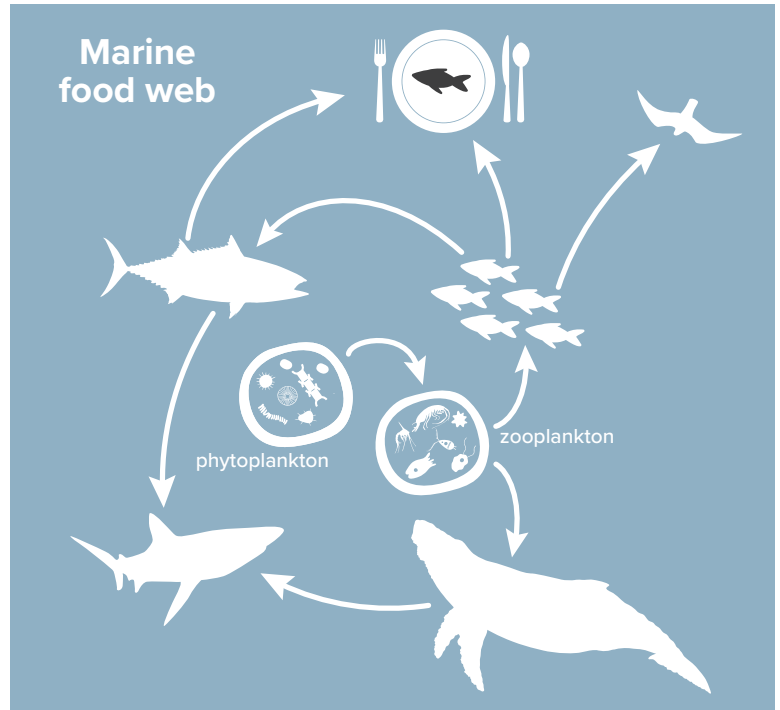


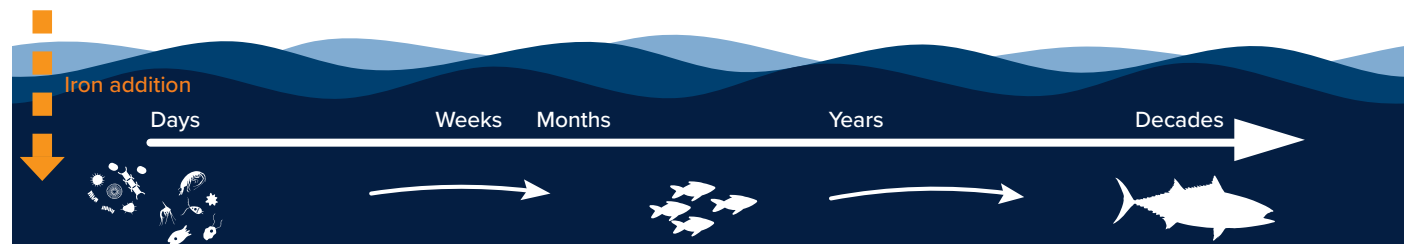
What is ocean iron fertilization?

Ocean iron fertilization (OIF) is the addition of iron to the ocean to stimulate growth of microscopic algae called phytoplankton, spurring the uptake of atmospheric carbon dioxide. Iron is a naturally occurring nutrient essential for the growth and health of phytoplankton, which form the base of marine food webs. Natural sources of iron include dust from land, ash from volcanic eruptions and wildfires, and upwelling of deep ocean waters.

In large parts of the ocean, including the offshore North Pacific, phytoplankton growth is limited by low levels of iron, so small additions can stimulate rapid growth. As phytoplankton grow, they deplete carbon dioxide in the surrounding seawater and cause the ocean to take up more of the greenhouse gas from the atmosphere. When they die, they sink to the deep ocean, taking the heat-trapping carbon in their cells with them, thus keeping it out of the atmosphere for long periods of time.



In the 1990s and 2000s, scientists conducted 13 field experiments in which they fertilized a patch of iron-limited ocean waters to observe the stimulated growth. These experiments mimicked natural processes but were not designed to measure carbon dioxide removal or associated environmental impacts. As a result, a new generation of experiments like ExOIS's proposed North Pacific Carbon Study would be needed to assess both the risks and effectiveness of OIF as a viable marine carbon dioxide removal (mCDR) strategy.



How could OIF impact fisheries?

