Fertilizing for Fish – Fraud or the Future?

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Summary:

One of the most contentious discussion issues that blends scientists with policymakers revolves around the question: "Can we geoengineer the ocean to alleviate climate change?" This case introduces students to the process of enriching oceanic regions (specifically High Nutrient, Low Chlorophyll; HNLC regions) with iron to alleviate trace metal limitation of phytoplankton primary productivity – potentially leading to more productive fisheries and carbon sequestration into the ocean depths. The case exposes students to the science behind ocean iron fertilization (**OIF**) efforts – knowledge gained from thirteen (13) OIF experiments conducted by scientists since 1993, but equally important – the controversies associated with OIF efforts to date.

Specifically whether OIF will: 1) serve as an effective climate change mitigation mechanism to enhance the sequestration of anthropogenic carbon dioxide into the deep sea, 2) increase the productivity of the base of the marine food chain – thus possibly leading to enhancement of fish yields, and/or 3) cause deleterious impacts on ocean ecology such as enhancement of microalgae that produce toxins leading to Harmful Algal Blooms (HABs).

The case is designed to introduce the basic concepts of biological oceanography to students with limited formal exposure to the processes of the surface ocean. To achieve this, we provide them with a debate and decision-making exercise that evokes discussion on the level of our biological, chemical and ecological knowledge of marine systems, our ability to modify the environment to ameliorate elevated concentrations of carbon dioxide (CO_2) in the atmosphere, and a discussion of the ethics and responsibilities of scientists that propose or conduct large-scale ecological manipulations of the oceans.

This case is appropriate for upper-division undergraduates or beginning graduate students; it is particularly useful in interdisciplinary problem solving courses, and has been used in a case-based 'Sustainable Environmental Health' course in the Master of Public Health (MPH) program

at Western University, and in a course entitled, 'Foundations in Global Change in Urbanized Coasts and Estuaries' in the Master of Science program in Interdisciplinary Marine & Estuarine Science (IMES) at San Francisco State University.

Acknowledgements:

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Resource Files:

Student Handout - the Case
Teaching Note - Instructor Guide

Estimated Time Frame:

Several class periods. The case is interwoven with Socratic method discussions and mini-lectures to ensure all students reach the required teaching plateau before continuing.

Socio-Environmental Synthesis Learning Goals:

- Systems Thinking
- Understand the structure & behavior of socio-environmental systems
- Integrative Research

Scientific Learning Objectives: Students should be able to:

- Follow the path and state (organic vs. inorganic) carbon from the atmosphere to the ocean and back to the atmosphere.
- Understand the environmental factors that regulate the rates of carbon processing in the surface ocean.
- Relate the energy entering the surface ocean with the structure of the food chain.
- Establish the "drivers" of primary production, the "source" of the drivers, and the "consequence" the drivers.

Pedagogical Learning Objectives: In this case, students will develop a strong appreciation with respect to:

- How they (as individual students) learn the scientific process.
- The importance of individual thought as well as the value of team (collaborative) learning.
- The differences in learning responsibilities when managing a project to its realization?
- The importance of competencies in developing a career – professionalism, communication, and collaboration predominate.
- The essential role of a scientist as the gatekeeper of knowledge and the communicator of decisions.

Key Words: Iron fertilization, evidence-based science decision, fisheries, climate change solutions, commercial-science-community relations, gatekeeping, professionalism, Haida-Gwaii.

Classroom Testing: This case has been tested in an interdisciplinary Master of Science graduate course in the Fall of 2019 at the Estuary & Ocean Science Center, San Francisco State University. A variation of this case was used in a 'Sustainable Environmental Health' course in the Master of Public Health program, and on three occasions in an undergraduate environmental science course at Western University, London Ontario, Canada. We have benefitted from these early experiences, and apologize to the students for using them as teaching "guinea pigs" in our endeavor to build creativity and passion into the teaching curriculum.

Student Handout

Fertilizing for Fish – Fraud or the Future?

This case is authored by Dr. William Cochlan (Estuarine & Ocean Science Center, San Francisco State University) and Dr. Charles Trick (Department of Biology, University of Saskatchewan). This case was created as part of the SESYNC case workshop and is being offered as a class-tested exercise on social-ecosystem change and the responsibility of scientists – in this case ocean scientists. Users of this material must acknowledge the sources of the material and the funders of the case writing education program: "This work was supported by the National Socio-Environmental Synthesis Center (SESYNC)."

