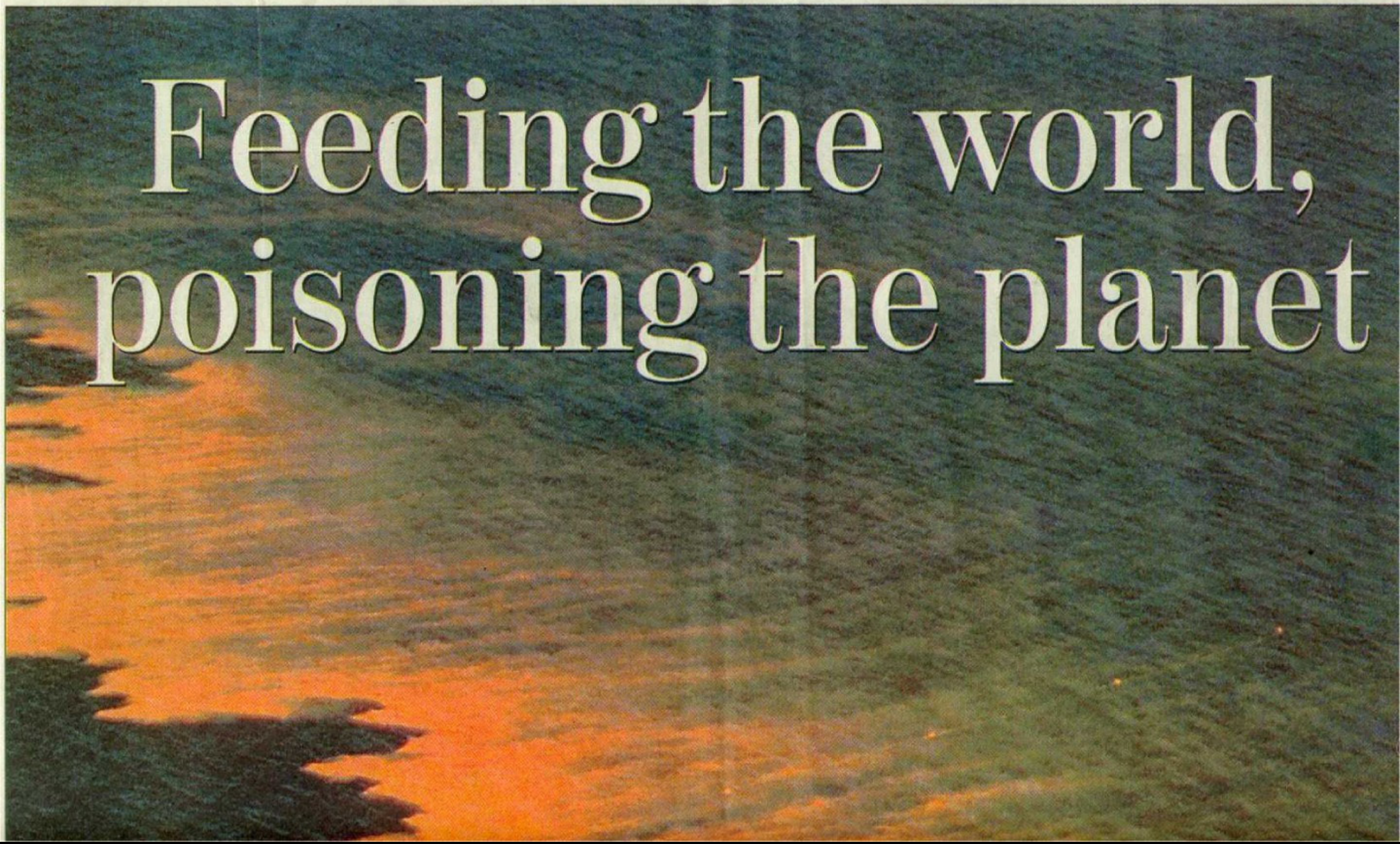
http://www.oceannourishment.com

THE SUN

Reprint of a five-part series that appeared in *The Sun* Sept. 24-28, 2000.

NITROGEN'S DEADLY HARVEST

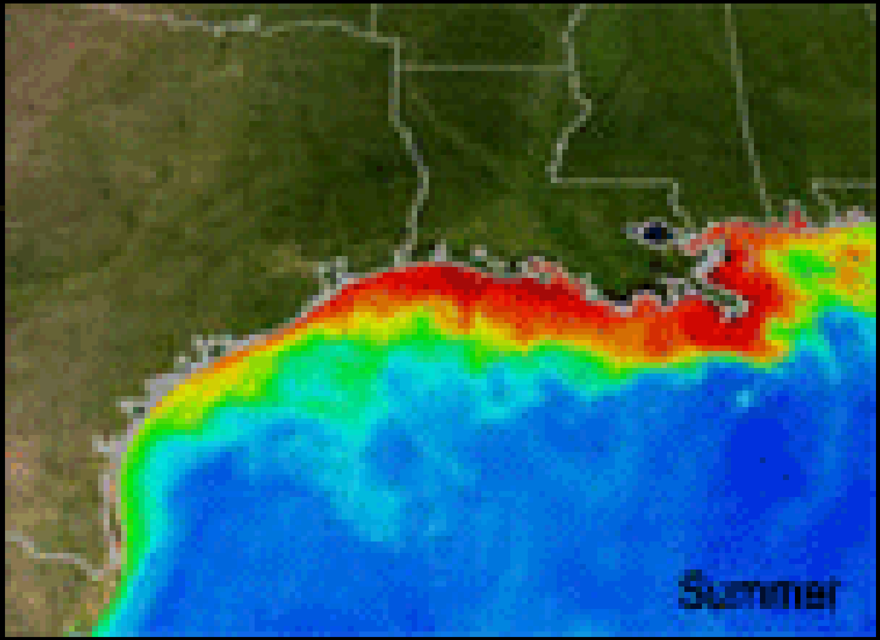
Feeding the world, poisoning the planet



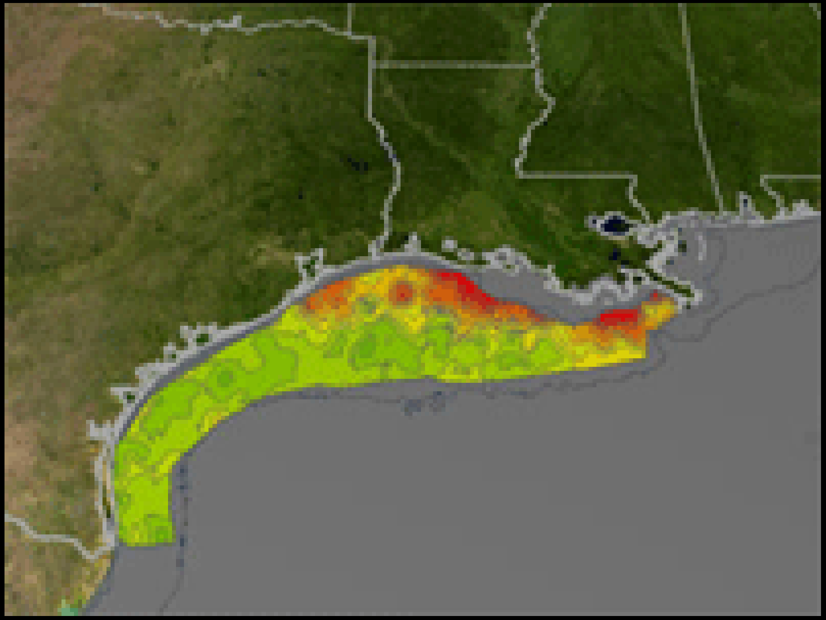
Mississippi 'Dead Zone'

Low oxygen water... has spread across nearly 5,800 square miles of the Gulf of Mexico