What we know

- 1. Added iron increases phytoplankton abundance.** Many lab and field studies have shown that added iron stimulates phytoplankton growth. Typically, large phytoplankton called diatoms, which are important for marine food webs have the largest growth response.
- 2. Natural iron inputs have been linked to phytoplankton productivity.** Some natural sources of iron like dust storms, volcanic eruptions, and other land-based inputs have been linked to increased phytoplankton productivity, the base of the marine food web.
- 3. Food webs respond to iron inputs.** Field studies^a on iron enrichment observed changes in the zooplankton, which feed on phytoplankton and are subsequently consumed by animals like small pelagic fish. Experiments also have shown vertical transport of plankton and associated carbon to deeper waters.

How could OIF impact fisheries?

What we don't know

- 1. Do increases in phytoplankton lead directly to more fish biomass?** It's difficult to determine if OIF would lead directly to increased fish biomass because of the mismatch in time and space between field experiments and fishery responses, but it is a goal of ExOIS to inform models that can begin addressing this question.
- 2. Would changes in plankton composition affect fish?** OIF tends to favor the growth of diatoms at the base of the food web, and basic marine biology suggests that this could increase fish biomass. But there are uncertainties about the impacts this would have on nutrition and ecosystem balance, and which fish species could benefit the most.
- 3. Could there be unintended environmental impacts that affect fisheries?** Some have suggested that OIF could unintentionally deplete oxygen, generate non-CO₂ greenhouse gases, stimulate the growth of harmful algae that produce toxins, or deplete nutrients in downstream environments. Past field experiments did not observe large or long-lasting effects like these, but the ExOIS experimental plan includes careful monitoring and go/no-go decision points in the event of unintended environmental impacts.

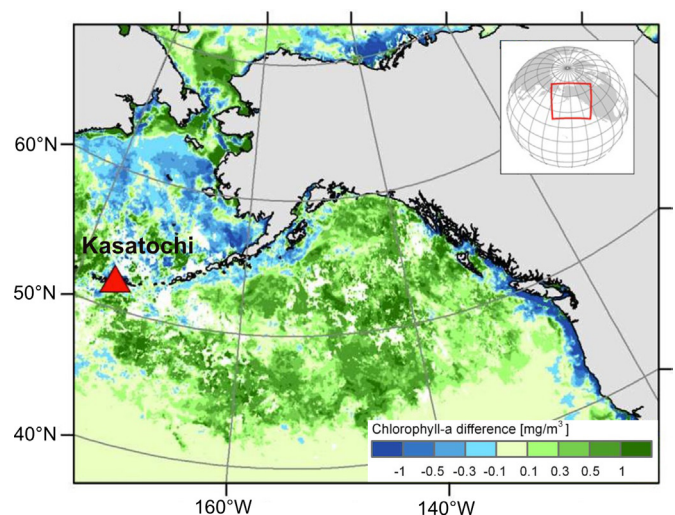
Case study: Kasatochi volcanic eruption

In August 2008, the Kasatochi volcanic eruption in the Aleutian Islands deposited iron-rich ash across a large region of the North Pacific. This input increased surface iron concentrations and triggered a phytoplankton bloom dominated by diatoms over more than 2,000,000 km²^b. This area is more than 2000 times larger with higher increases in surface iron concentration than ExOIS's proposed North Pacific Carbon Study.

Following the eruption, the increase in large diatoms supported zooplankton such as copepods, a key food source for juvenile sockeye salmon^c. Some suggested that this boost at the base of the food web contributed to a record sockeye salmon return to the Fraser River in British Columbia two years later^{b,d}, but this speculation could not be proven. Other analyses found that sockeye salmon survival rates were typical in 2010 compared to historical averages. Strong yields were largely explained by high parent abundance, and nearby salmon populations did not show similar increases^e.

Fisheries and the North Pacific Carbon Study

Potential connections between OIF and fisheries will be important for future decision-making on mCDR regulation and scaling. The experiments in the North Pacific Carbon Study are not designed to enhance fish production and are too small to impact fisheries, but they will monitor key environmental indicators to inform models for better forecasting of fisheries impacts.



Enhanced chlorophyll a (a proxy for phytoplankton growth) in August 2008 following the Kasatochi volcanic eruption compared to 2002-2007. Iron-rich ash stimulated phytoplankton growth. Adapted from Langmann et al. (2010) and Lindenthal et al. (2013).

The Kasatochi eruption demonstrated that iron inputs can stimulate large ecosystem responses and increases in food sources for fish, but it does not provide clear evidence that these changes translate to increased fish production.



References: ^aYoon et al. (2018), *Biogeosciences*; ^bOlgun et al. (2013), *Marine Ecological Progress Series*; ^cHamme et al., (2010), *Geophysical Research Letters*; ^dParsons & Whitney (2012), *Fisheries Oceanography*; ^eMcKinnell (2013), *Fisheries Oceanography*