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Katie reflected deeply as the Pacific Coastal Airways flight circled Masset[1], British Columbia in an attempt to land in the coastal fog. Living in Haida Gwaii[2] was just what was needed for Katie to escape the turmoil of her recent life at San Francisco State University (SFSU). No one but Katie fully understood her need to be in an area where she wouldn't constantly feel challenged by questions, concerns and demands of the changing global environmental landscape. She had chosen graduate studies at SFSU with the belief that she would have an Ed Rickett's style of life – where each day she would walk down to the seashore with a bucket and grab some marine creatures, spending long days in the lab learning their secrets and mysteries. That was the life she learned from her favorite book "*The Log from the Sea of Cortez*." But, as she learned at the Estuary & Ocean Science Center (EOS Center), there's no money for that type of life. The future of marine sciences comes from decision making and actions – and she was overwhelmed and needed to escape.

Now that she had just completed her Master's degree from SFSU, Katie has accepted two, part-time positions of "Greenskeeper" at Canada's most western golf course (Dixon Entrance) and Biology Interpreter at the Dixon Entrance Maritime Museum[3] ["The grandest museum in town – and only five bucks for admission"]. This was not her parent's dream, but for Katie a very remarkable marine adventure. And with a calmer daily pace, potentially a great post-graduate career choice. She even brought her "Ed Ricketts" bucket and looked forward to filling it with marine life.

As the new "biologist" in town, Katie garnered considerable attention. The town was energized by the claim of some mainland scientists that they could fertilize the ocean with iron, and bring back the "missing" salmon fisheries[4,5,6]; revitalize the sea into something productive again! As one member of the tribal council (Old Massett Village Council of Haida Gwaii) shared with her while she was sorting through some old biology displays at the museum – "It's simple, they just add fertilizer, the algae (phytoplankton) grow, the fish eat the algae, the fish get fat and return to our streams to spawn. It's just so simple – what could go wrong?" Katie just looked carefully at the Elder – was she supposed to say something, or was he just sharing a biology story with her?

It seems this story was the talk of the town. "You're a greenskeeper. You know you can fertilize the grass and it will grow so you can trim it to just the right height. Isn't that what you do?" Katie responds that it is not that simple. If she adds the wrong fertilizer or adds it at the wrong time, the natural turfgrasses will not grow, but will be replaced with smooth crabgrass and signalgrass. These look like grasses but are serious persistent weeds that become rough and dry – patches that golfers hate, and groundskeepers hate even more since they have an expansive root system and can seemingly sprout anywhere.

Katie found herself being swept up daily in the discussion of the community. She knew from her studies that a few years after the 2008 eruption of Mt. Kasatoshi there was a massive sockeye salmon run in the Pacific Northwest[8,10,11,12]; could that be the same thing, but with humankind enriching the seas to ensure more phytoplankton and hence more food for fish? "It only costs around $2.5 million dollars, and they guarantee that the salmon will return!" was the most repeated statement she heard around this First Nation's village. "Russ[7] is a good guy. He married into the Haida community. If we can't trust him who can we trust?" And as those scientists from down south kept saying, 'Fish is plankton, and plankton need iron. The more iron, the more fish."

After a few weeks, Katie could no longer sleep soundly. Her new hometown was awash in stress and anguish; it was splitting the town; into warring factions. There was so much turmoil and argument about spending all this money to bring the salmon home. Was this a real sound plan to save the community and by extension their salmon fisheries and Haida culture? Or, was it an ill-conceived plan to gather a few million dollars prior to the fish returning naturally on their own? But most important, there was a deep-down responsibility for Katie to use her SFSU skills to move this problem from emotional jibber jabber to evidence-based decision making. The purpose for her working so hard at university has now been brought to the surface. Her inner soul kept repeating a line from her comic book reading past:

"… remember that, in a world of ordinary mortals, you are a Wonder Woman."

Directions for the Learning Teams: Place yourself into the situation of Katie. Start with these questions. It is unlikely that you will have the complete answer to any of these questions at this stage. As the exercise progresses your confidence in achieving an answer will improve. Think of these as guideposts to discussion in your Learning Teams.

1. Katie needs to contribute to the island discussion. It is part of the competencies that have been instilled by her graduate studies: Professionalism, Intellectualism, Communication, Leadership and Gatekeeper.
2. Katie has vowed to contribute evidence-based, decision-making to the community.
3. Katie needs to know whether following an actual iron fertilization experiment is the only way to obtain evidence-based environmental decisions?
4. What data or information does Katie need to collect now to make an informed decision?
5. What information does Katie need to assess and communicate to the community?
6. How should Katie go about expressing her evidence-based decisions?

