Science, Policy, and Fertilization of the Ocean for Carbon Offsets: Reflections on Twenty Years of Debate

John J. Cullen

Department of Oceanography, Dalhousie University
Halifax, Nova Scotia, Canada B3H 4J1
John.Cullen@Dal.CA

ASLO Aquatic Sciences Meeting 2009

Nice, France

January 30, 2009

IMAGE: *NASA Goddard Space Flight Center*

Potential conflicts of interest

Support from organizations opposed to ocean fertilization: **none**

Support from or agreements with organizations proposing commercial ocean fertilization: **none**

Mary Silver images

Potential conflicts of interest

Affiliation with commercial organization trying to reduce CO_2 emissions:

Cellana (algal biofuels and protein; since 2007)

Mary Silver images

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.

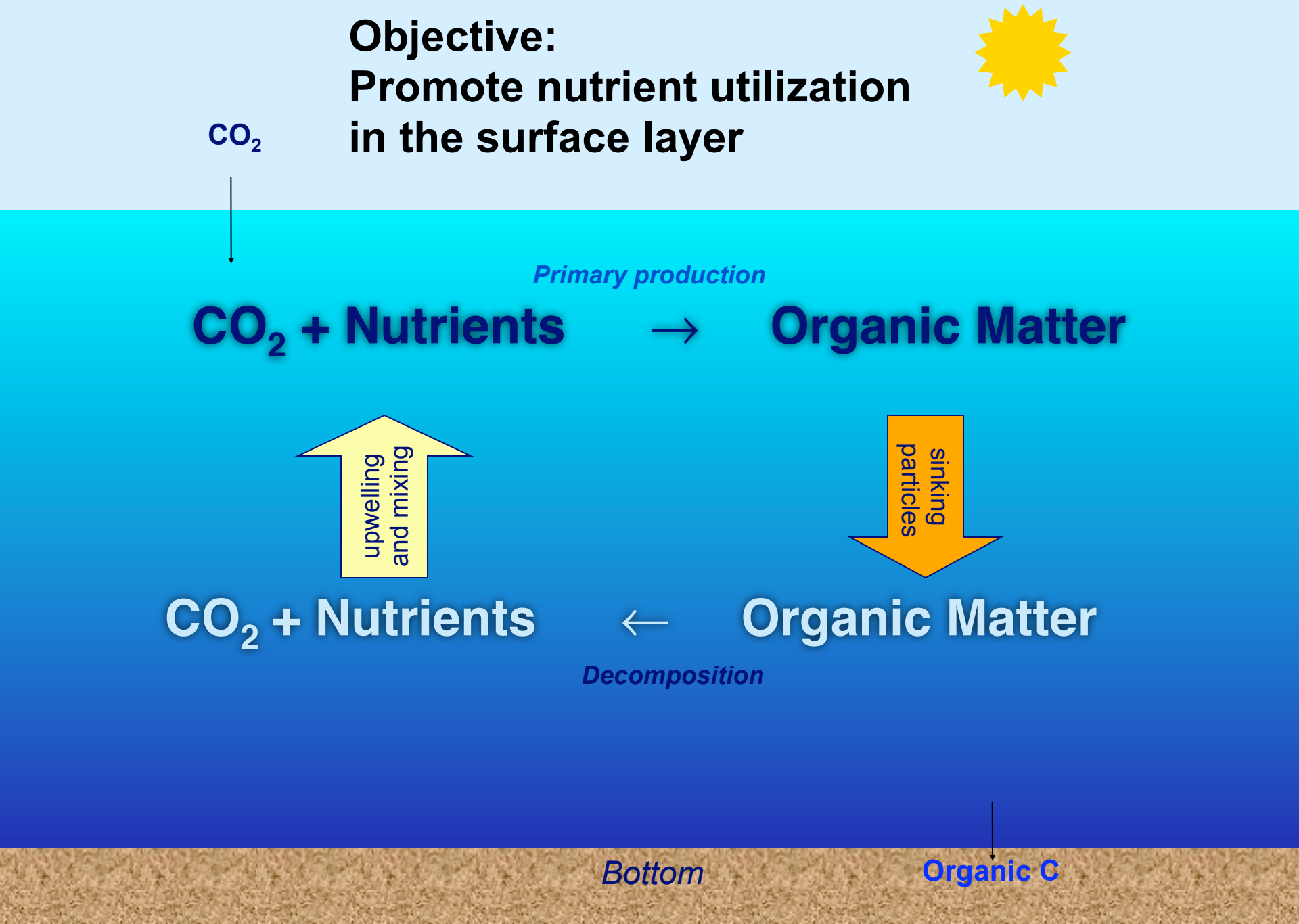
The “Iron Hypothesis” gains prominence

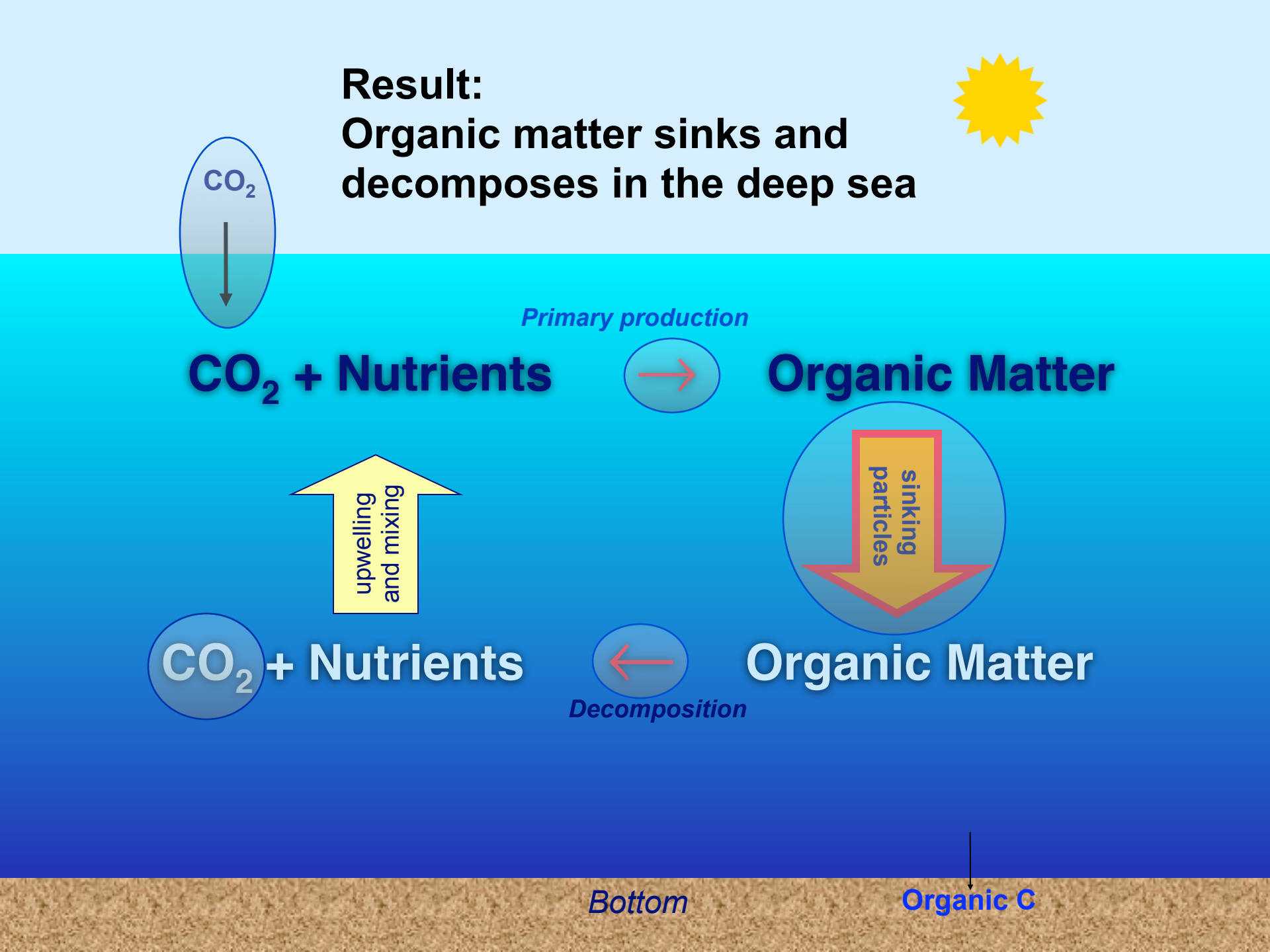
Nature 331 p341-343 1988

"give me half a tanker of iron, and I will give you the next ice age"

… John Martin

Objective:
Promote nutrient utilization in the surface layer




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

1989: Discussions in the boardroom

NATIONAL RESEARCH COUNCIL BOARD ON BIOLOGY

Workshop on Reducing Global Warming by Enhancing Carbon Dioxide Assimilation in Phytoplankton
December 4-5, 1989

FINDING #1:

It is conceptually feasible to slow the increase in atmospheric CO_2 levels through enhanced new primary production …

Estimate: 2 gigatons C per year
Cost: < $10 billion per year

RECOMMENDATION #1:

After careful modeling and appropriate preliminary experiments in regions with unused nutrients…an international transient iron enrichment experiment be implemented.