Nutrient input the cause



Plankton Biomass

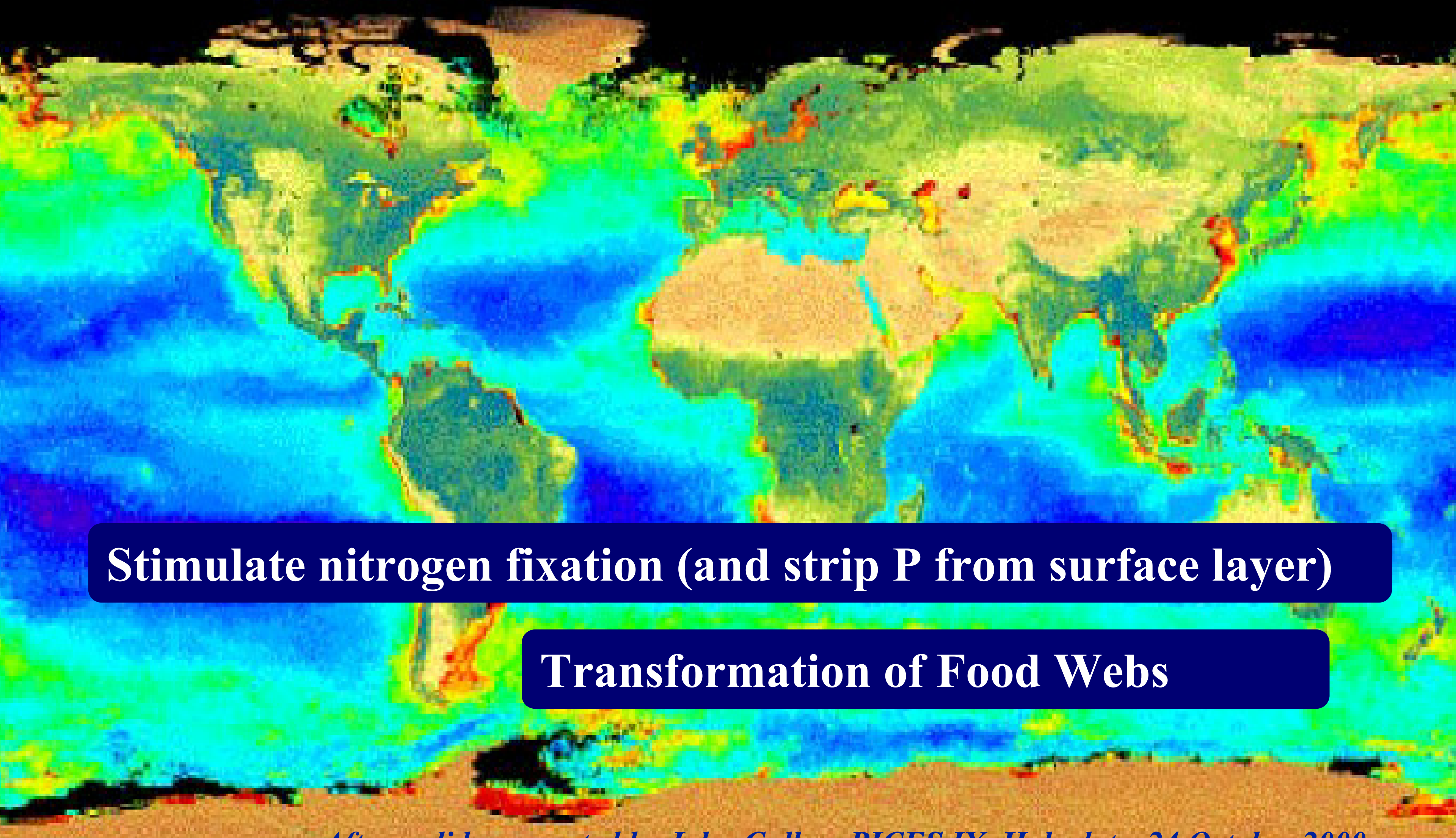


oxygen concentration
(red and orange very low)

Chisholm slide

WHOI Ocean Fertilization 2007: John Cullen

Both “High-Nutrient, Low-Chlorophyll” and Open-Ocean Blue Waters have been identified as Targets



After a slide presented by John Cullen, PICES IX, Hakodate, 24 October 2000

Objections were raised

SCIENCE'S COMPASS • POLICY FORUM

POLICY FORUM: OCEANS

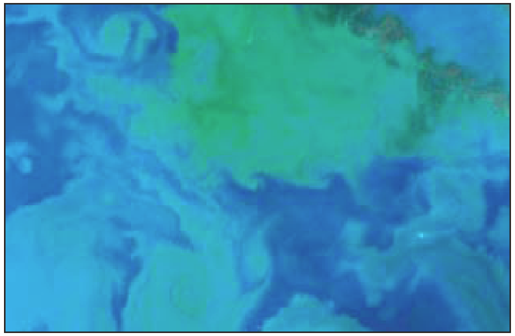
Dis-Crediting Ocean Fertilization

Sallie W. Chisholm,* Paul G. Falkowski, John J. Cullen

The oceans play a key role in the global carbon cycle and climate regulation. Central to this function are phytoplankton, single-celled photosynthetic organisms that convert CO_2 to organic carbon in the surface oceans. Although accounting for <1% of photosynthetic biomass, phytoplankton are responsible for roughly half of the carbon fixation on Earth (*1*). The organic carbon they produce is mostly eaten by other organisms in the surface waters, and regenerated to CO_2 as these organisms respire. But some organic carbon sinks to the deep ocean, thus reducing CO_2 in the surface layer and elevating it in the deep sea.

The CO_2 concentration gradient maintained by this "biological pump" removes CO_2 from the atmosphere by storing it in the ocean interior. Increased interest in car-

never exhausted in surface waters, and phytoplankton biomass is less than expected. Martin (*6, 7*) suggested that it is the scarcity of biologically available iron in these high-nutrient, low-chlorophyll (HNLC) regions that makes it impossible for the phytoplankton to use the excess N and P. He also recognized that atmospheric dust from land is an important source of iron for the sea and that HNLC regions receive a relatively small dust flux. Furthermore, he noted that ice core records of atmospheric CO_2 and dust concentrations over the past 180,000 years are anticorrelated: when dust was high, CO_2 was low. This is consistent with the notion that during



True color satellite image of a 200-km

Over the past 10 years, four such small-scale experiments have been conducted in the equatorial Pacific and the Southern Ocean (*10–13*). They have shown that adding small amounts of iron to these waters increases phytoplankton productivity and biomass over periods of a few days to weeks. In one experiment, phytoplankton biomass increased 20- to 30-fold (*11*).

These scientific experiments, which were conducted on very small scales, did not document a net transfer of CO_2 from the atmosphere to the deep sea. Press coverage, however, left the impression that phytoplankton hold the cure for global warming. Corporations and private entrepreneurs took note, and numerous patents were filed on ocean fertilization processes (*14*), anticipating a global market in which credits for carbon sequestered through fertilization might be traded.

One such enterprise, GreenSea Venture, Inc. (*15*), has recruited leading oceanographers to join their mission, which includes a proposed 8000 km^2

A range of views

Science's

COMPASS

LETTERS SCIENCE & SOCIETY POLICY FORUM BOOKS *ET AL.* PERSPECTIVES REVIEWS

Is Ocean Fertilization Credible and Creditable?

IT IS POSSIBLE THAT THE INCREASE IN atmospheric carbon dioxide, which drives global warming, could be partially mitigated by adding iron to ocean waters. In their Policy Forum "Dis-crediting ocean fertilization" (12 Oct., p. 309), S. W. Chisholm *et al.* argue that "the known consequences and uncertainties of ocean fertilization already far outweigh hypothetical benefits." We believe that they have greatly overstated the current knowledge of ocean processes in reaching their opinion that iron fertilization is not a vi-

days (*6*). Upon cessation of fertilization, the phytoplankton stock would rapidly return to prefertilization conditions as iron concentrations decreased to ambient levels.

They write that ocean fertilization "does not mimic nature." Yet, large, natural episodic iron addition events of similar magnitude to the IronEx II addition (*7*) regularly occur in the ocean. We recently observed an aerosol deposition event in the North Pacific that raised dissolved iron concentrations to 0.7 nM over hundreds of kilometers (*8*). Such events may periodically stimulate nitrogen fixation, alter ecosystem structure, and result in the export of carbon (*9*). Elevated iron concentrations have also been observed in surface waters

Considerable uncertainty remains about these issues. Decisions to initiate or abandon ocean fertilization must be weighed carefully after we have learned substantially more about carbon cycling through the ocean. It is simply not credible, or creditable, to suggest that we know enough to understand the impacts of ocean fertilization at the present time.