References:

Selected Web links (from superscripts)

1. Massett, http://massetbc.com
2. Haida Gwaii Trip Planner: https://www.gohaidagwaii.ca
3. Dixon Entrance Maritime Museum: https://www.gohaidagwaii.ca/museums-heritage-centre/
4. Haida Salmon Restoration Company (HSRC): website no longer available.
5. HSRC reborn as 'Oceaneos': http://oceaneos.org/company/
6. Canadian Broadcasting Co – 'Oceaneos plans for Chile': http://www.cbc.ca/news/canada/british-columbia/haida-gwaii-ocean-fertalizing-chile-1.3550783
7. Scientific American: - Can Controversial Ocean Iron Fertilization Save Salmon? http://www.scientificamerican.com/article/fertilizing-ocean-with-iron-to-save-salmon-and-earn-money/
8. Globe and Mail Newspaper Article: Sept 12, 2013; updated May 11, 2018 https://www.theglobeandmail.com/news/british-columbia/pink-salmon-reaching-fraser-river-in-massive-numbers/article14298697/
9. WHOI Ocean Iron Fertilization Web Informational Web Resources: https://web.whoi.edu/ocb-fert/ EXCELLENT RESOURCE
10. ETC Group : Case Study on Ocean Fertilization near Haida Gwaii: COMPREHENSIVE web links, including background, the science, the controversy, and the press coverage: http://www.etcgroup.org/content/case-study-ocean-fertilization-near-haida-gwaii

Peer-reviewed publications:

11. Parsons, T.R.P. and F.A. Whitney. 2012. Opinion: Did volcanic ash from Mt. Kasatoshi in 2008 contribute to a phenomenal increase in Fraser River sockeye salmon (*Oncohynchus nerka*) in 2010? Fish. Oceanogr. 21: 374-377.

12. McKinnell, S. 2013. Short Communication: Challenges for the Kasatoshi volcano hypothesis as the causeof a large return of sockeye salmon (*Oncorhynchus nerka*) to the Fraser River in 2010. Fish. Oceanogr. 22: 337-344.

13: Langmann, B., Zaksek, K. Hort, M. and S. Duggen. 2010. Volcanic ash as fertilizer for the surface ocean. Atmos. Chem. Phys. 10: 3,891–3,899. www.atmos-chem-phys.net/10/3891/2010/

14. Batten, S.D., and J.F.R. Gowe. 2014. Did the iron fertilization near Haida Gwaii in 2012 affect the pelagic lower trophic level ecosystem? J. Plankton Res. 36: 925-932. https://academic.oup.com/plankt/article/36/4/925/2963103

15. Buesseler, K.O., *et al.* 2008. Ocean Iron Fertilization — Moving Forward in a Sea of Uncertainty. Science 319: 10.1126/science.1154305

Background:

This is a real case based on activities by a founder and former chief executive of Planktos, Inc., Russell George, (http://www.planktos.com). This is one of several companies that Mr. George has created, and it seems to be alive and well, in spite of media reports (https://www.nature.com/articles/news.2008.604).

The expertise and promises of Planktos are presented in the company website and may have a bearing on the classroom discussion. There are other 'green fertilization' companies proposing to make money through the ocean seeding of the ocean (e.g., Oceaneos; http://oceaneos.org), but the activities of Russ George and the Haida Salmon Restoration Company (HSRC) are the best known and the Haida Gwaii experiments conducted in 2012 come with a full array of comments and discussion from "greatest idea since slide bread" to "this will kill the earth."

The case challenges the key competencies of students and scientists in general: professionalism, intellectual enquiry, communication, and gatekeeping (i.e., promoting the responsible use scientific knowledge).

Here we will consider the scientific foundation of the proposal that Mr. George sold to the Haida Salmon Restoration Corporation and the Haida Gwaii First Nations community (Old Masset Economic Development Corporation). Be aware that there are many commercial names in this narrative (Planktos, Haida Salmon Restoration Corporation, Ocean Pastures, Haida Climate, etc.), but the common link is Mr. George and his economic promises of "ocean seeding."

Specific Problem:

There are several ways to consider this narrative. All are important, and all will be needed to achieve a final, individual understanding. The word 'individual' is key. There is no right answer even when we share the same class discussion and data set. This leads us to wonder if perhaps we all have a unique location on the science-community-economics spectrum.

We start with the scientific promise – does the promise make sense given the foundational knowledge we bring into the narrative?

What information is provided to the community? What level of knowledge and certainty does the scientist have to provide the community?

What sort of experience do we require our leaders to have in order to be credible? Do scientist leaders need a PhD? Russ George claimed to have a PhD from the California Institute of Technology (Ranked #1 or #2 of the technological universities in the world). Recent reports state that he attended a mid-western university for a couple years without graduating. Does that matter or are good ideas just good ideas no matter the pedigree?