Estimated cost — $50 to $150 million

– from Workshop Summary released in May 1990

May 20, 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.

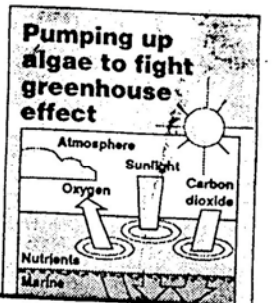
Although he does no research, he has brought together scientists and engineers from around the

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-



OPINION

Manipulation of ocean dangerous

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

PUBLIC FORUM

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.

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.

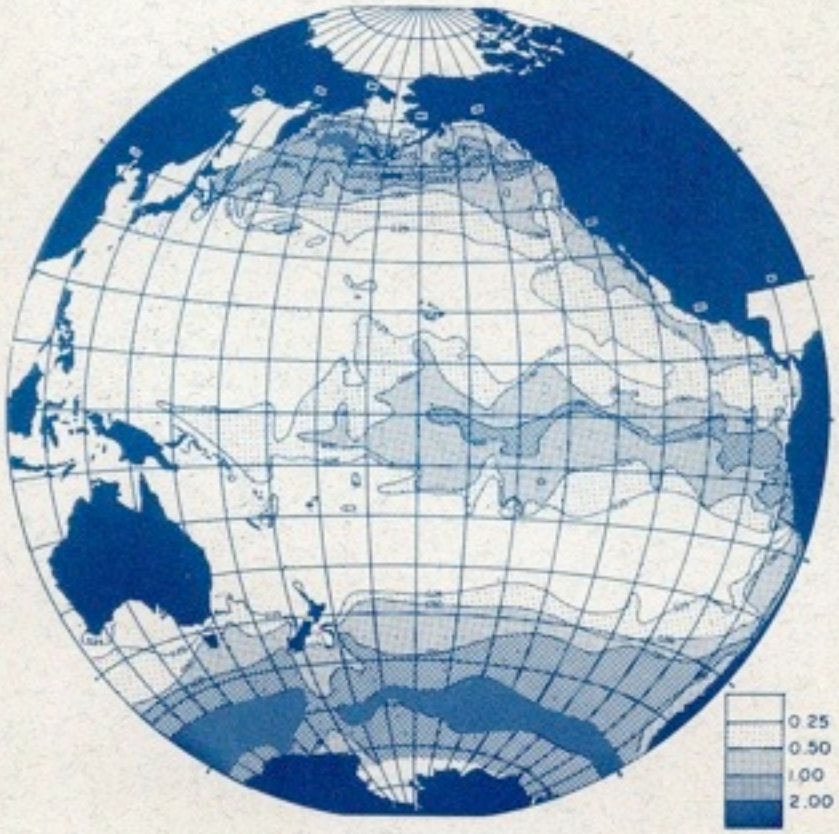
As they are eaten and decompose, the carbon that they took up will be released into the water and into the atmosphere. These changes in species composition would have important and unpredictable effects on marine ecosystems.

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

Consensus Resolution

The American Society of Limnology and Oceanography (ASLO) formally "…urg[es] all governments to regard the role of iron in marine productivity as an area for further research and not to consider [large scale] iron fertilization as a policy option that significantly changes the need to reduce emissions of carbon dioxide."

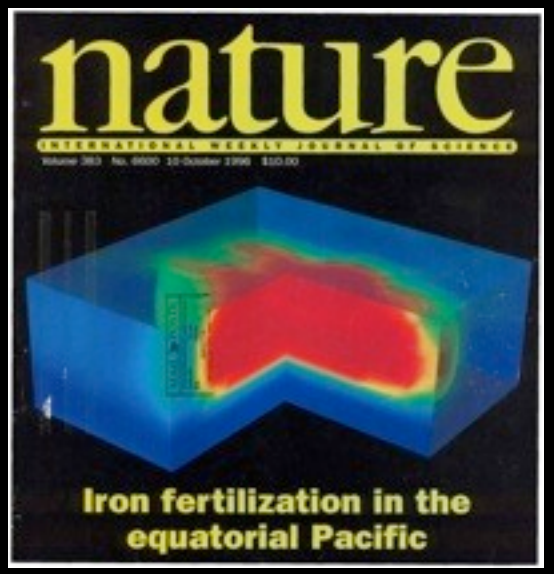
(Limnology and Oceanography 1991, Vol. 36)

1991 Consensus Resolution: Synopsis

- Research — ***YES***

- Geoengineering — ***NO***

1993-2009
Research has been successful



Mesoscale Iron Enrichment Experiments 1993–2005: Synthesis and Future Directions

P. W. Boyd,[1*] T. Jickells,[2] C. S. Law,[3] S. Blain,[4] E. A. Boyle,[5] K. O. Buesseler,[6] K. H. Coale,[7] J. J. Cullen,[8] H. J. W. de Baar,[9] M. Follows,[5] M. Harvey,[3] C. Lancelot,[10] M. Levasseur,[11] N. P. J. Owens,[12] R. Pollard,[13] R. B. Rivkin,[14] J. Sarmiento,[15] V. Schoemann,[10] V. Smetacek,[16] S. Takeda,[17] A. Tsuda,[18] S. Turner,[2] A. J. Watson[2]

GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L09703, doi:10.1029/2005GL022449, 2005

Feasibility of ocean fertilization and its impact on future atmospheric CO_2 levels

R. E. Zeebe
School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, Hawaii, USA

D. Archer
Geophysical Sciences, University of Chicago, Illinois, USA

…details virtually inaccessible to the general public

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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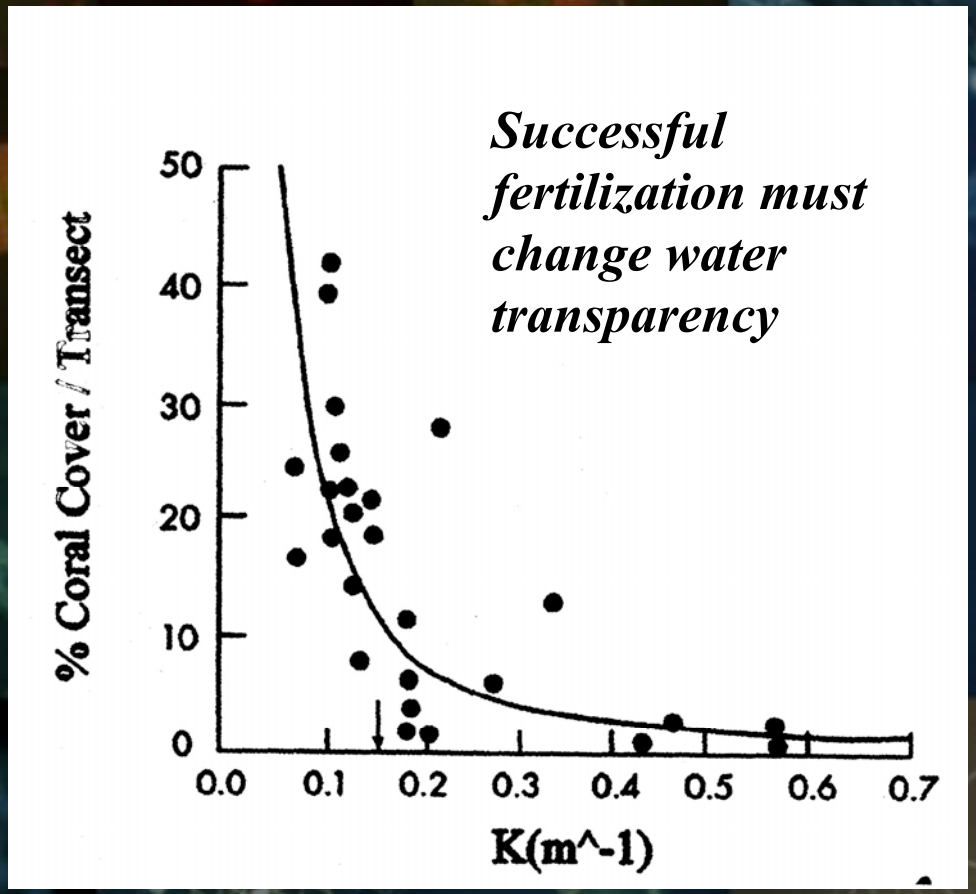
Michael Markels, Jr.

Recurring theme:

Unrecognized Potential Side Effects



Mary Silver images

Tomascik et al. 1993

Objections were raised

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 carbon 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

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.