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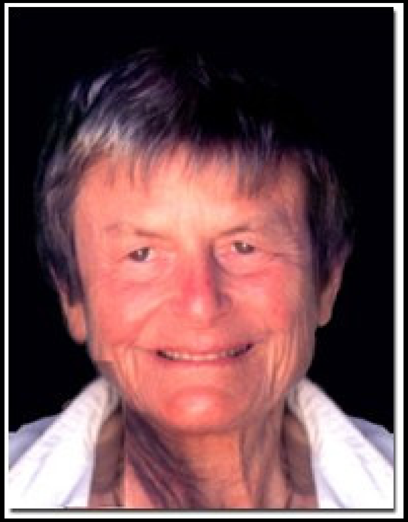
Barely accessible to the general public

Maritime Law: 1990 – 2006

- **Jurisdiction is unclear**
- **No obvious recognition of the problem**
- **No strong lines of communications with oceanographers**
- **“Policy vacuum”**

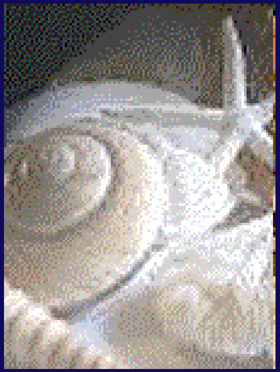
Elizabeth Mann Borgese
March, 2000



Promotions continued

PLANKTOS

Multi-Benefit Bio-Remedies for the Climate's Carbon Ills



Where most CO2 can go and rightfully should be

Save the Earth … and Get Rich!

This pioneering R&D company has big plans that Wall Street hasn't heard about yet – and it is nothing less than solving the gravest environmental threat facing the world today.

Their innovative technology for helping big corporations comply with the Kyoto Protocol could generate $300 million in new revenues within the next 12 months – sending the share price soaring!

Turn $10,000 into $50,000 in 12 months with the "Kyoto Protocol"

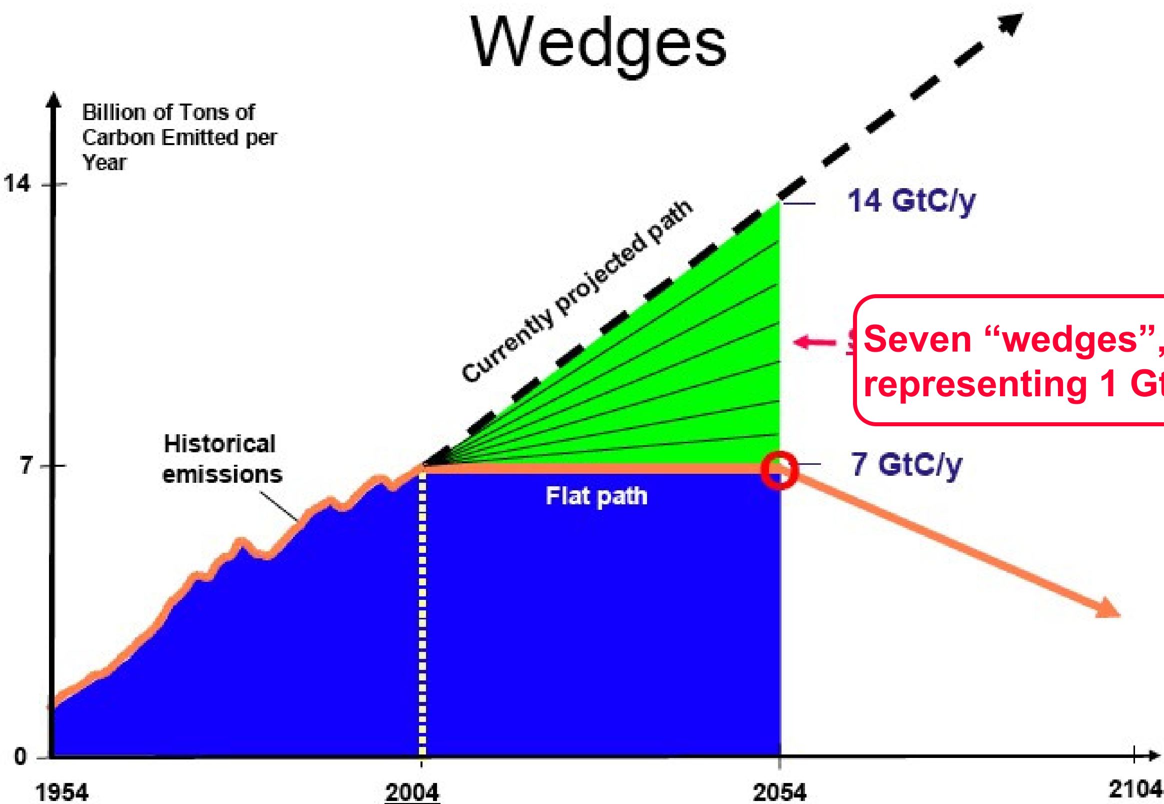
The Kyoto Protocol has created a $3 trillion market for technology that can reduce carbon dioxide levels contributing to global warming.

A more realistic target: one “Wedge”

REVIEW

Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies

S. Pacala[1*] and R. Socolow[2*]



Each represents a great deal of carbon. Feasibility unproven at this time

The ultimate goal of all proposed plans

Modification of the global environment

IMAGE: *NASA Goddard Space Flight Center*

March, 2007

Major program of iron fertilization announced

NGOs raise concerns

INTERNATIONAL MARITIME ORGANIZATION

IMO

E

SCIENTIFIC GROUP OF THE LONDON CONVENTION – 30th Meeting; and

SCIENTIFIC GROUP OF THE LONDON PROTOCOL – 1st Meeting
18 – 22 June 2007
Agenda item 12

LC/SG 30/12
8 May 2007
ENGLISH ONLY

ANY OTHER BUSINESS

Regulation of CO_2 sequestration

Submitted by the World Conservation Union (IUCN)

After 20 years, ocean fertilization is finally gaining recognition in ocean policy

3. The Scientific Groups of the London Convention and London Protocol note with concern the potential for large-scale ocean iron fertilisation to have negative impacts on the marine environment and human health. **They therefore recommend that any such operations be evaluated carefully to ensure, among other things, that such operations are not contrary to the aims of the London Convention and London Protocol.**

Basically, a call for an environmental impact assessment

4. *Such an evaluation should include, among other things, consideration of:*

   1. *the estimated amounts and* ***potential impacts of iron and other materials*** *that may be released with the iron;*

   2. *the* ***potential impacts of gases*** *that may be produced by the expected phytoplankton blooms or by bacteria decomposing the dead phytoplankton;*

   3. *the estimated extent and* ***potential impacts of bacterial decay of the expected phytoplankton blooms****, including reducing oxygen concentrations;*

   4. *the* ***types of phytoplankton that are expected to bloom and the potential impacts of any harmful algal blooms*** *that may develop;*

   5. *the nature and extent of* ***potential impacts on the marine ecosystem*** *including naturally occurring marine species and communities;*

   6. *the estimated* ***amounts and timescales of carbon sequestration****, taking account of partitioning between sediments and water; and*

   7. *the estimated* ***carbon mass balance*** *for the operation.*

…and markets will require stringent verification

IETA

INTERNATIONAL EMISSIONS TRADING ASSOCIATION

°C

THE VOLUNTARY CARBON STANDARD

VERIFICATION PROTOCOL AND CRITERIA

Proposed Version 2

One example of a developing carbon trading standard

IETA
INTERNATIONAL EMISSIONS TRADING ASSOCIATION

Key Requirements for Verification

- Measurable – within standard margins of measurement error (e.g., +/- 3%)

- Secondary effects of the project must be quantified

- Permanent – *with mechanism for immediate replacement or compensation if GHG reduction is reversed*

IETA
INTERNATIONAL EMISSIONS TRADING ASSOCIATION

Key Concept: Project Boundary

"the project boundary shall encompass all anthropogenic emissions by sources of greenhouse gases (GHG) under the control of the project participants that are significant and reasonably attributable to the project activity."