Is "ocean seeding" a fancy form of ocean polluting or an advancement on environmental progression?

Instructor Guide

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Introduction:

The case entitled, 'Fishing for Fish – Fraud or the Future,' (see student handout) is centered around employing a 'real world' case of geoengineering in a geographically remote and culturally distinct community.

The basis of the case is to put students in the active role of a protagonist (named Katie here) asked to provide scientific advice for solving a real world environmental problem - the scarcity of returning salmon.

The solution, as proposed by the Haida Salmon Restoration Company (HSRC) - a private for-profit 'scientific' company, is to alleviate iron limitation in the waters of the northeast subarctic Pacific Ocean off the islands of Haida Gwaii thereby increasing phytoplankton abundance and resulting in an enhancement of salmon returns. The HSRC solution promised to revive depleted local salmon runs, while providing a meaningful response to the threat of anthropogenic climate change.

The problem and proposed geoengineering solution have substantial cultural, socio- and environmental implications, and the 'solution' was actually conducted in 2012 with unresolved results. However, the case takes advantage of the 'flux capacitor' allowing students to be transported back in time when the community was still debating whether iron fertilization of a Haida Eddy would result in increased fish returns for the indigenous people of this First Nations community, with the added benefit of reducing greenhouse gases by sequestering carbon into the deep ocean sediments - a 'win-win.' Additionally, the sale of carbon credits through carbon sequestration would provide a significant economic benefit to an economically-challenged community.

Alternatively, the case can be used to determine whether the community should invest in a second iron fertilization effort in the year following the first attempt - an attempt which resulted in worldwide criticism by many environmental organizations, but a mixed community response – the project was either a success (http://www.oldmassettvillagecouncil.com/new-page) or a grand manipulation (https://www.bccourts.ca/jdb-txt/ca/16/00/2016BCCA0012.htm).

Immediate Issues for presenting this case to the students:

- Students have no idea how to decipher this issue or define the goal of the project.
- Most teaching is 'lecture-based' and students are only prepared to be told the answer. Only a few students, are willing to learn how to 'create' an answer.
- Students are only emotionally prepared to work independently.
- There is an absolute need that the students do the readings and discuss the readings in their groups (learning teams) prior to class.

These fears need to be broken if this is a student's <u>first</u> case study. (see 'Simple Food Chain' below)

Basic Science Issues:

1. Anthropogenically-produced carbon dioxide (CO_2) is released into the atmosphere. We measure it without realizing that a significant portion is being partitioned into the surface ocean.
   [At this stage CO_2 is considered an environmental contaminant]
2. CO_2 in the surface ocean serves as a nutrient for photosynthetic micro-organisms (marine phytoplankton).
   [At this stage CO_2 is considered an elemental nutrient]
3. Provided that the other nutrients for the growth of phytoplankton are also available in abundance, the phytoplankton can consume the CO_2 and eventually transfer the carbon from the atmosphere into fish (here there is serious controversy on this process– and key to the discussion.
   [At this stage CO_2 is considered an environmental fertilizer]
4. Can scientists direct the CO_2 into fish and/or sequestered it into oceanic sediments?
   [At this stage CO_2 is considered a venture capitalist enterprise]

It is important to remember that these are the instructions to the students. We refer back to the list constantly

Directions for the Learning Teams: - Place yourself into the situation of Katie. Start with these questions:

1. Katie needs to contribute to the island discussion. It is part of the competencies that have been instilled by her graduate studies: Professionalism, Intellectualism, Communication, Leadership and Gatekeeper.
2. Katie has vowed to contribute evidence-based, decision-making to the community.
3. Katie needs to know whether following an actual iron fertilization experiment is the only way to obtain evidence-based environmental decisions?
4. What data or information does Katie need <u>to collect</u> now to make an informed decision?
5. What information does Katie need <u>to assess</u> and communicate to the community?
6. How should Katie go about expressing her evidence-based decisions?"

CLASSROOM MANAGEMENT (Each class is 2-3 hours)

This is best done when students have ample wipe boards or flip charts to diagram their ideas.

Day 0: Prior to first class - Student Preparation

1. Students are instructed to read one 'opinion' scientific article, and at least one of two scientific research articles in preparation for the first class.

   The 'opinion' article suggests that Nature, as iron-laden volcanic ash from the 2008 eruption of Mt. Kasatoishi in southwestern Alaska, contributed to a massive increase in sockeye returns to the Fraser River in 2010: Parsons, T.R.P. and F.A. Whitney. (2012).