KENNETH S. JOHNSON[1]* AND DAVID M. KARL[2]
[1]Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing, CA 95039, USA. [2]Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, HI 96822, USA.
*To whom correspondence should be addressed. E-mail: johnson@mbari.org

Still virtually inaccessible 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.

2007

Major program of iron fertilization announced

Planktos Launches Galapagos "Voyage of Recovery"

Planktos Launches Galapagos "Voyage of Recovery" Green Climate Initiative
Week One Milestones
DC launch of unprecedented ocean science mission to slow global warming and heal the seas features Greenpeace escort, Discovery Channel coverage, eminent National Press Club send-off, bipartisan lobbying, and stock market birth of Planktos Corp as public company.

Washington, DC -- (PRWeb) -- March 12, 2007 -- To introduce its remedial reprise of Darwin's 1831 Voyage of Discovery, Silicon Valley ecorestoration firm Planktos, Inc. sailed its research ship Weatherbird II to the nation's capitol on March 6 for a series of events to awaken policymakers and the public to the immense climatic, ecological and economic significance of ocean plankton restoration. Covered by the Discovery Channel for a special Earth Day program, the mission's Greenpeace-escorted DC arrival was the highpoint of a busy week of lobbying and briefing activity.
Planktos is working to ensure the ocean's enormous natural CO2 sequestration potential is recognized and prioritized in any future federal climate change laws, and we are finding real enthusiasm for this powerful green approach.

NGOs raise concerns and the International Maritime Organization responds

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 was 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.**

After 20 years, ocean fertilization was 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, they called for an environmental impact assessment

2007: Climos rises as Planktos sinks

CLIMOS

- ABOUT
- CLIMOS NOTES
- EVENTS
- TEAM
- SCIENTIFIC ADVISORY BOARD
- RECENT PRESS
- CARBON NEWS
- REFERENCE

THE CLIMOS CODE OF CONDUCT FOR OCEAN FERTILIZATION

"BRINGING SEAPOWER TO THE FIGHT AGAINST GLOBAL WARMING"

CEO Dan Whaley interview featured on Neal Dikeman's Cleantech Blog

In a posting to his C-Net syndicated Cleantech Blog, Neal Dikeman conducts an extensive interview with Dan Whaley.

>> read the posting

PRESS STATEMENT
SAN FRANCISCO, CA (DECEMBER 3, 2007)

Climos Receives First Methodology for Ocean Iron Fertilization from EcoSecurities, Signs with DNV for Assessment

A draft methodology for Ocean Iron Fertilization, developed by Ecosecurities, has been delivered to DNV (Det Norske Veritas) for Assessment. Climos and DNV

Commitment to science-based policy

CLIMOS

- About
- Climos Notes
- Events
- Team
- Scientific Advisory Board
- Recent Press
- Carbon News
- Reference

The Climos Code of Conduct for Ocean Fertilization

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Commercial model: Carbon offsets

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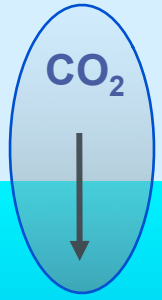
Objective:

Mitigate climate change by moving a large amount of organic matter to the deep sea



Primary production

CO_2 + Nutrients → Organic Matter

upwelling and mixing

sinking particles

CO_2 + Nutrients ← Organic Matter

Decomposition

Bottom

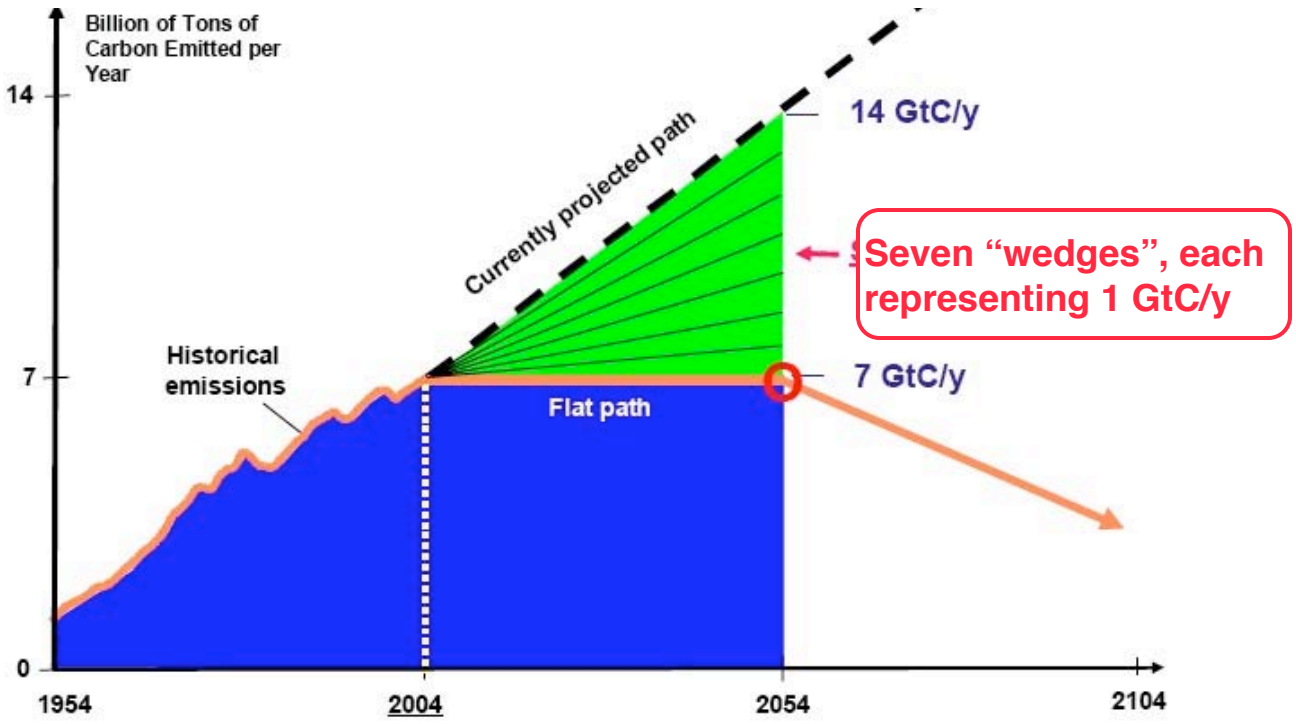
Organic C

A commonly mentioned target:
one "Wedge" = 1 Gt C / y = a lot

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

oceanironfertilization

come to listen · learn · debate · explore

2007 - 2008: Scientists offer support

Commitment to science-based policy

Recognition of significant uncertainties

POLICYFORUM

ENVIRONMENT

Ocean Iron Fertilization—Moving Forward in a Sea of Uncertainty

Ken O. Buesseler,[1]* Scott C. Doney,[1] David M. Karl,[2] Philip W. Boyd,[3] Ken Caldeira,[4] Fei Chai,[5] Kenneth H. Coale,[6] Hein J. W. de Baar,[7] Paul G. Falkowski,[8] Kenneth S. Johnson,[9] Richard S. Lampitt,[10] Anthony F. Michaels,[11] S. W. A. Naqvi,[12] Victor Smetacek,[13] Shigenobu Takeda,[14] Andrew J. Watson[15]

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

Special issue published (open access)