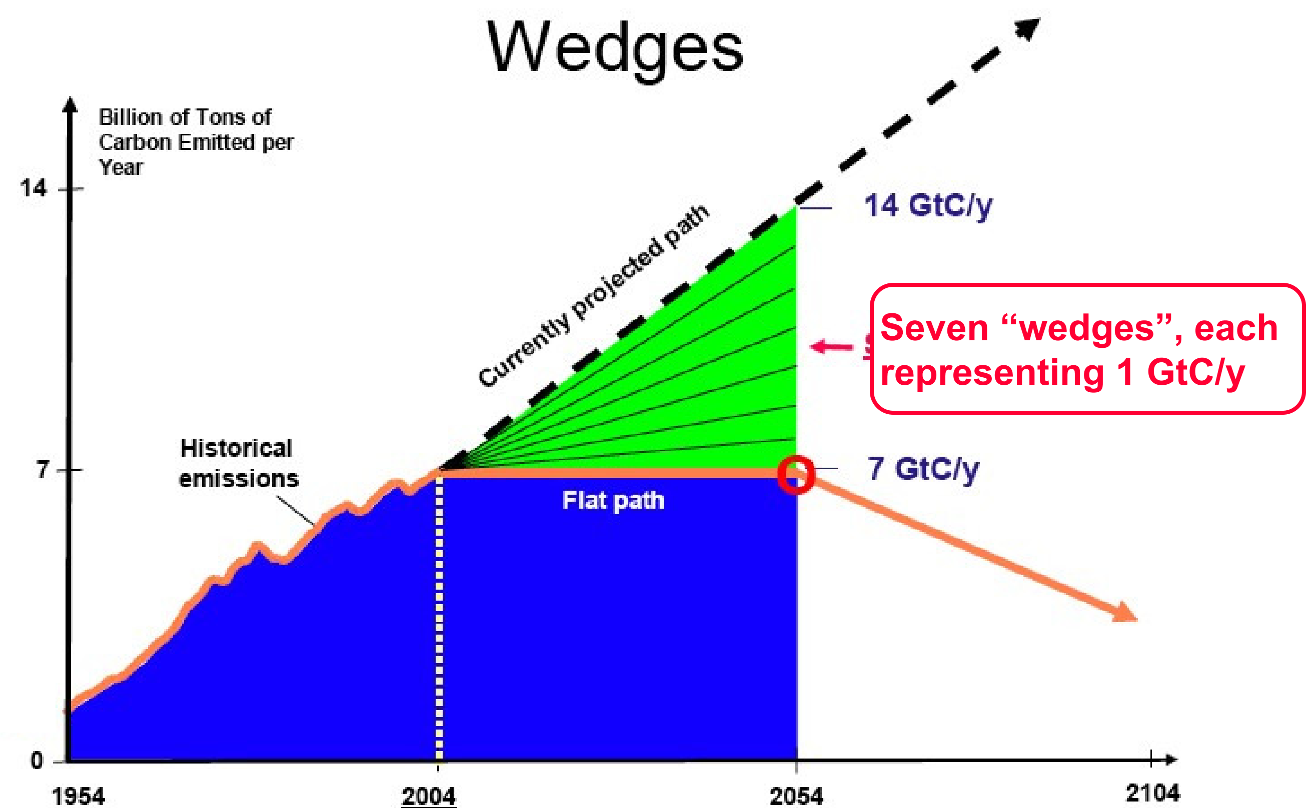
What is the Project?