   The two scientific articles provide the scientific evidence that support the association of volcanic ash with increased phytoplankton biomass in the northeastern Pacific Ocean in 2008: Hamme et al. (2010) and Langmann et al. (2010)
2. Purpose of these readings is to stimulate student's belief that Nature (as volcanic ash) can solve the problem, and if humankind can simulate Nature, then what's the harm with considering this 'natural' solution?

Day 1: Preparing students for the course and the case

As this case is usually integrated into a lecture-style curriculum, it is critical to re-set the pedagogical approach from a basic lecturing format to an active learning-team exercise, driven by the Socratic Method. The Socratic Method provides a guided tour of the subject or problem, where information is exchanged from the student to the class through the use of probing questions by the faculty member. Traditionally, questions/answers lead to further questions/answers and eventually lead to a self-realization of the solutions.

We believe that this is the most effective method to present this and other case studies.

It is also our belief that students should work in defined small groups, staying in the group for the entire case analysis. These groups, referred to as 'learning teams,' should be in the range of 3-5 students to ensure there are enough individuals for productive dialogues, but not so many such that students either avoid or feel discouraged from active participation.

First class is structured as follows: The students come prepared (through their readings) with an understanding that there may be a link between volcanic ash, and increased chlorophyll and fish. We use this lecture to show them the power of discussing, the strength in diagraming ideas and relationships, and the importance of being prepared by doing the pre-class readings.

1. <u>Socratic Approach.</u> Very brief class discussion about hypothesis elimination - by drawing out ideas and underlying assumptions, becoming creative and learning deeper; most importantly considering other viewports (interdisciplinary approach).

2. <u>Individual activity</u>. Students are then given time in class to diagram their ideas on the **linkages of a marine food chain** – emphasizing the connections between volcanic ash and fish.

   The diagrams they will create are similar to an "influence diagram" and will serve as the start of the diagram that may include the societal links as the discussion progresses. Influence diagrams are concise graphic representations of a decision situation. There are several approaches to creating concept diagrams, but we encourage non-structured idea maps.

3. <u>Team building exercise</u>. At this point the class members are separated into learning teams (everyone has an approach to this, but we rely on an artificially random approach: students sitting together are not allowed to be in the same group – usually have group experience.)

   Still using the Socratic Method, we discuss with the students (now organized in their learning teams) what is important and what is missing in their individual food chain ideas -, what is the full story? The students are then given a chance to share ideas with their learning teams and **create a single learning team food chain** that represents the connection of volcanic ash and fish. They will compare the complexity of their individual food chain and the group food chain with regards to scale, complexity, uniqueness. The value of team learning is often revealed in this exercise.

4. <u>Presentations</u>. The groups then present their food chain to the class (in larger classes the issues will be repeated so we choose 3-4 of the groups to present). Still using the Socratic Method of questioning we evaluate as a class the construction of the food chain - are there aspects missing, what do the arrows connecting to organism mean? What units might they have? Is the something 'unusual' with the food chain?

Following class discussion with the food chains, students are provided with hard copies of the actual case entitled, ***Fertilizing for Fish – Fraud or the Future?*** Following a reading of the case, the Instructor then poses questions for discussion. These may include:

- Understanding the waters and location of the Haida Gwaii (formerly known as the Queen Charlotte Islands.) Why here and not in some other archipelago, such as the islands of Hawai'i? (structure of eddies, iron-limited waters, etc.) What's the association between Haida and salmon - the significance of salmon as their "life blood?" Why conduct iron fertilization here and not somewhere else?
- Basic introduction of the concepts of nutrient limitation in the sea.
- Is fertilizing a golf course the same as fertilizing the ocean? Is iron a nutrient; does it work the same way as macronutrients like C, N, P and Si?
- How strong is the linear food chain? (does Increase Nutrient Supply-> More Plankton (are all types salmon food?) > More Salmon Returns (abundance vs. fatter salmon)?
- Watching from space - remote sensing of chlorophyll fluorescence. If one sees the phytoplankton bloom, is the food chain connected? Would a big bloom mean the plankton are not being eaten or simply that phytoplankton grow fast - always staying ahead of their predators?
- How do the salmon know where the food is? Who eats phytoplankton - salmon?
- Does salmon life history need to be considered?
- Are there legalities involved in oceanic iron enrichment?

The students working in their learning teams have 10-15 minutes to develop an initial short (~ 5 min.) 'coffee-shop' outline of their thoughts on the wisdom of conducting such ocean iron fertilization (OIF) experiments to replenish salmon stocks in Haida Gwaii and/or sequester carbon……..prior to their really knowing the scientific basis and issues, or if such OIF efforts have been conducted previously in the waters off Haida Gwaii or elsewhere in the World.