Vol. 364: 213–218, 2008
doi: 10.3354/meps07541

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published July 29

THEME SECTION

OPEN ACCESS

Implications of large-scale iron fertilization of the oceans

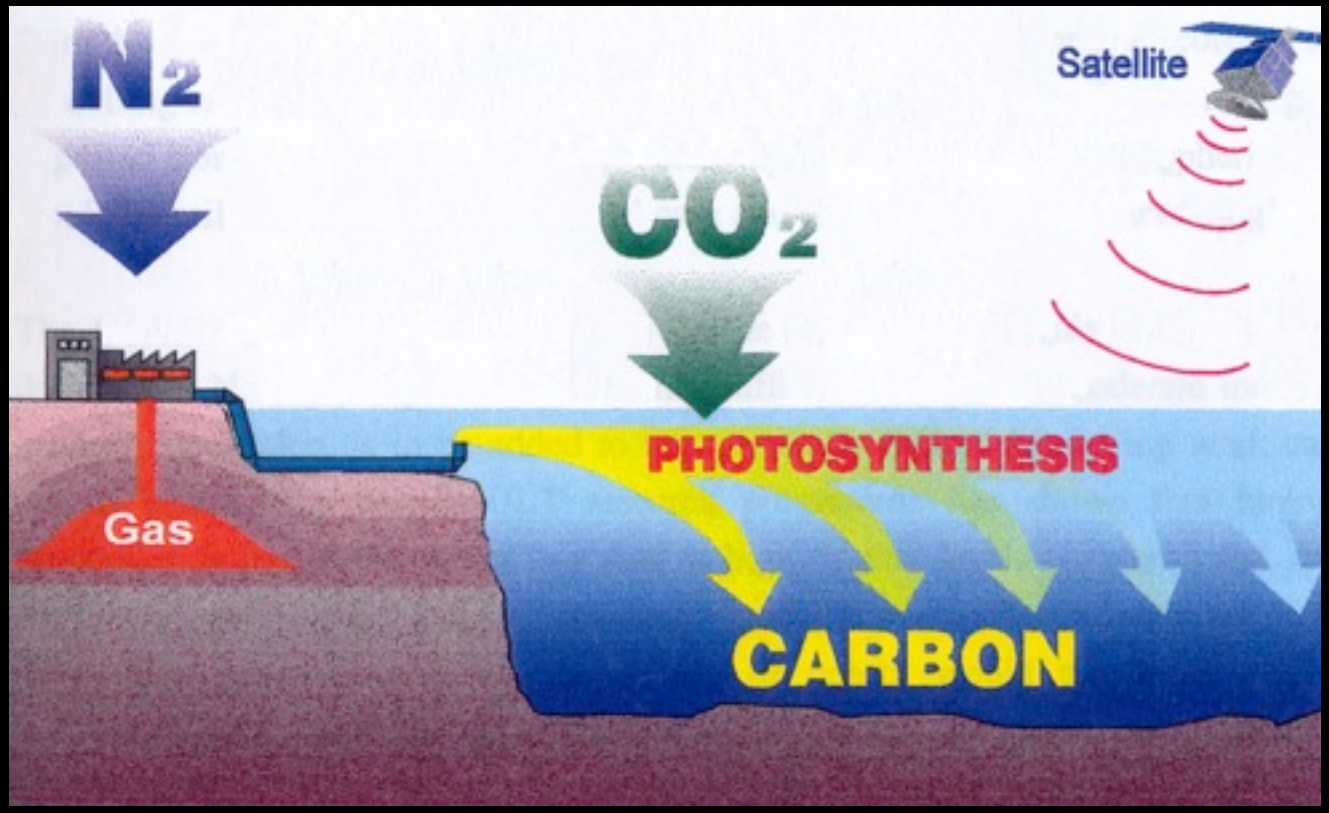
Idea: Howard Browman, Philip W. Boyd
Coordination: Philip W. Boyd

CONTENTS

Mary Silver images

One issue did generate scientific consensus:

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



http://www.oceannourishment.com

Roots in papers / patent application in mid 1990's

Marine Pollution Bulletin 56 (2008) 1049–1056

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Viewpoint

Ocean urea fertilization for carbon credits poses high ecological risks

Patricia M. Glibert [a,*], Rhodora Azanza [b], Michele Burford [c], Ken Furuya [d], Eva Abal [e], Adnan Al-Azri [f], Faiza Al-Yamani [g], Per Andersen [h], Donald M. Anderson [i], John Beardall [j], G. Mine Berg [k], Larry Brand [l], Deborah Bronk [m], Justin Brookes [n], JoAnn M. Burkholder [o], Allan Cembella [p], William P. Cochlan [q], Jackie L. Collier [r], Yves Collos [s], Robert Diaz [m], Martina Doblin [t], Thomas Drennen [u], Sonya Dyhrman [i], Yasuwo Fukuyo [v], Miles Furnas [w], James Galloway [x], Edna Granéli [y], Dao Viet Ha [z], Gustaaf Hallegraeff [aa], John Harrison [ab], Paul J. Harrison [ac], Cynthia A. Heil [ad], Kirsten Heimann [ae], Robert Howarth [af], Cécile Jauzein [s], Austin A. Kana [u], Todd M. Kana [a], Hakgyoon Kim [ag], Raphael Kudela [ah], Catherine Legrand [y], Michael Mallin [ai], Margaret Mulholland [aj], Shauna Murray [ak], Judith O'Neil [a], Grant Pitcher [al], Yuzao Qi [am], Nancy Rabalais [an], Robin Raine [ao], Sybil Seitzinger [ap], Paulo S. Salomon [y], Caroline Solomon [aq], Diane K. Stoecker [a], Gires Usup [ar], Joanne Wilson [as], Kedong Yin [c], Mingjiang Zhou [at], Mingyuan Zhu [au]

http://www.smh.com.au/news/environment/climate-scientists-seek-a-urea-moment/2009/01/20/1232213646774.html

Climate scientists seek a urea moment
Ben Cubby Environment Reporter
January 21, 2009

SYDNEY researchers are pushing ahead with controversial plans to fertilise the ocean off Australia's coast and use plankton to slow climate change.

Important question:

Can OIF be demonstrated to have acceptable, predictable and verifiable environmental impacts?

Vol. 364: 295–301, 2008
doi: 10.3354/meps07551

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published July 29

Contribution to the Theme Section 'Implications of large-scale iron fertilization of the oceans'

OPEN ACCESS

Predicting and verifying the intended and unintended consequences of large-scale ocean iron fertilization

John J. Cullen[1,*], Philip W. Boyd[2]

[1]Department of Oceanography, Dalhousie University, 1355 Oxford Street, Halifax, Nova Scotia B3H 4J1, Canada
[2]NIWA Centre for Chemical and Physical Oceanography, Department of Chemistry, University of Otago, PO Box 56, Dunedin, New Zealand

For more illustrations, download video or slides at
http://www.whoi.edu/page.do?pid=14618

Mary Silver images

The ultimate goal of all proposed plans

IMAGE: *NASA Goddard Space Flight Center*

The ultimate goal of all proposed plans

Modification of the global environment

IMAGE: *NASA Goddard Space Flight Center*

Intended consequences of large-scale fertilization

IMAGE: *NASA Goddard Space Flight Center*

Intended consequences of large-scale fertilization

Increased deep ocean concentrations of CO_2, N and P

IMAGE: *NASA Goddard Space Flight Center*

Intended consequences of large-scale fertilization

Increased deep ocean concentrations of CO_2, N and P

Decreased deep ocean concentrations of O_2

IMAGE: *NASA Goddard Space Flight Center*

Intended consequences of large-scale fertilization

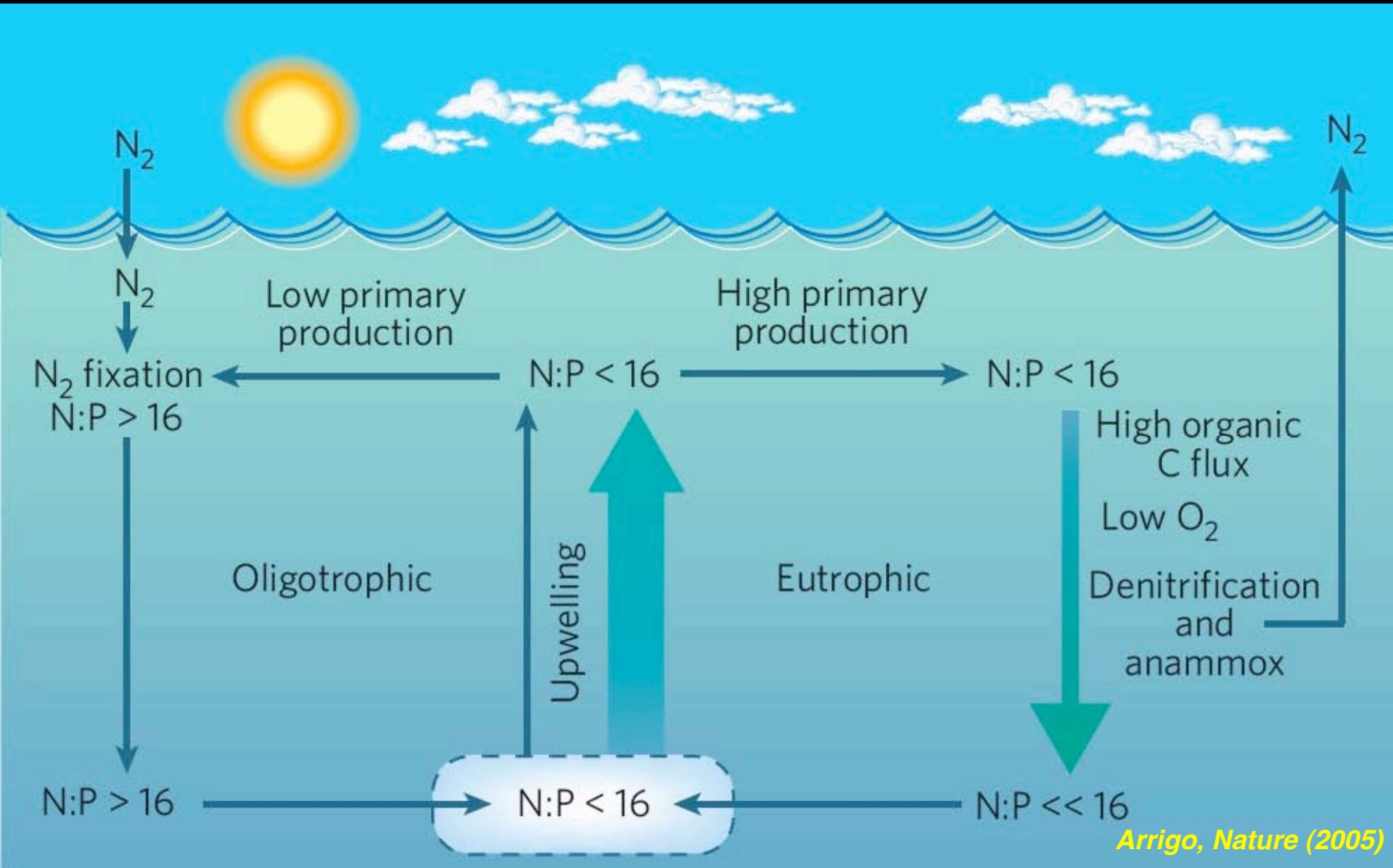
Increased deep ocean concentrations of CO_2, N and P

