OCEAN FERTILIZATION

The ocean is a natural carbon reservoir, absorbing almost a third of the carbon dioxide (CO_2) emitted to the atmosphere by anthropogenic activities over the last 250 years. One of the processes that allows this to happen is the uptake and conversion of atmospheric carbon into organic matter through photosynthesis by marine phytoplankton. Scientists have long wondered whether phytoplankton could be stimulated to uptake even greater quantities of CO_2 from the atmosphere through the addition of nutrients, such as iron. In 1991, oceanographer John Martin famously stated "Give me a half a tanker of iron and I will give you another ice age," giving rise to the concept of ocean fertilization. With the predicted increases in atmospheric CO_2 concentrations and their impact on humankind and life on Earth, all ideas and concepts to mitigate climate change – controversial or not – must be considered. Ocean fertilization is an intriguing concept: it utilizes the ocean (the largest carbon reservoir on Earth); is based on natural processes; and, in theory, suggests that large amounts of CO_2 could be sequestered at a relatively low financial cost. But would it work? And at what cost to the marine ecosystem?

The oceans: natural carbon reservoirs

The ocean plays an important role in the regulation of atmospheric CO_2 and hence climate change. One of the largest natural reservoirs of carbon, the ocean absorbs almost a third of total CO_2 emissions from human activities each year. This has led to an increase in the total inorganic carbon content of the oceans of over 100 billion tonnes since 1800.

Once dissolved, inorganic carbon is converted to organic matter through photosynthesis by marine phytoplankton, the dominant form of plant life in the open ocean and the base of the marine food web (figure 1). A fraction of the surface ocean, generally 50 to 200 metres deep (the "euphotic zone"), is sufficiently sunlit to support photosynthesis by phytoplankton. Here, using sunlight for energy and dissolved inorganic nutrients, phytoplankton convert dissolved inorganic carbon in seawater into organic matter through photosynthesis, prompting the drawdown of additional CO_2 from the atmosphere. This organic carbon is later released in the deep ocean as the phytoplankton die or are consumed. Some of it will sink to the deeper ocean, isolated from further interaction with the atmosphere for an estimated 1,000 years (i.e., sequestered). The concept of ocean fertilization is based on artificially increasing this natural process by stimulating primary production in surface ocean waters.

The rationale for ocean fertilization

The physiological needs (e.g., nitrate, phosphate, silicate) of marine phytoplankton must be met from within the water column. The world's oceans contain vast reservoirs of nutrients, however, they are primarily located at depths below the euphotic zone (i.e., they are unavailable to marine life). One of the nutrients essential to photosynthesis is almost always lacking, however, thereby limiting photosynthesis.

An estimated 20–30 per cent of the world's open-ocean surface waters have adequate nutrients in the euphotic zone, but a relatively low phytoplankton biomass (and hence low chlorophyll, which is contained in phytoplankton and necessary for photosynthesis). Biological productivity is often limited by a lack of micronutrients, such as iron. These high nutrient, low-chlorophyll (HNLC) areas are found in the equatorial and subarctic Pacific Ocean, the Southern Ocean and in some strong upwelling regimes, such as the equatorial Pacific.

Scientific experimentation has demonstrated that iron availability plays a role in regulating phytoplankton photosynthesis and resulting primary production in HNLC ocean areas, influencing the associated uptake of carbon over large areas of the ocean. Contemporary ocean observations following natural iron inputs to the Southern Ocean and the North Pacific Ocean support the theory that natural iron fertilization leads to rapid growth of phytoplankton and an increased export of carbon to the deep sea. The Southern Ocean is the largest