This talk is intended just for their new colleagues/friends they've made in the Old Massett community; they are being asked an opinion; can they provided an informed one?

Part of the purpose of this exercise is to get students to realize WHAT they need to understand before they can provide an informed scientific opinion, and also that their opinion on a scientific issue is in fact MORE IMPORTANT than the opinions of fellow community members. Students need to realize that their opinion should be of greater value since this is their area of expertise, but that it is their professional responsibility to convey this information in a clear and respectful manner to others, in particular to those less informed on the complexities of the issue. There is also the consideration of cultural sensitivity in speaking with members of a First Nations community that have been largely marginalized economically and socially by the historical, Euro-Canadian colonial violation of the Haida way of life.

Class ends after each group presents their short coffee-shop talks with the instructor asking probing questions for them to consider, but not necessarily attempting to answer them here and now.

Assignment No. 1: Students are instructed to prepare as a learning team a listing of the scientific knowledge that they are currently lacking and what is needed for them (as Katie) to understand before they can provide an informed recommendation to the Old Massett community. Essentially a listing of what **KATIE NEEDS TO KNOW.**

This assignment (1-2 pages) of 'must-knows' will set the stage for instruction and discussion over the following 2 4 days of instruction.

Days 2 & 3: Understanding the case; the scientific basis behind the HSRC Solution – "more iron - more phytoplankton - more fish" hypothesis.

Preparation In preparation for day 2, students are provided with more on-line resources to understand the basics of iron limitation and the controversy surrounding when such an iron-fertilization was actually conducted in a Haida Eddy off Haida Gwaii (namely the ETC Group News Release (from 17 Oct. 2012)

Students are also provided with McKinnell's (2013) 'Short Communication' which disputes the relationship between volcanic dust and increased sockeye salmon returns. It is expected that students' thoughts on the proposed scheme will change significantly from those developed after initially reading Parsons and Whitney (2012).

Students are instructed to start familiarizing themselves with the actual iron enrichment experiment conducted off Haida Gwaii, and come prepared to discuss what the learning team needs to know ('must-knows') before they can provide Katie's evidence-based opinion on the merits of conducting such an iron-enrichment experiment to increase salmon returns to the First Nations community of Old Massett on the northern island of Haida Gwaii.

In other words, what scientific knowledge is currently lacking to provide an informed recommendation to the Community?

Days 2 & 3 Classroom Activities

At the beginning of Day 2, students transfer their bullet points of 'must-knows' to large sticky notes on a LARGE bare bones FISHBONE diagram (a.k.a. Ishikawa diagram), with 'iron added' at one end - the tail, and 'more salmon returns' at the other end - the head.

Instructor (with active student participation) helps to arrange the stickies in appropriate groupings along the backbone (akin to a food chain) as well as the ribs which branch off the backbone to identify the major abiotic and biotic factors influencing the potential process at various trophic levels. This active exercise is performed on large white boards or open wall space surfaces, and is designed to facilitate discussion on the topics that students feel they must understand before providing advice to the community over the merits of alleviating iron limitation in the sea to improve salmon returns.

As this is a graduate course, and keeping with the Socratic Method of discussion, classroom mini-lectures may include a large number of topics depending on the overall goal of the course, the background preparation of the students, and the topics they feel they need to know in greater depth. Topics include:

1. Types of Phytoplankton - What is Their Role in the Sea?
    a) Basic taxonomic groupings
    b) Life cycle and phases (lag, exponential and stationary)
2. How do we Measure Phytoplankton Abundance (production) and Rate of Growth (productivity)?

3. Abiotic Factors that Regulate Phytoplankton Growth
    a) Light and Mixing including the Critical Depth Hypothesis,
    b) Nutrient Availability and Herbivore Grazing
4. Concept of Nutrient Limitation and High Nutrient Low Chlorophyll (HNLC) Regions in the Sea
5. Nutrient and Growth Kinetics (Michaelis-Menten vs. Droop)
6. Review of Previous Ocean Iron Fertilization (OIF) experiments
7. Iron as a Limited Nutrient in the Ocean

Day 4: The Village Meeting

In preparation for the final class, student must be prepared to provide scientific guidance to the Old Massett Village Council to determine whether they should consider funding the Haida Salmon Restoration Company to conduct an Ocean Iron Fertilization effort within international waters of the subarctic Pacific Ocean off Haida Gwaii. It should be noted that the council was subject to strong criticism from conservation groups from around the World (including the ETC Group) for funding the first OIF 'experiment' in July 2012, and the Council is now considering whether to fund HSRC to conduct another (second) OIF 'experiment' as a mechanism to restore greater salmon returns to their people, help mitigate climate change, and provide economic relief to the community through the sale of carbon credits. The meeting is taking place in Old Massett on March 6, 2013.