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)

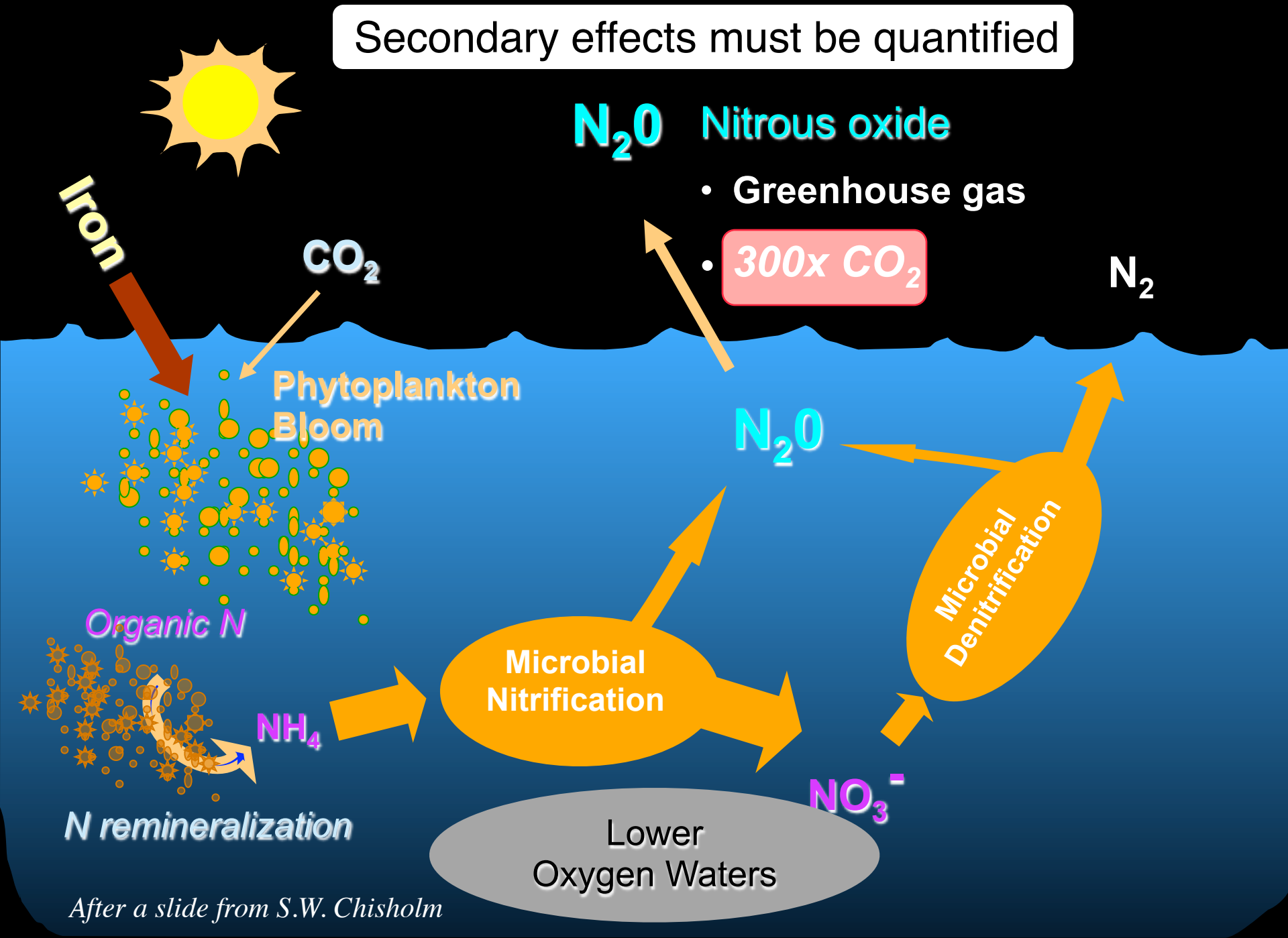
One Intended Effect

IMAGE: *NASA Goddard Space Flight Center*

One Intended Effect

An
increased
deep ocean
inventory
of nitrogen

IMAGE: *NASA Goddard Space Flight Center*


Secondary effects must be quantified
N_2O Nitrous oxide
• Greenhouse gas
• 300x CO_2
N_2
Iron
CO_2
Phytoplankton Bloom
N_2O
Organic N
Microbial Denitrification
Microbial Nitrification
NH_4
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?*

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Assessing proximate effects of experiments is not enough (see Cullen and Boyd 2008).