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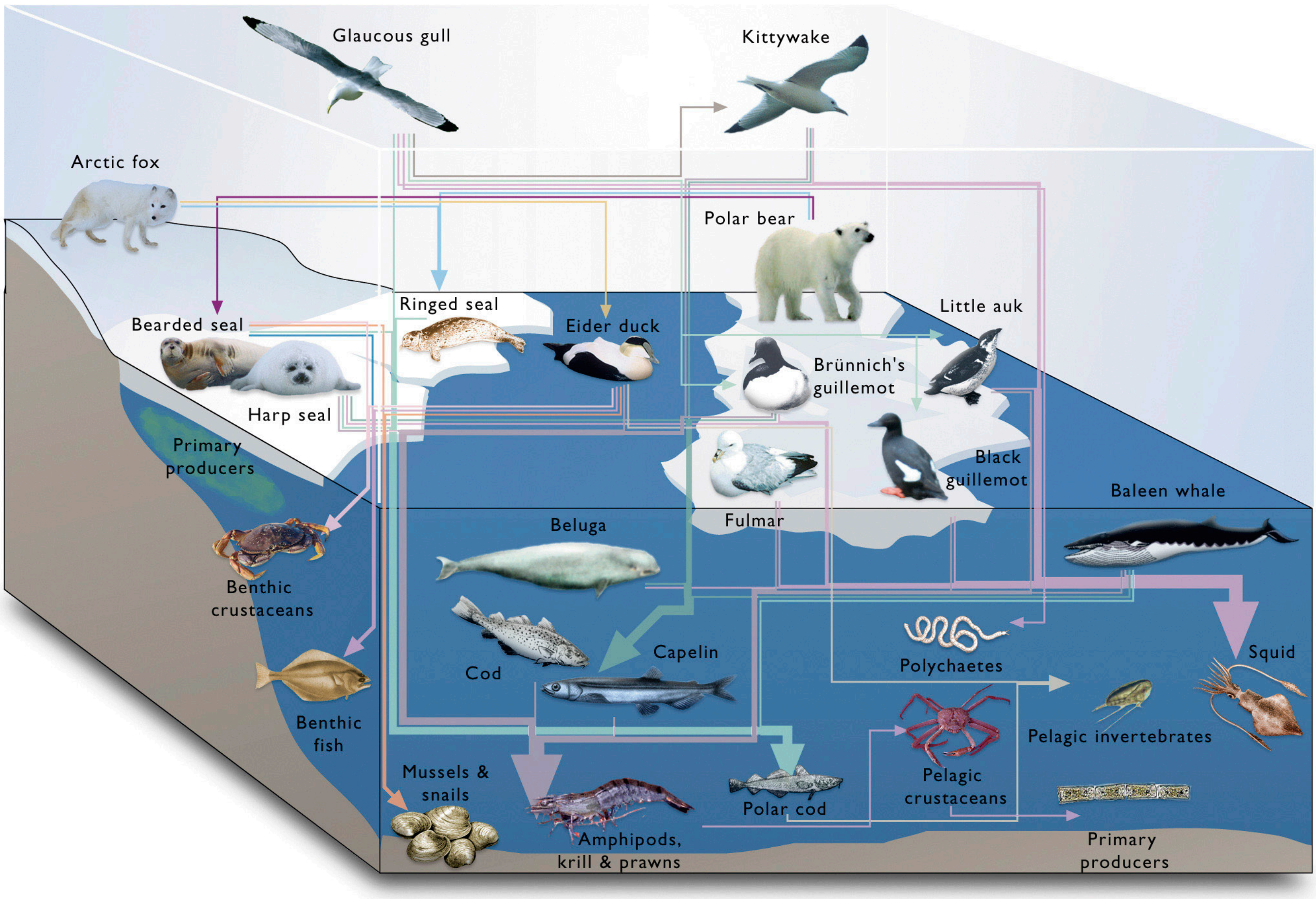

Figure 1: Trophic linkages in the Beaufort Sea.
Source: Arctic Climate Impacts Assessment Impacts of a Warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press, 2007.

HNLC area of the global ocean and is very important for the regulation of the global climate system due to its potential as a carbon sink.

Other surface waters, such as the subtropical and tropical oceans, have low sea-surface concentrations of both nitrate and chlorophyll and are characterized by low rates of organic matter production and export of carbon to the deep ocean. These low-nitrate, low-chlorophyll (LNLC) areas have no expectation of further primary productivity and little carbon sequestration potential. Given that these regions occupy approximately 50 per cent of the ocean, however, they remain important in the global marine carbon export budget.

Box 1: Definition of ocean fertilization

Ocean fertilization can be defined as any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans to induce biologically mediated CO_2 uptake from the atmosphere.

Box 2:"Half a tanker of iron"

The examination of aeolian dust particles obtained from ice and sediment cores suggests that during glacial periods the supply of iron to the world's oceans was higher than during interglacial periods. Oceanographer John Martin and his colleagues proposed that the increasing iron supply from dust during glacial periods stimulated primary productivity, which in turn led to a decrease in atmospheric CO_2 levels and further global cooling. It is estimated that this increase in iron induced productivity could have accounted for 30 per cent of the 80 parts per million decrease in atmospheric CO_2 during glacial maxima. Hence Martin's famous statement: "Give me a half a tanker of iron and I will give you another ice age."

What if HNLC and LNLC areas were provided with micronutrients, such as iron, and macronutrients, such as nitrogen, phosphate and silica, to stimulate phytoplankton photosynthesis? Would additional CO_2 be drawn down from the atmosphere and climate change mitigated? John Martin's iron hypothesis has sparked much interest in the potential of specific ocean regions to mitigate further climatic warming by

improving the drawdown of CO_2 from the atmosphere through the intentional fertilization of ocean surface waters with macro- and micronutrients.

But would it work?

Most of the ocean fertilization experiments conducted to date were designed solely to test the concept of ocean fertilization (i.e., whether it was possible to stimulate plankton growth) and to gain a better scientific understanding of the artificially created plankton blooms. These studies have established that iron plays a fundamental role in some regions of the oceans and have advanced scientific understanding of ocean biogeochemistry. As a result, the general components and functions of ocean fertilization are known.