~ 25 Gt(C) over 50 years

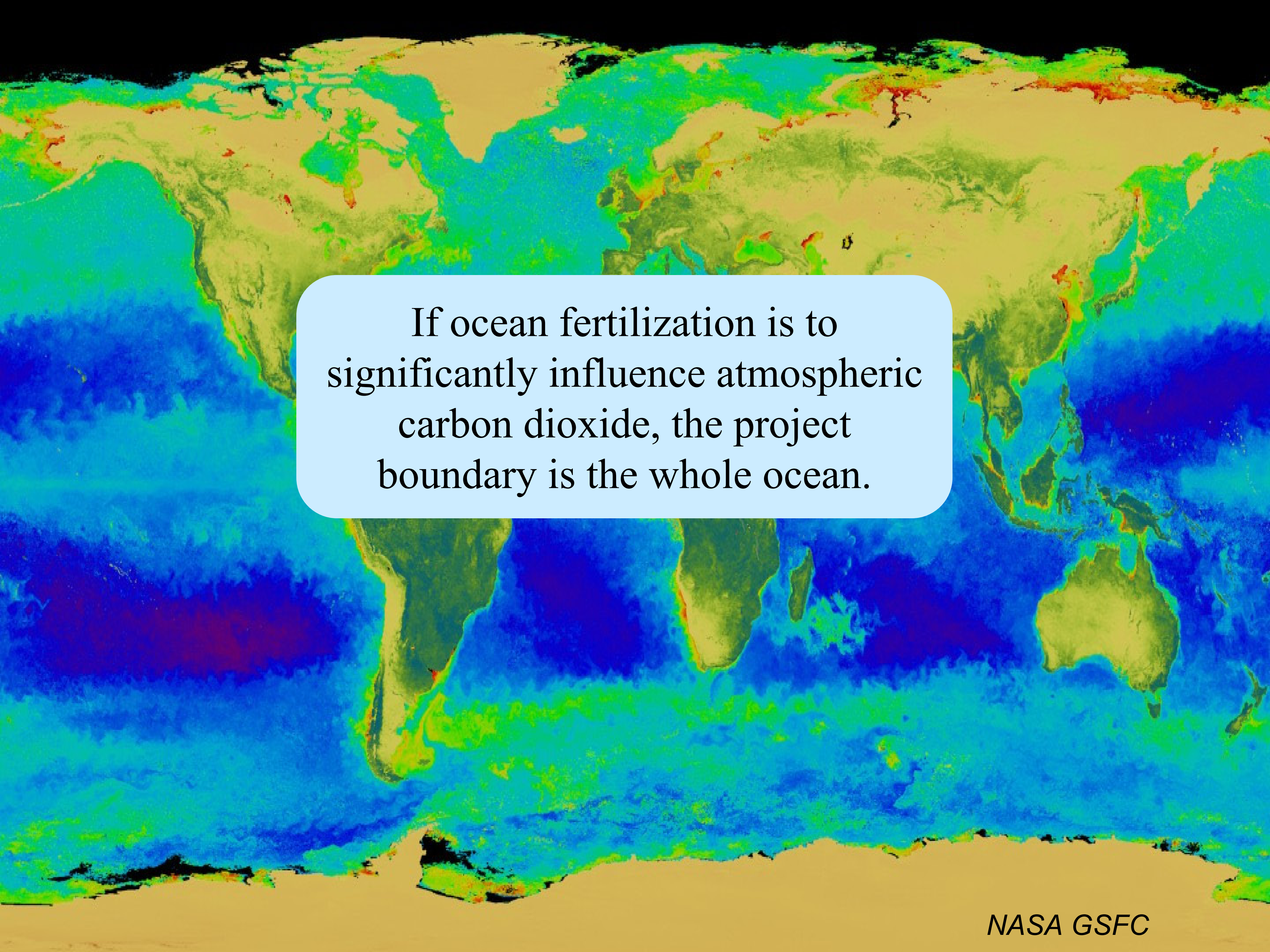
REVIEW

Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies

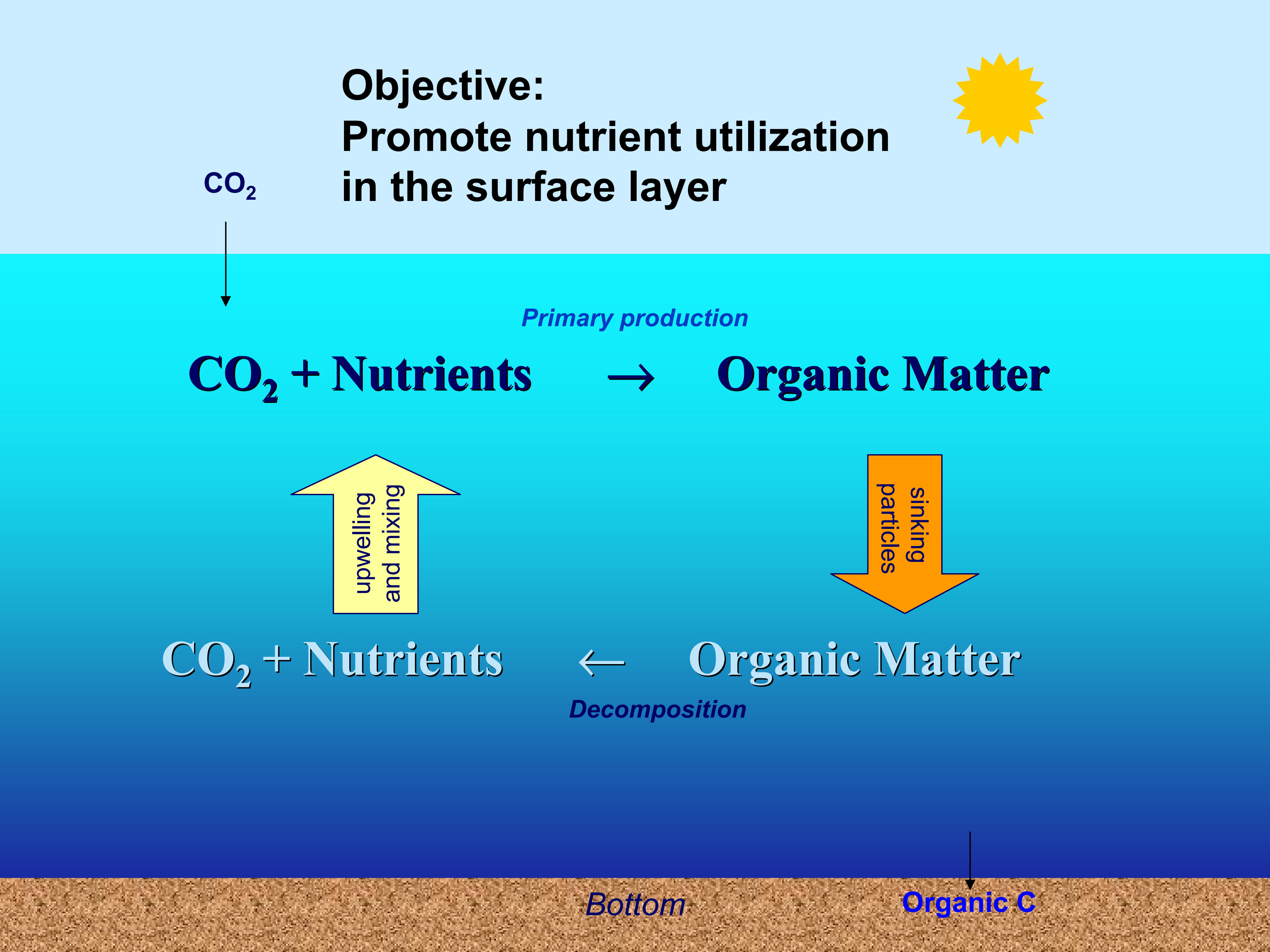
S. Pacala[1]* and R. Socolow[2]*



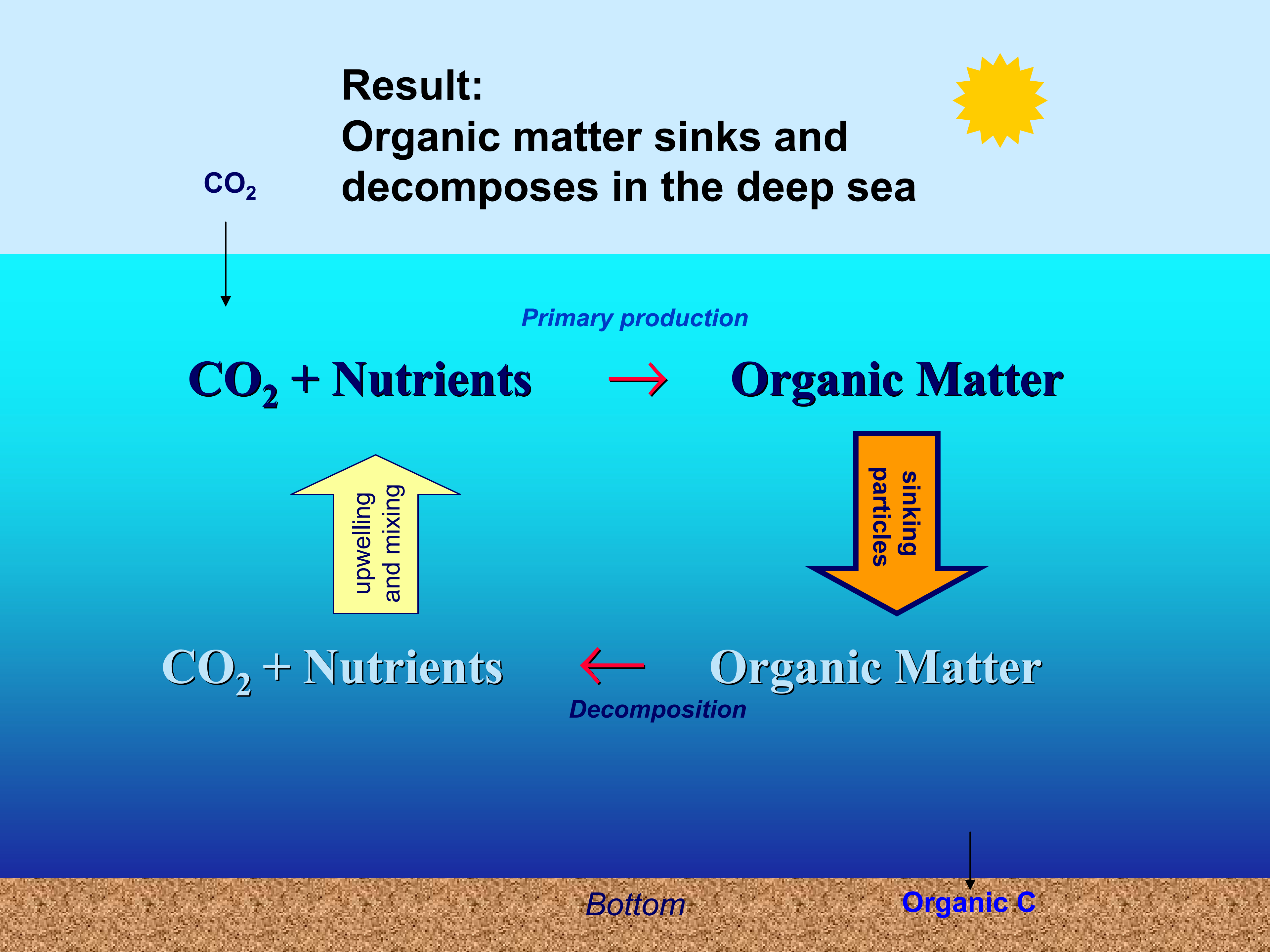
If ocean fertilization is to significantly influence atmospheric carbon dioxide, the project boundary is the whole ocean.



NASA GSFC



Objective:
Promote nutrient utilization in the surface layer
CO_2
Primary production
CO_2 + Nutrients → Organic Matter
upwelling and mixing
sinking particles
CO_2 + Nutrients ← Organic Matter
Decomposition
Bottom
Organic C


Result:
Organic matter sinks and
decomposes in the deep sea
CO_2
Primary production
CO_2 + Nutrients
Organic Matter
sinking particles
upwelling and mixing
CO_2 + Nutrients
Organic Matter
Decomposition
Bottom
Organic C

Intended consequences of large-scale fertilization

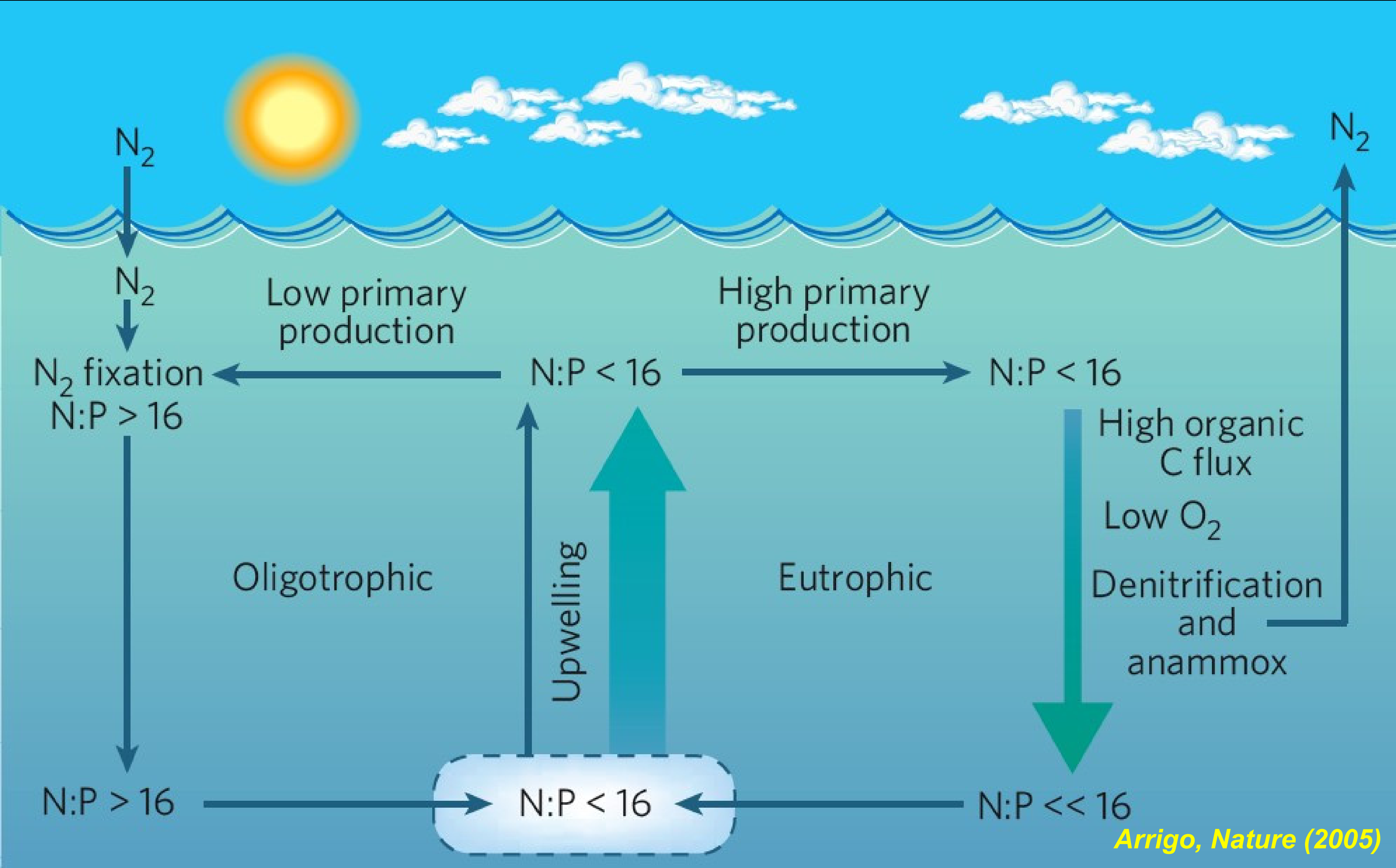
Increased deep ocean concentrations of CO_2, N and P