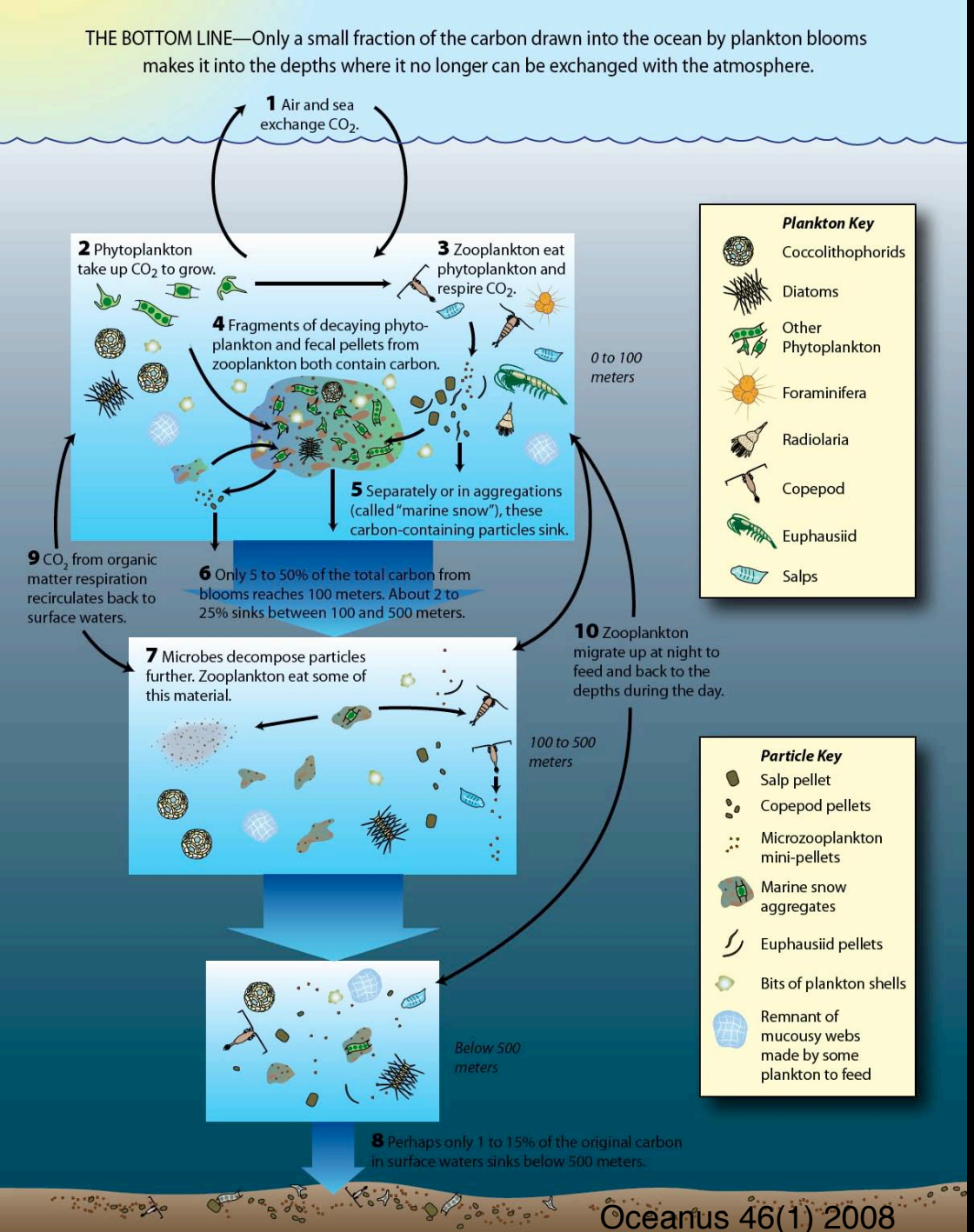
Another Intended Effect

IMAGE: *NASA Goddard Space Flight Center*

Another Intended Effect

Decreased oxygen concentrations in the deep ocean

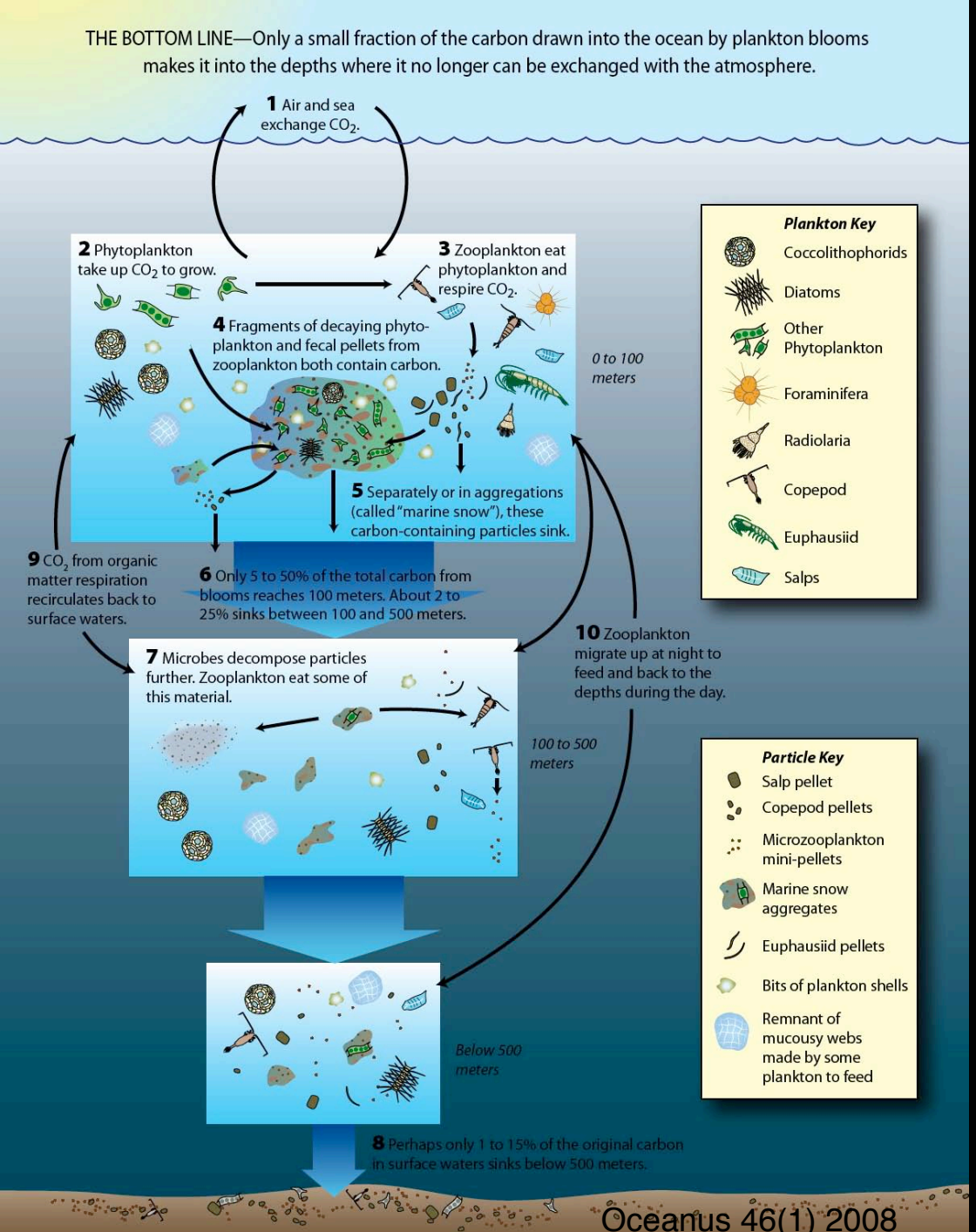
IMAGE: *NASA Goddard Space Flight Center*



Oceanus 46(1) 2008

Much of the organic matter
that is moved
downward will be
remineralized
above the "100-year
horizon"

ASLO ASM 2009: John Cullen



Oceanus 46(1) 2008

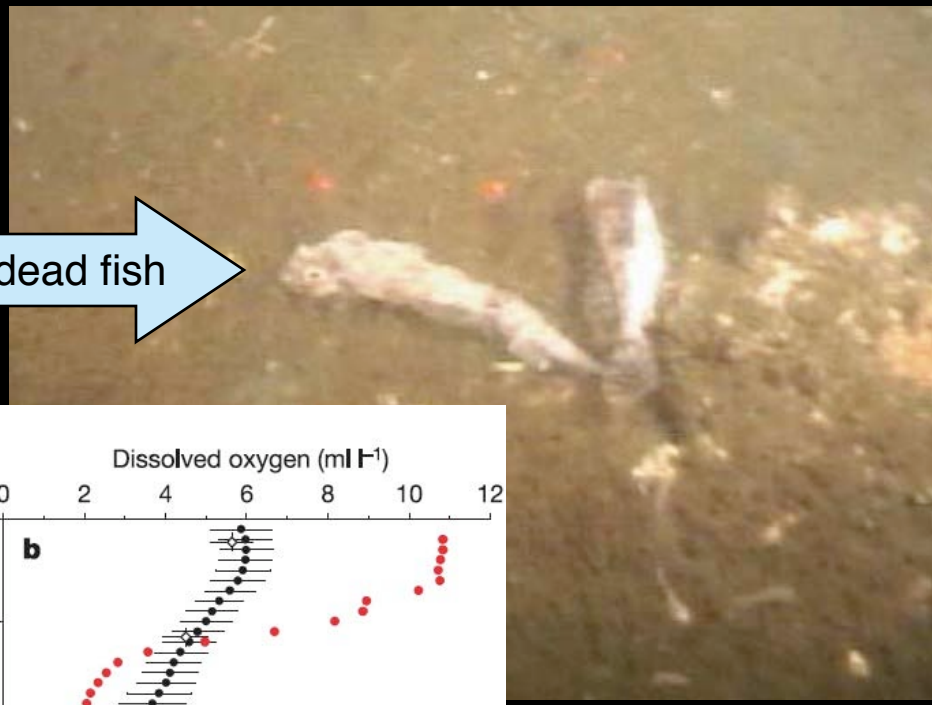
Much of the organic matter that is moved downward will be remineralized above the "100-year horizon"

Mid-depths will be enriched

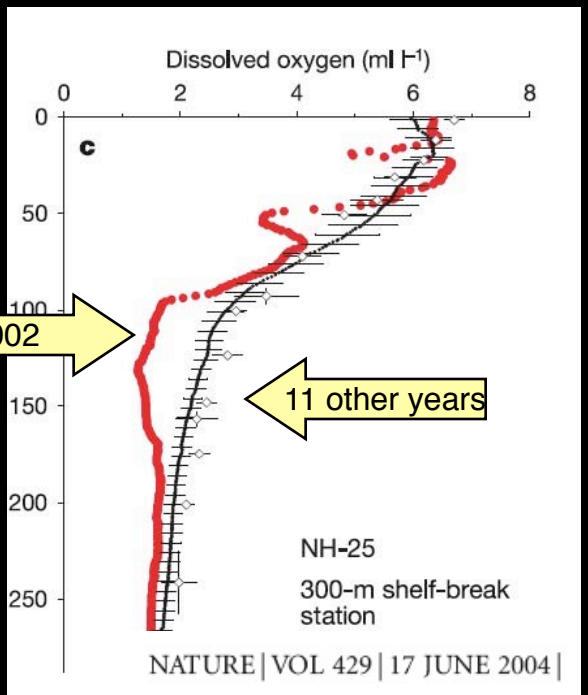
Predictable result:
greater probability of hypoxic events— but by how much?