Assignment No. 2: Learning Teams will present group presentations (**5-slide maximum**) to the people of the Village of Old Massett on a possible second OIF experiment proposed by the Haida Salmon Restoration Company (HSRC).

Presentation should provide an understanding of the scientific consequences of such an OIF experiment in an Haida Eddy - especially in terms of:

1) potentially increasing salmon returns and

2) sequestering carbon through iron enrichment.

Learning Teams should express their views based on their understanding of what regulates phytoplankton productivity in HNLC regions, and the relationship between phytoplankton blooms and the size of salmon returns.

Assessment:

As it is difficult to separate the performance of the individual student and the learning teams, each individual is evaluated at the level of the learning team performance. Key is a daily evaluation of the contribution of the learning teams – were they prepared? How organized was their daily product? Was the student a team leader or a follower in the discussion? How complete and appropriate was their presentation to the First Nations Community Council?

Students also are asked to evaluate both their own contribution and their fellow team members on the preparation and conduction of their final presentation.

Clarity, care, professionalism are prime factors in the evaluation of the learning teams' final presentations to the First Nations Community.

Background References:

The association of volcanic ash and the oceanic ecosystem of the Northeast Pacific Ocean

Parsons, T.R.P. and F.A. Whitney. (2012). Opinion: Did volcanic ash from Mt. Kasatoshi in 2008 contribute to a phenomenal increase in Fraser River sockeye salmon (*Oncohynchus nerka*) in 2010? *Fisheries Oceanography* 21: 374-377.

McKinnell, S. (2013). Short Communication: Challenges for the Kasatoshi volcano hypothesis as the cause of a large return of sockeye salmon (*Oncorhynchus nerka*) to the Fraser River in 2010. *Fisheries Oceanography* 22: 337-344.

Langmann, B., Zaksek, K. Hort, M. and S. Duggen. (2010). Volcanic ash as fertilizer for the surface ocean. *Atmos. Chem. Phys.* 10: 3,891-3,899. www.atmos-chem-phys.net/10/3891/2010/

Batten, S.D., and J.F.R. Gowe. (2014). Did the iron fertilization near Haida Gwaii in 2012 affect the pelagic lower trophic level ecosystem? *Journal of Plankton Research* 36: 925-932. https://academic.oup.com/plankt/article/36/4/925/2963103

Ocean Iron Fertilization (OIF) Efforts

There is an extensive listing of peer-reviewed scientific publications of the OIF experiments conducted to date, and the reader is advised to refer to the 'Ocean Fertilization' webpage: https://web.whoi.edu/ocb-fert/ developed by the Ocean Carbon & Biochemistry (OCB) Program group and administered by the Woods Hole Oceanographic Institute (WHOI) for this scientific literature: https://web.whoi.edu/ocb-fert/scientific-literature/ and media reports: https://web.whoi.edu/ocb-fert/media/ that also contain hyperlinks.

We have provided a few salient, and predominantly review articles divided into four subject sections. Students are encouraged to read a minimum of one article of each section.

OIF Synthesis and Foundational Publications

Allsopp, A., D. Santillo, and P. Johnson. (2007). A scientific critique of oceanic iron fertilization as a climate change mitigation strategy. *Greenpeace Research Laboratories Technical Note* 07/2007 September 2007. 32 pp.

Behrenfeld, M.J., *et al.* (1996). Confirmation of iron limitation of phytoplankton photosynthesis in the equatorial Pacific Ocean. *Nature* 383: 508–511.

Boyd, P.W., *et al.* (2008). Implications of large-scale iron fertilization of the oceans. *Marine Ecology Progress Series* 364: 213-218. *A whole issue devoted to OIF experiments*

Boyd, P.W., *et al.* (2007). Mesoscale Iron Enrichment Experiments 1993-2005: Synthesis and Future Directions. Science 315: 612- 617. doi: 10.1126/science.1131669
A succinct synthesis

Coale, K.H., *et al.* (1996). A massive phytoplankton bloom induced by an ecosystem-scale iron fertilization in the equatorial Pacific Ocean. *Nature 383*: 495-501. *The game changer*

deBaar, H.J.W., *et al.* (2005). Synthesis of iron fertilization experiments: From the Iron Age in the Age of Enlightenment. *Journal of Geophysical Research* 110: C09S16, doi:10.1029/2004JC002601, 2005. DOI: 10.1029/2004JC002601.