Decreased deep ocean concentrations of O_2

Decreased surface layer concentrations and ratios of N, P and Si

IMAGE: *NASA Goddard Space Flight Center*

That is: fundamental alteration of ecosystems and biogeochemical cycles

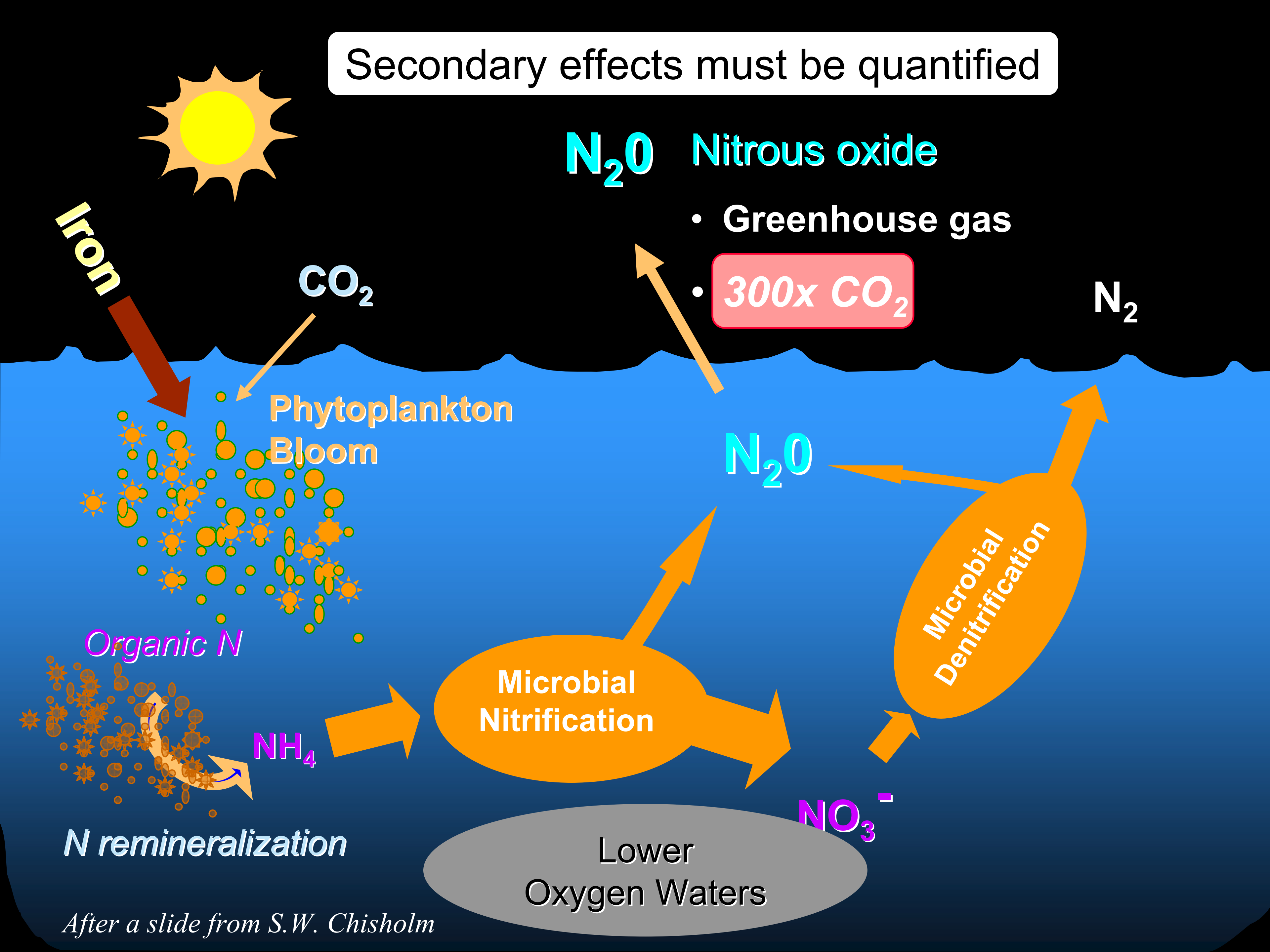


Arrigo, Nature (2005)

One Intended Effect

An
increased
deep ocean
inventory
of nitrogen

IMAGE: *NASA Goddard Space Flight Center*


Secondary effects must be quantified
N_20 Nitrous oxide
• Greenhouse gas
• 300x CO_2
N_2
Iron
CO_2
Phytoplankton Bloom
N_20
Microbial Denitrification
Organic N
NH_4
Microbial Nitrification
NO_3^-
N remineralization
Lower Oxygen Waters
After a slide from S.W. Chisholm

Arguably it cannot be done with acceptable accuracy

Limnol. Oceanogr., 36(8), 1991, 1951–1959

Possible biogeochemical consequences of ocean fertilization

Jed A. Fuhrman
Department of Biological Sciences, University of Southern California, Los Angeles 90089-0371

Douglas G. Capone
University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory, Solomons 20688-0038

SCIENTIA MARINA 65 (Suppl. 2): 85-105

The oceanic fixed nitrogen and nitrous oxide budgets: Moving targets as we enter the anthropocene?*

L.A. CODISPOTI[1], JAY A. BRANDES[2], J.P. CHRISTENSEN[3], A.H. DEVOL[4], S.W.A. NAQVI[5], HANS W. PAERL[6] and T. YOSHINARI[7]

Another Intended Effect

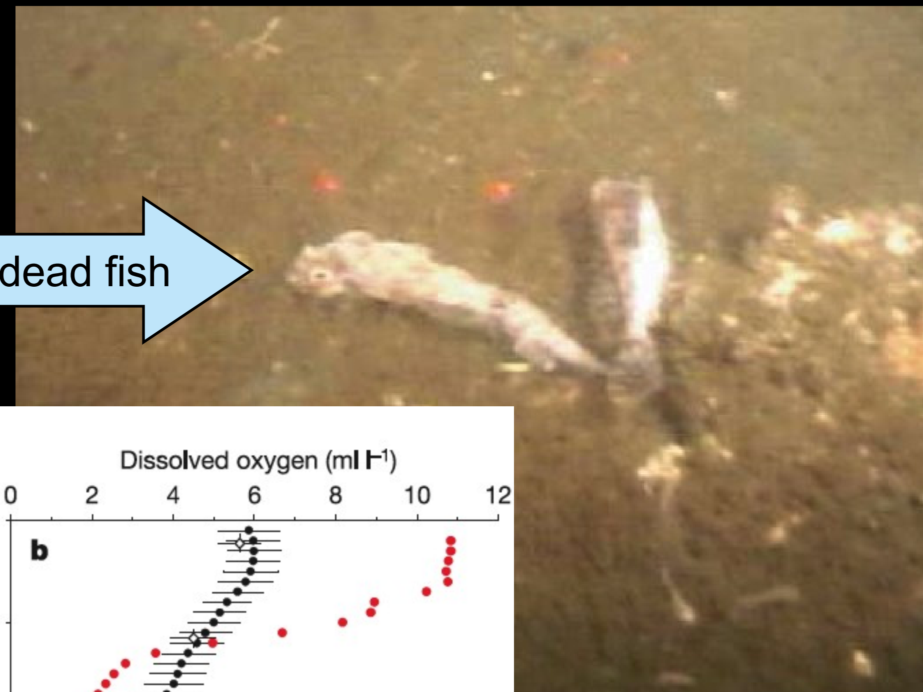
Decreased oxygen concentrations in the deep ocean