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

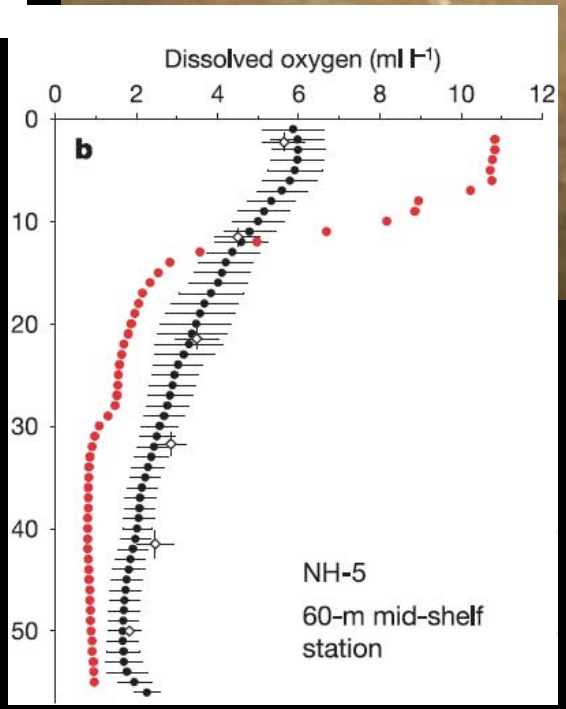
Brian A. Grantham[1]*, Francis Chan[2]*, Karina J. Nielsen[4]*, David S. Fox[5], John A. Barth[3], Adriana Huyer[3], Jane Lubchenco[2] & Bruce A. Menge[2]



Rotting dead fish



NATURE | VOL 429 | 17 JUNE 2004 |



ASLO ASM 2009: John Cullen

Is this likely?

Who or what is to blame?

Could effects ever be ascribed to fertilization?

Must be climate change

Must be “IronCorp”

NATURE | VOL 429 | 17 JUNE 2004 |

Will there be unexpected and unwanted effects?

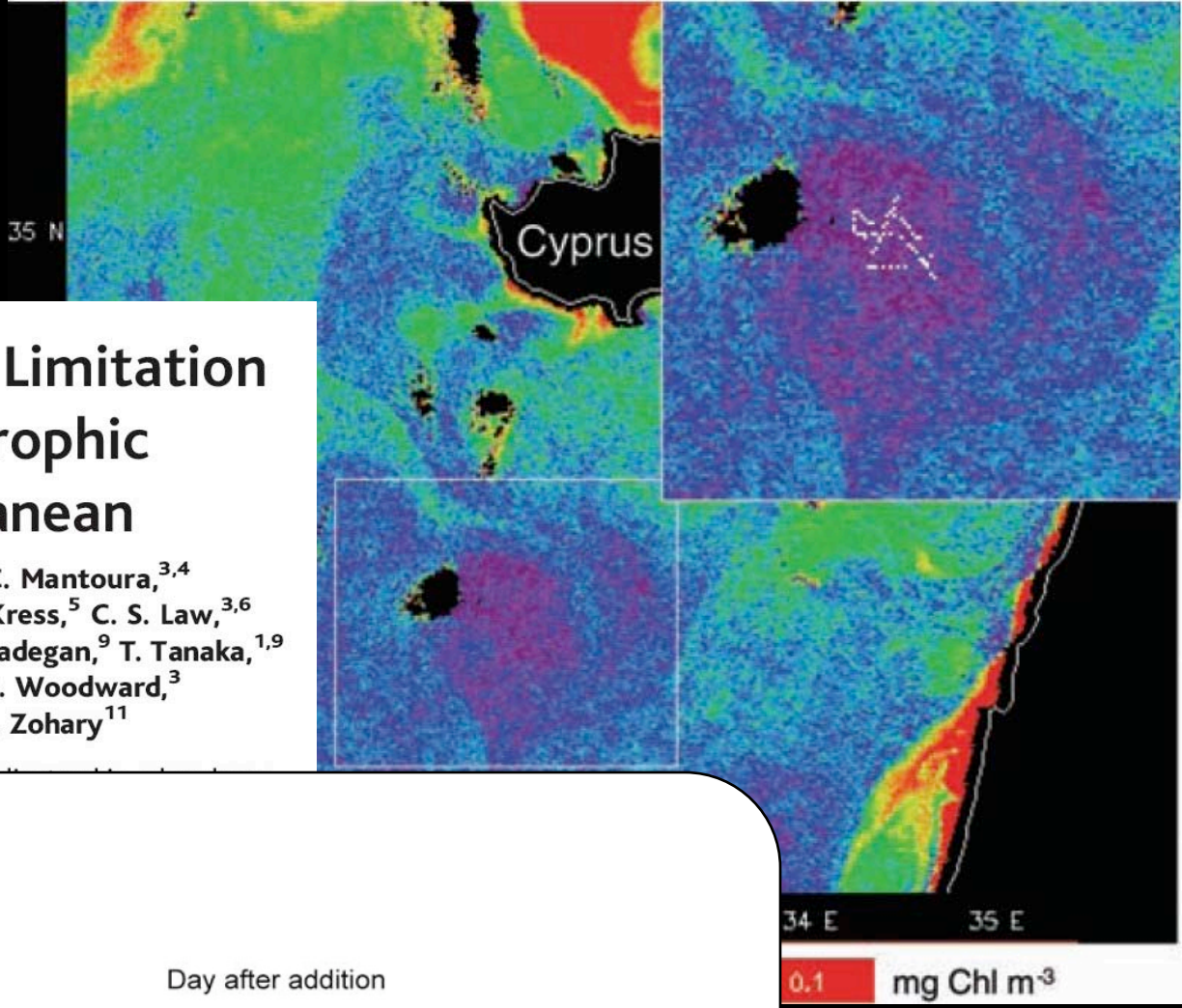
IMAGE: *NASA Goddard Space Flight Center*

Will there be unexpected and unwanted effects?

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

IMAGE: *NASA Goddard Space Flight Center*

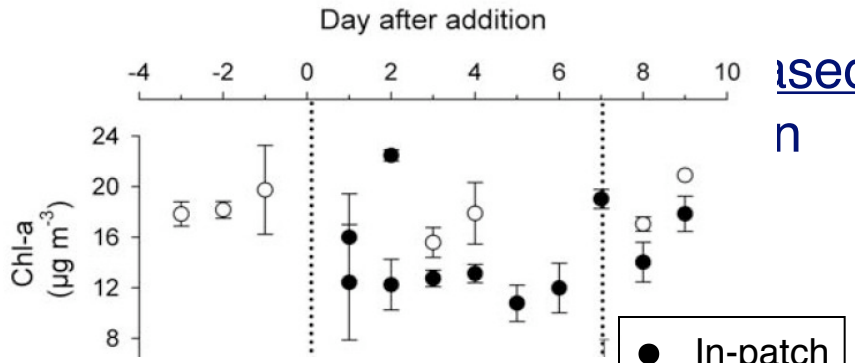
Can complex ecological responses be predicted?



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
starved eastern Mediterranean in a
ecosystem responses. The syster
increase in bacterial production ar
and phosphorus colimitation hinde
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



ased
n

We propose that until the side-effects of widespread OIF can be shown to be verifiable—and there is good reason to believe that they cannot—OIF should not be considered a viable technology for climate mitigation.

Cullen and Boyd, MEPS 2008

IMAGE: *NASA Goddard Space Flight Center*

Counter-argument:

"This is an incremental thing. If you start to see that it's going wrong, then you can roll back. Taking the first step does not inevitably mean that you have to go the whole road."

—Andrew Watson, Univ. of East Anglia

Oceanus Magazine 46(1), 2008

“an incremental thing”

Ocean Pumping

Atmocean, Inc.™

Upwelling Animation | Preserving Coral Reefs | Biological Ocean Sequestration of CO_2 | Reduce Hurricane Intensity | Open Ocean Aquaculture

Upwelling System Animation

Vol. 364: 257–268, 2008
doi: 10.3354/meps07547

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published July 29

Contribution to the Theme Section 'Implications of large-scale iron fertilization of the oceans'

OPEN ACCESS

Nitrogen fixation-enhanced carbon sequestration in low nitrate, low chlorophyll seascapes

David M. Karl[1,*], Ricardo M. Letelier[2]

[1]Department of Oceanography, University of Hawaii, Honolulu, Hawaii 96822, USA
[2]College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon 97331, USA

“This is really exciting for me, because once we can prove that this technology works, we can scale it to millions of pumps.”

Dr. Brian Von Herzen on the Discovery program “Hungry Oceans.”

The viewer should understand that this Program and those individuals who appear in it (with the exception of Dr. Brian Von Herzen) are not affiliated with Atmocean and do not endorse Atmocean's designs and applications of our wave-driven upwelling pumps.

www.atmocean.com

If you start to see that it's going wrong, then you can roll back."