Martin, J.H., *et al.* (1994). Testing the iron hypothesis in ecosystems of the equatorial Pacific Ocean. *Nature* 371: 123-129. *First OIF!*

Secretariat of the Convention on Biological Diversity. (2009). Scientific Synthesis of the Impacts of Ocean Fertilization on Marine Biodiversity. Montreal, CBD Technical Series No. 45, 53 pp. ISBN: 92-9225-166-X

Smetacek, V., *et al.* (2012). Deep carbon export from a Southern Ocean iron-fertilized diatom bloom. Nature 487: 313-319. DOI:10.1038/nature11229

Yoon, J., *et al.* (2018). Reviews and syntheses: Ocean iron fertilization experiments – past, present, and future looking to a future Korean Iron Fertilization Experiment in the Southern Ocean (KIFES) project. *Biogeosciences* 15: 5,847-5,889. https://doi.org/10.5194/bg-15-5847-2018.

OIF Policy and Opinion

The legalities of conducting OIF efforts in international waters is provided in the "London Convention" available on the International Maritime Organization (IMO) website at: http://www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx
SEARCH: ocean fertilization for full listing of agreements and concerns.

Action Group on Erosion, Technology and Concentration, (ETC Group) website. This Canadian environmental organization provides an extensive compilation of the media reports and controversy surrounding the HSRC OIF effort, and was arguably the lead environmental organization appraising the wisdom of conducting such OIF experiments to revive salmon runs in Haida Gwaii. Their website can be found at: http://www.etcgroup.org/content/case-study-ocean-fertilization-near-haida-gwaii

Buesseler, K.O. *et al.* (2008). Ocean Iron Fertilization: Moving forward in a sea of uncertainty. *Science* 319: 162.

Chisholm, P. G. Falkowski, and J. Cullen. (2001). Dis-crediting ocean fertilization. *Science* 294: 309-310.

Strong, A.L., S. Chisholm, C. Miller, and J. Cullen. (2009). Opinion: Ocean fertilization: time to move on. *Nature* 461: 347-348.

Biello, D. (2012). Can controversial ocean iron fertilization save salmon? *Scientific American* http://www.scientificamerican.com/article/fertilizing-ocean-with-iron-to-save-salmon-and-earn-money/

Gannon, K. and M. Hulme. (2018). Geoengineering at the 'edge of the world': exploring perceptions of ocean fertilization through the Haida Salmon Restoration Corporation. Geo: Geography and Environment, 5 (1). e00054. ISSN 2054-4049, http://doi.org/10.1002/geo2.54

Iron Bioavailability in the Sea

Boyd, P.W., and M.J. Ellwood. (2010). The biogeochemical cycle of iron in the ocean. *Nature Geoscience* 3: 675-682.

Lis, H., Shaked, Y., Kranzler, C., Keren, N, and F.M.M. Morel. (2015). Iron bioavailability to phytoplankton: An empirical approach. *ISME Journal* 9: 1003-1013. doi: 10.1038/ismej.2014.199

Railsback, B.L. (2006). Iron as a limiting nutrient in the sea. In: *Some Fundamentals of Mineralogy and Geochemistry. Available as a downloadable PDF or JPG outlining the states of iron in the oceanic environment at*: http://railsback.org/FundamentalsIndex.html.

Shaked Y., and H. Lis. (2012). Disassembling iron availability to phytoplankton. *Frontiers in Microbiology* 123: 1-26. *comprehensive scientific review article.*

Unattended Consequences of OIF Experiments

Cullen, J.J., and P.W. Boyd. (2008). Predicting and verifying the intended and unintended consequences of large-scale ocean fertilization. *Marine Ecology Progress Series* 364: 295-301.

Strong, A.L., Cullen, J.J., and S.W. Chisholm. (2009). Ocean fertilization: Reviewing the science, policy, and commercial activity and charting a new course forward. *Oceanography* 22: 236-261. *comprehensive and easy to read*

Silver, M.W. *et al.* (2010). Toxic diatoms and domoic acid in natural and iron enriched waters of the oceanic Pacific. *Proceedings of the National Academy of Sciences: 107: 20,762-20,767.* doi.org/10.1073/pnas.1006968107

Trick, C.G. *et al*. (2010). Iron enrichment stimulates toxic diatom production in high-nitrate, low-chlorophyll areas. *Proceedings of the National Academy of Sciences* 107: 5,887-5,892. doi:10.1073/pnas.091057910.

Haida Governance & Sovereignty

Dowie, M. (2017). The Haida Gwaii Lesson: A Strategic Playbook for Indigenous Sovereignty, Inkshares, Inc., San Francisco California, 249 pp. ISBN: 9781942645559, e-ISBN: 9781942645566