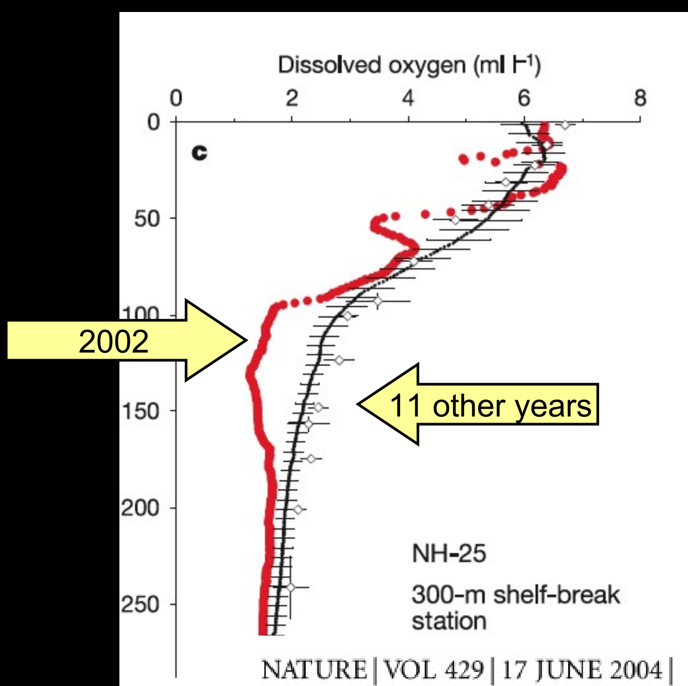
IMAGE: *NASA Goddard Space Flight Center*

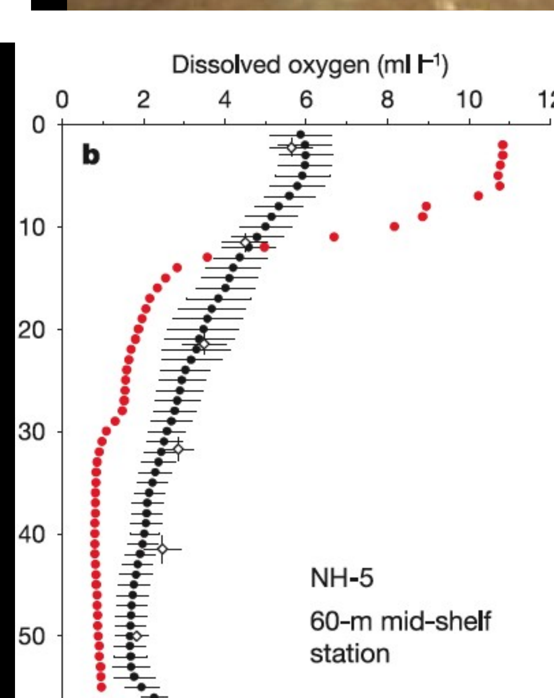
Predictable result:
greater probability of hypoxic events

Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific

Brian A. Grantham[1]*, Francis Chan[2]*, Karina J. Nielsen[4]*, David S. Fox[5], John A. Barth[3], Adriana Huyer[3], Jane Lubchenco[2] & Bruce A. Menge[2]



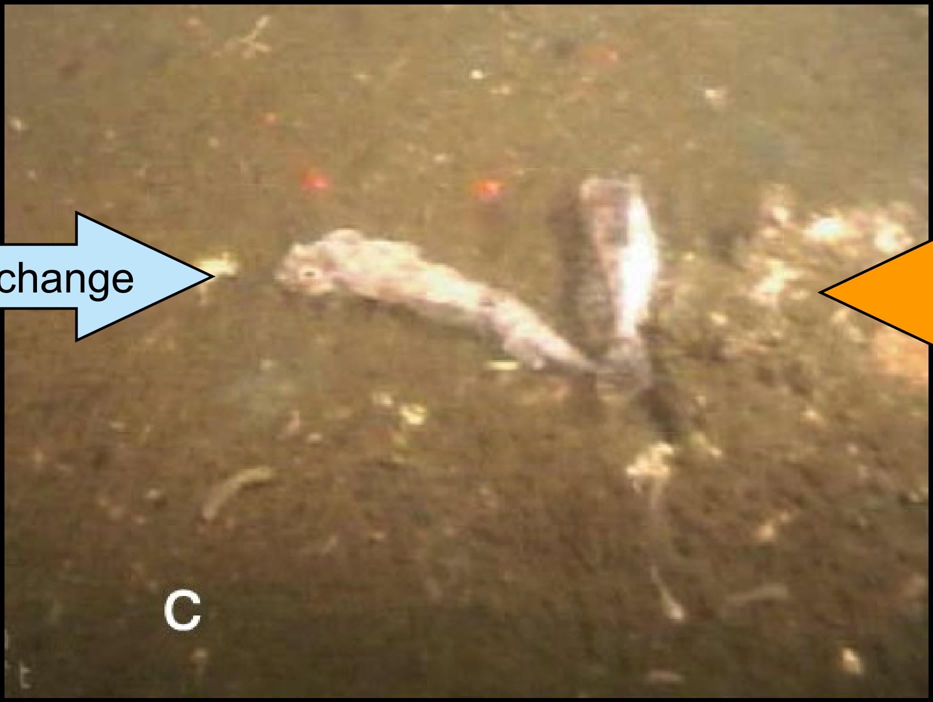




WHOI Ocean Fertilization 2007: John Cullen

Who or what is to blame?