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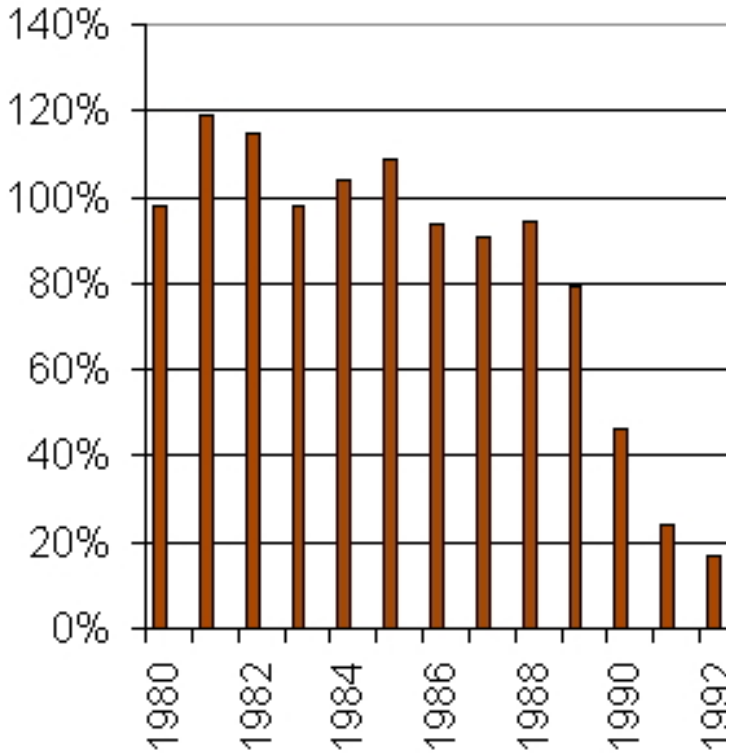
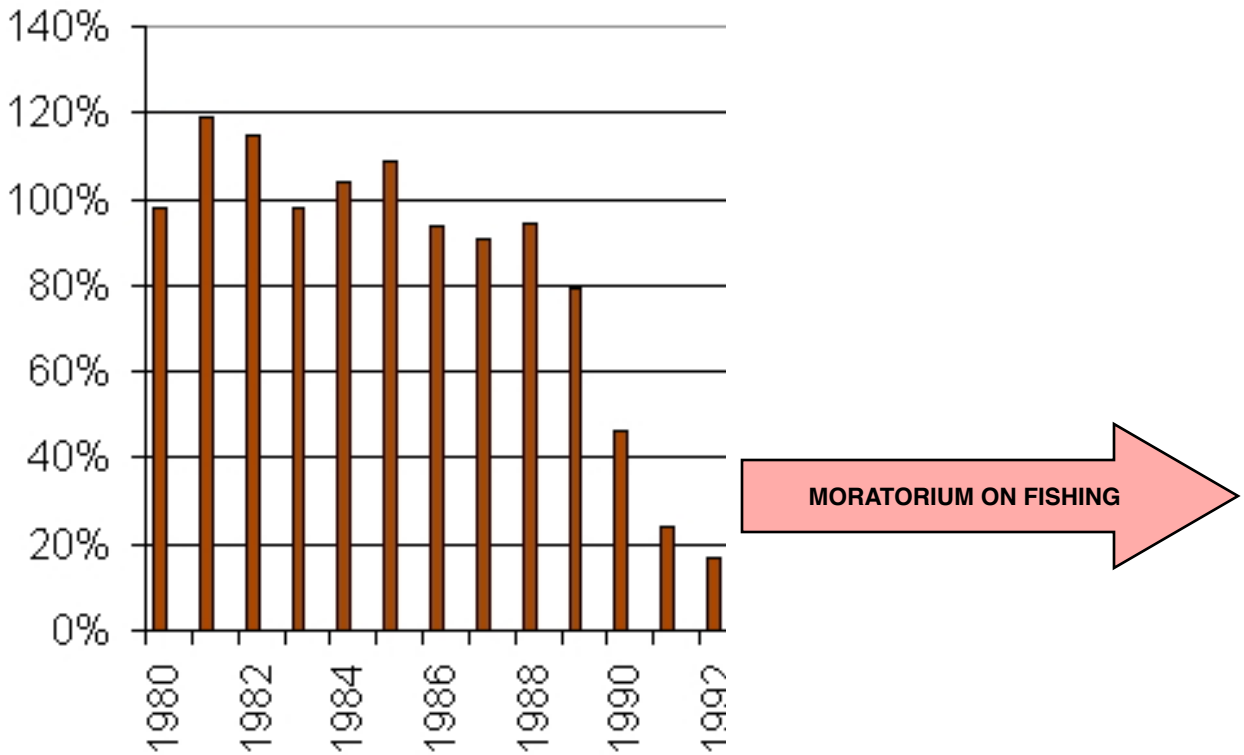
Oceanus Magazine 46(1), 2008

1992: Cod stocks were going wrong



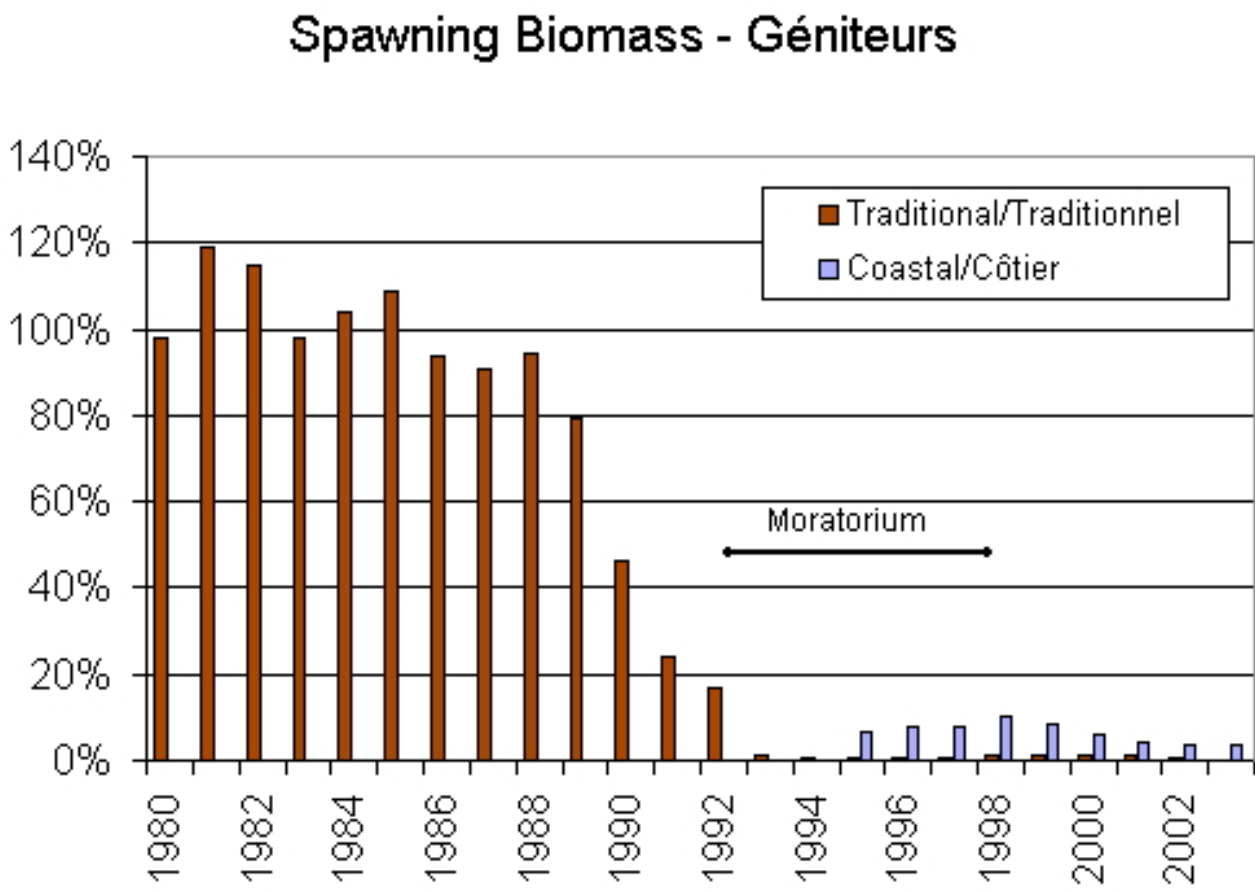
http://www.dfo-mpo.gc.ca/media/infocus-alaune/images/20030424/Cod-science003.gif

Fishing was stopped



http://www.dfo-mpo.gc.ca/media/infocus-alaune/images/20030424/Cod-science003.gif

The cod did not come back



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Three Central Questions: Can they be answered?

What are the effects of large scale ocean fertilization?

IMAGE: *NASA Goddard Space Flight Center*

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What are the effects of large scale ocean fertilization?

Fundamental alterations of marine ecosystems and biogeochemical cycles

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Can they be quantified with acceptable accuracy?

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Can negative outcomes be attributed to individual applications and remediated?

IMAGE: *NASA Goddard Space Flight Center*

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IMAGE: *NASA Goddard Space Flight Center*

Three Central Questions: Can they be answered?

What are the effects of large scale ocean fertilization?

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Can they be quantif accept accura

?

Burden of proof is on the proponents, not on “anti-offset crusaders”

Can negative outcomes be attributed to individual applications and remediated?

?

IMAGE: *NASA Goddard Space Flight Center*

One Earth