EXPLORING OCEAN IRON SOLUTIONS

Ocean iron fertilization and algae blooms

Recognizing concerns & monitoring needs

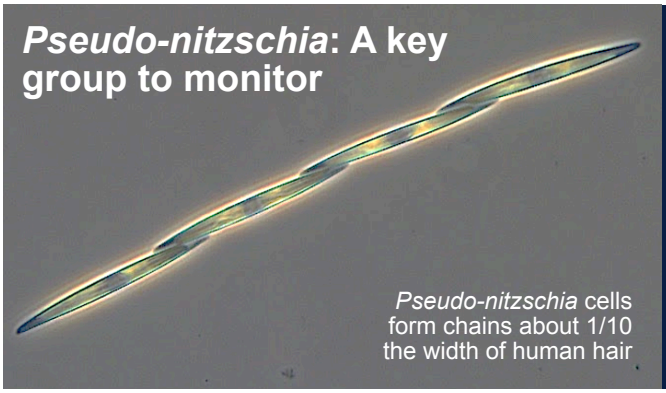
What is a harmful algal bloom?

Phytoplankton are microscopic algae that form the base of marine food webs. Blooms of phytoplankton are natural, often seasonal events that occur in both coastal and offshore waters. They support marine ecosystems and fisheries, as well as the lives and livelihoods that depend on them. Stimulating the growth of algae is a fundamental goal of ocean iron fertilization.

Some phytoplankton species also produce toxins that adversely affect ocean and human health. These events are known as harmful algal blooms (HABs). HAB-forming species found in the North Pacific include diatoms in the *Pseudo-nitzschia* genus and dinoflagellates such as *Alexandrium* and *Dinophysis*.

However, not all algal blooms are harmful, and the presence of HAB species does not always mean toxins are produced. In addition, many HAB species only produce toxins under specific environmental conditions, for reasons that are still not fully understood.

Pseudo-nitzschia: A key group to monitor



Pseudo-nitzschia cells form chains about 1/10 the width of human hair

- *Pseudo-nitzschia* are diatoms commonly found in offshore High-Nutrient, Low-Chlorophyll (HNLC) regions
- Of the roughly 60 known *Pseudo-nitzschia* species, about half are known to produce the neurotoxin domoic acid
- Domoic acid may pose risks to wildlife, fisheries, and human health
- Toxin-producing species do not always produce toxin
- Toxin production appears to depend on environmental conditions and physiological state

Ecosystem impacts and management

Toxins such as domoic acid can bioaccumulate in organisms over time and move through marine food webs. Because shellfish filter large volumes of seawater, they are especially prone to bioaccumulating toxins, creating a path for high concentrations to enter marine food webs.

Coastal HAB monitoring programs typically look at two measurements:

- HAB species abundance (cell counts)
- Toxin concentration in shellfish tissue

When toxin concentrations exceed regulatory thresholds, fisheries are temporarily closed until toxin levels decline. Live shellfish naturally purge domoic acid over time and can eventually be harvested.

HAB monitoring typically focuses on shellfish, which are filter feeders. Pelagic fish can accumulate domoic acid but usually to a lesser degree.

Typical coastal monitoring and management process

Weekly/monthly cell counts of HAB species in seawater

↓ Threshold surpassed

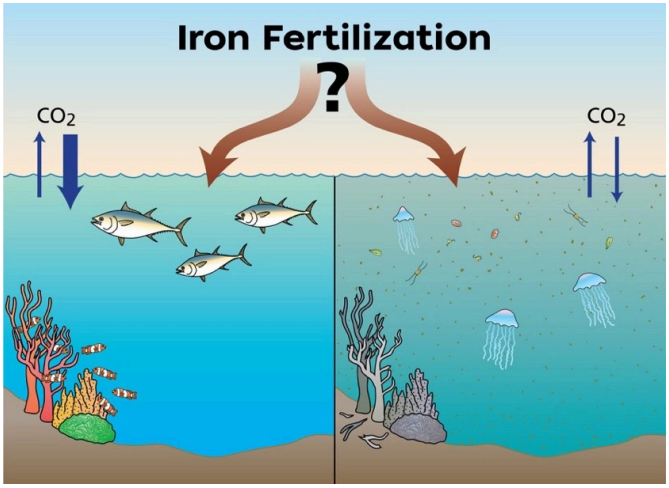
Testing of toxin in shellfish or crabs

↓ Threshold surpassed

Fisheries harvest closure until toxins return below threshold

HABs & Ocean Iron Fertilization (OIF)

Studies have shown that iron additions (natural or human-caused) in HNLC regions primarily stimulate the growth of diatoms, including some offshore *Pseudo-nitzschia* species. This makes HAB monitoring an important component of OIF research. Although *Pseudo-nitzschia* are common members of offshore phytoplankton communities, domoic acid is rarely measured offshore because HAB monitoring efforts are largely focused on coastal waters. **As a result, baseline data on offshore HAB communities and toxins remain limited, representing an important knowledge gap that targeted OIF research can help address.** Offshore study areas also generally lack shellfish populations, which are often the primary pathway for toxin accumulation to levels of concern in marine food webs. Targeted monitoring and future field research can help to better constrain these uncertainties.



What did past OIF field studies show?

None of the 13 past OIF field experiments were designed to evaluate HAB impacts, and only a small number of samples were collected to measure toxins in the environment. Although toxin sampling was limited, available observations did not detect sustained toxic blooms or report impacts on fish or higher trophic levels.

Key findings from past studies:

- *Pseudo-nitzschia* are common offshore diatoms and are well adapted to iron-limited environments.
- *Pseudo-nitzschia* abundance increased in approximately half of OIF experiments.
- Only about one-quarter of experiments attempted to measure domoic acid, and it was detected retroactively in only two studies.
- The few positive measurements were not compared to nearby unfertilized waters[1], and toxin production per cell was not elevated with added iron[2].

References: [1] Silver et al. (2010), *PNAS*. [2] Trick et al. (2010), *PNAS*.

HAB monitoring in the North Pacific Carbon Study (NPCS)

The NPCS includes HAB monitoring protocols designed to address key knowledge gaps and provide early warning signs of toxic bloom development. Frequent samples will be collected inside the iron fertilized area and will be directly compared to samples from nearby unfertilized waters. Although *Pseudo-nitzschia* has been the primary HAB focus of previous OIF studies, additional toxin-producing HAB taxa will also be monitored to provide broader ecological context. Monitoring will include:

- **Cell abundance measurements** for *Pseudo-nitzschia* and selected dinoflagellate HAB species using microscopy and/or imaging tools.
- **Real-time toxin measurements** for domoic acid and two dinoflagellate toxins (saxitoxin and okadaic acid) using onboard assays.
- **Toxin sample collection for laboratory validation**, including mass spectrometry measurements to validate real-time shipboard assays.
- **Genetic analyses of phytoplankton communities** to identify HAB species.

Evidence to date suggests low risk of sustained toxic blooms from research scale OIF. The NPCS monitoring program is designed to detect ecological responses and help reduce uncertainties that remain.

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