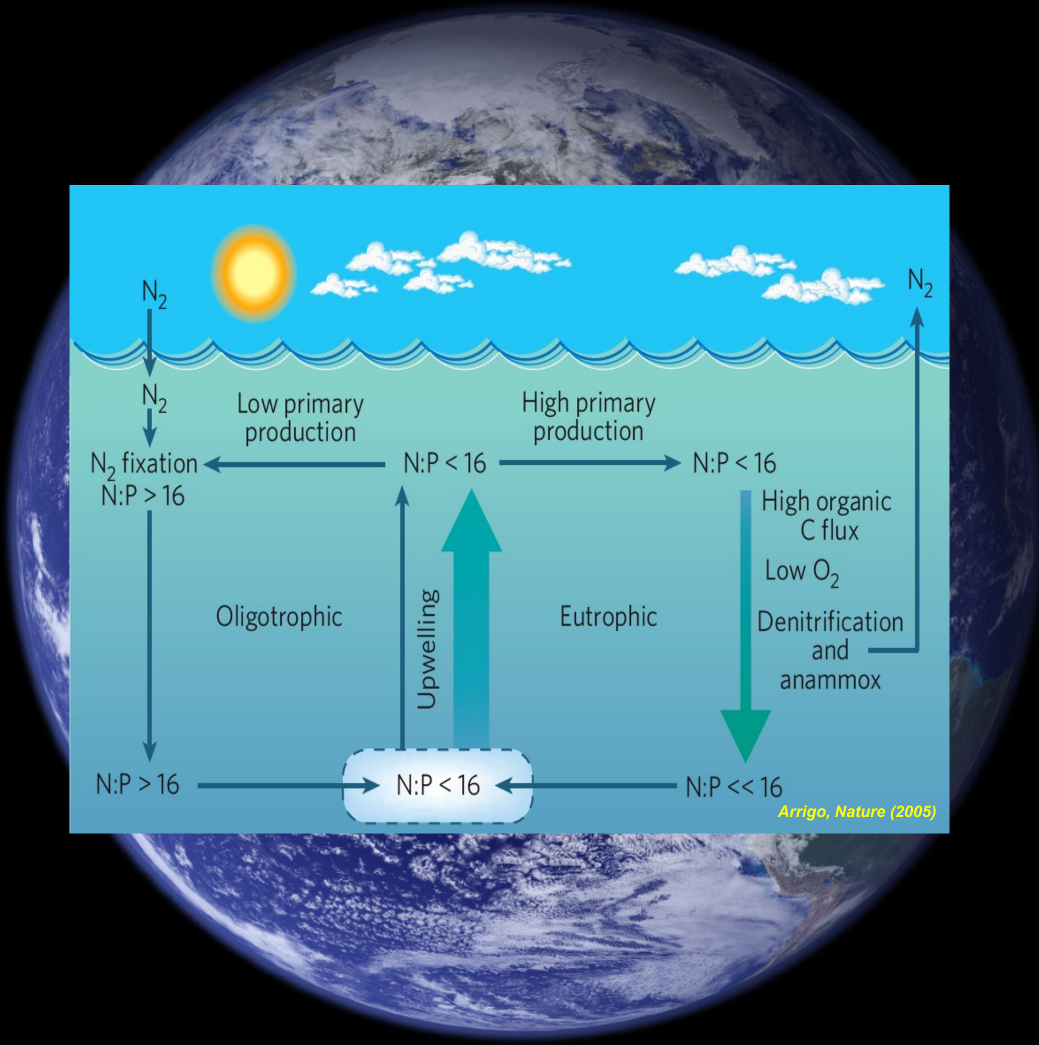
Must be climate change



Must be “IronCorp”

NATURE | VOL 429 | 17 JUNE 2004 |

A Third Intended Effect



Fundamental alteration of nutrient ratios and the limiting nutrients: factors that structure pelagic ecosystems

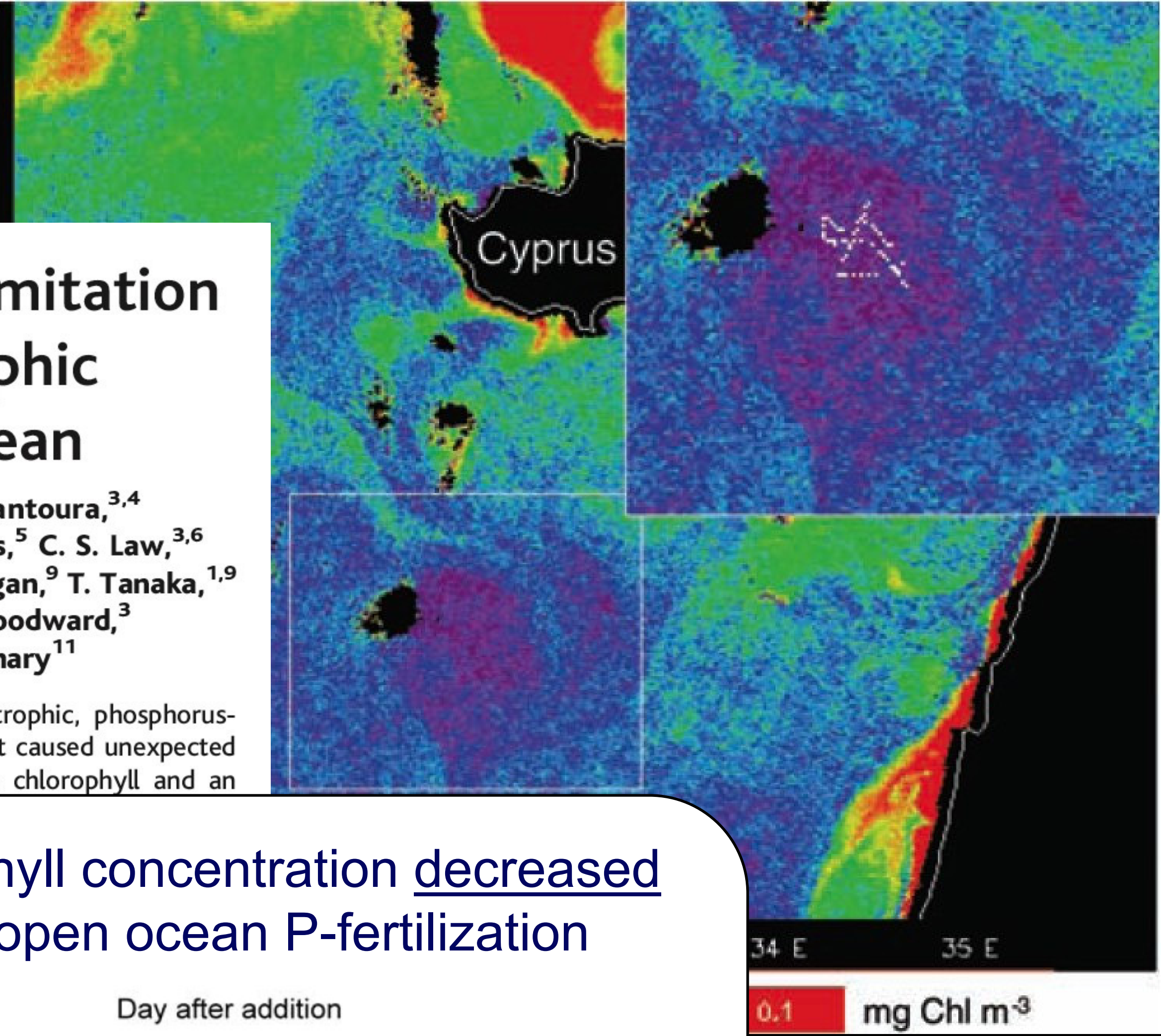
IMAGE: *NASA Goddard Space Flight Center*

Prediction is beyond our capabilities

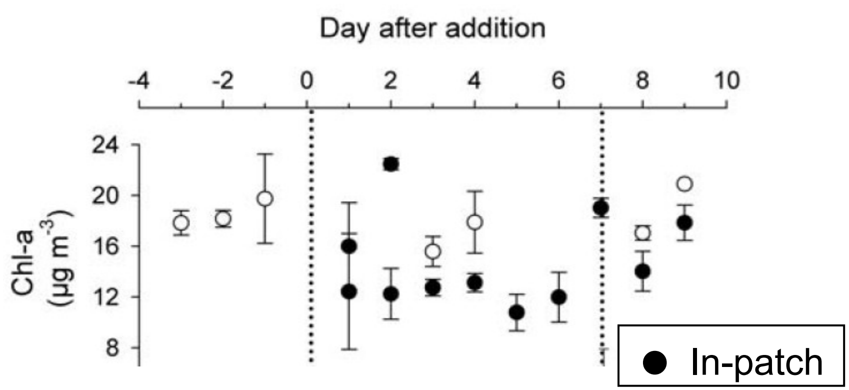
Nature of Phosphorus Limitation in the Ultraoligotrophic Eastern Mediterranean

T. F. Thingstad,[1*] M. D. Krom,[2] R. F. C. Mantoura,[3,4] G. A. F. Flaten,[1] S. Groom,[3] B. Herut,[5] N. Kress,[5] C. S. Law,[3,6] A. Pasternak,[7] P. Pitta,[8] S. Psarra,[8] F. Rassoulzadegan,[9] T. Tanaka,[1,9] A. Tselepides,[8] P. Wassmann,[7] E. M. S. Woodward,[3] C. Wexels Riser,[7] G. Zodiatis,[10] T. Zohary[11]

Phosphate addition to surface waters of the ultraoligotrophic, phosphorus-starved eastern Mediterranean in a Lagrangian experiment caused unexpected ecosystem responses. The system exhibited a decline in chlorophyll and an increase in bacterial production and c
and phosphorus colimitation hinder
have been transferred through the
mutually exclusive, pathways: (i) b
phosphorus uptake in heterotro
phosphate luxury consumption ra
copepod prey. Copepods may thu
interactions not usually considere



Chlorophyll concentration decreased after open ocean P-fertilization



Unintended Effects

IMAGE: *NASA Goddard Space Flight Center*

http://www.canetoads.com.au/

Three Central Questions

What are the effects of large scale ocean fertilization?

Fundamental alterations of marine ecosystems and biogeochemical cycles

Can they be quantified with acceptable accuracy?

No

Can negative outcomes be attributed to individual applications and remediated?

No

IMAGE: *NASA Goddard Space Flight Center*

Proposition:

Ocean fertilization for carbon offsets cannot be verified so it is not a viable technology for climate mitigation.

Thank you

IMAGE: *NASA Goddard Space Flight Center*