Less certain is whether large-scale ocean fertilization is viable as a climate-change mitigation strategy and what effect it might have on marine biodiversity. To reduce atmospheric CO_2 concentrations in quantities large enough to mitigate climate change, large-scale ocean fertilization activities would have to be both effective (capturing carbon and isolating it from further interaction with the atmosphere for a minimum period of 100 years in a verifiable manner) and repeated on a continuous basis. Direct experimental evidence that ocean fertilization actually induces an increased downward transport of captured carbon into the deep sea remains elusive.

Early model calculations predicted that the sustained fertilization of HNLC areas with iron, over decades, could temporarily remove half a gigatonne of carbon per year from the atmosphere. The 13 open-ocean iron fertilization experiments conducted to date in polar, sub-polar and tropical HNLC areas have, however, required more than twice the predicted amount of iron to trigger a phytoplankton bloom. Furthermore, recent estimates suggest that even with sustained fertilization of open oceans, only a minor impact on the increase in atmospheric CO_2 will be possible.

As far as phosphorous fertilization is concerned, few open-ocean experiments have been conducted thus far, and sequestration potential has not been measured; to date, no experiments have been conducted using nitrogen fertilization (urea, ammonia or nitrate).

Another technique that has been suggested for enhancing primary production and export, and hence CO_2 sequestration, is the purposeful delivery of deep-water nutrients to the euphotic zone, via controlled or artificial upwelling. Five ship-based experiments testing this theory were conducted in 2003. They demonstrated a consistent increase in phytoplankton biomass and primary production following fertilization.

What would be the impact on biodiversity?

Ocean fertilization, by definition, is intended to change and interfere with natural processes, and is likely, therefore, to have an impact (adverse or beneficial) on marine biodiversity. Given current knowledge it is difficult to predict the nature and extent of such an impact. There are significant concerns, however, regarding intended and unintended impacts on marine ecosystem structure, function and dynamics, including the sensitivity of species and habitats and the physiological changes induced by large-scale additions of nutrients to surface waters.

A change in the composition of phytoplankton communities was observed in 5 out of 13 mesoscale iron enrichment experiments carried out. Depending on location, changes to phytoplankton and bacterial communities could follow unpredictable pathways and have consequences for global ocean food chains, favouring, for example, the proliferation of opportunistic, less commerciallyviable species such as jellyfish. Global ocean models suggest that continuing fertilization may lead to the depletion of macronutrients necessary for phytoplankton production in the downstream water column for several thousand kilometres. In one of the 13 experiments, there was an increase in nitrous oxide, a climate active gas that has a global warming potential some 300 times that of CO_2 and contributes to ozone depletion.

Fertilization with phosphorous or nitrogen and the upwelling of deep seawater similarly bear the risk of decreasing phytoplankton biodiversity together with other community shifts. Furthermore, urea is preferentially used as a nitrogen source by marine species associated with harmful or toxic algal blooms. Nitrogen loading in coastal areas or sensitive areas such as coral reefs may result in the proliferation of algae and overgrowth of corals, impacting the continued provision of goods and ecosystem services. The upwelling of deep seawater runs the additional risk of accelerating the spread of ocean acidification (colder, deep waters absorb large amounts of CO_2), which is expected to have a negative affect on marine organism shells and skeletons.

Looking ahead

In 2008, the Conference of the Parties to the Convention on Biological Diversity requested Parties to abide by the precautionary approach, to ensure that ocean fertilization activities did not take place until there was an adequate scientific basis for them and a control and regulatory mechanism for such activities was in place (decision IX/16 C). In the same year, the governing bodies of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) and its Protocol adopted a resolution on the regulation of ocean fertilization, in which the Contracting Parties declared that ocean fertilization activities other than legitimate scientific research should not be allowed. Work is continuing in the context of the London Convention and its Protocol to develop a regulatory mechanism, as referred to in decision IX/16 C.

To understand the potential adverse impacts of ocean fertilization on marine biodiversity, there is a need for further work to enhance our knowledge and modelling of ocean biogeochemical processes and research to advance our understanding of marine ecosystem dynamics and the role of the ocean in the global carbon cycle.

Ocean fertilization, whether carried out as legitimate scientific research or on a commercial basis, presents serious challenges for the Convention on Biological Diversity, a fundamental objective of which is to ensure that activities conducted on, in or under the oceans do not negatively impact marine biodiversity. Ocean fertilization is one of many recently proposed or emerging uses of the oceans that require an integrated, concerted response from stakeholders, relevant international bodies and organizations to ensure that our oceans and their resources are protected, conserved and managed sustainably.

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[1] The present issue paper is based on *Scientific Synthesis of the Impacts of Ocean Fertilization on Marine Biodiversity*, Technical Series No. 45, published by the Secretariat of the Convention on Biological Diversity, 2009 (www.cbd.int/ts).

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