**1) Working title of your thesis**

Profitability and feasibility analysis of offshore, native-species, integrated multitrophic aquaculture (IMTA) systems in the Strait of Juan De Fuca

**2) In 250 words or less, summarize the key background information needed to**   
**understand your research problem and question.**

**T**here is massive demand for sea proteins (such as shellfish and finfish), and sustainably and cost-effectively producing these sea proteins using an offshore aquaculture model could reduce demand on wild fisheries without utilizing coastlines, which can be expensive to lease and highly desired by a variety of stakeholders. Vitamin rich farmed flora and fauna can nourish humans and support our growing global population.  
  
Offshore aquaculture faces a variety of serious challenges:

* Regulatory difficulties
* Substantial capital required for infrastructure investment
* Wear, tear, and worker safety in an open ocean environment

Additionally, its environmental impacts must be considered in terms of:

* Organism escape (mitigated through farming indigenous species)
* Genetic contamination of wild stock with farmed stock (particularly relevant to shellfish, who reproduce through spat)
* Disease escape (dense stocking of aquaculture can encourage disease)
* Nutrient and particulate escape
* Disturbance of benthic environment

Offshore integrated multi trophic aquaculture also has several advantages:

* When shellfish, kelp, or other low trophic organisms utilize finfish waste, they take up nutrients excreted by the fish. This dramatically reduces nutrient pollution and substantially increases profitable and harvestable biomass generation.
* Cultivating multiple species can reduce risk, if one organism type is killed off by disease, others may still be harvestable
* Offshore location can avoid water quality issues nearshore and riverine aquaculture faces
* Offshore location avoids expensive and highly desired coastal locations.

**3) State your research question(s).**

* What could be the environmental impacts of a hypothetical IMTA in the strait of Juan de Fuca in terms of:
  + Nutrient pollution
  + Species escape risk
  + Genetic contamination of wild populations
* How can we model the production of harvestable biomass and waste streams for the species in the IMTA?
* Is an offshore IMTA operation financially viable under present market conditions? How might the market conditions change in the near future?
* What indigenous species are most profitable at each trophic level?
  + Finfish, shellfish, kelp (potentially other invertebrates, such as crab)
* What conceptual frameworks of modelling can be applied to environmental impact and profitability analyses of shellfish aquaculture?

**4) Situate your research problem within the relevant literature. What is the theoretical and/or practical framework of your research problem?**

This thesis intends to use existing tools and literature to establish a rigorous model of the profitability of IMTA operations in the Strait of Juan De Fuca. It seeks to analyze in terms of the costs and benefits the operation imposes on its environment, and the benefits the sea proteins pose to the human species. This socioecological systems framework incorporates economic analysis as well, noting that the operation cannot exist if it is not profitable. The thesis will uncover whether an environmentally sustainable offshore IMTA operation is possible, and if it is not, under what conditions might it become profitable/possible.

There is a plethora of rigorous and sophisticated literature and models associated with shellfish aquaculture. Even a relatively niche topic, like offshore aquaculture, sees extensive practical and theoretical analysis. Examples include Troell et al.’s ‘Ecological Engineering in Aquaculture – Potential for Integrated Multi Trophic Aquaculture in Marine Offshore Systems’, Neori et al.’s ‘Integrated Aquaculture: Rationale, Evolution and State of the Art Emphasizing Seaweed Biofiltration in Modern Mariculture’ the NOAA Technical Memorandum edited by Michael Rubino in 2008: ‘Offshore Aquaculture in the United States: Economic Considerations, Implications & Opportunities Prepared by the NOAA Aquaculture Program’, a 263-page treatise covering conceptual models of profitability, regulatory challenges, and historiography of aquaculture industry.

Additionally, the National Oceanic and Atmospheric Administration has shown an interest in the farmed cultivation of species native to the Pacific Northwest, producing literature on the topic. One example of this literature is the 104-page NOAA technical memorandum ‘Sablefish Aquaculture: An Assessment of Recent Developments and Their Potential for Enhancing Profitability’.

This thesis will benefit from its research-rich environment, and growing interest in sustainable development, sustainable aquaculture, and native-species conservation all coincide nicely with the topic of study.

**5) Explain the significance of this research problem. Why is this research important? What are the potential contributions of your work? How might your work advance scholarship?**

Offshore integrated multitrophic aquaculture systems are an appealing and significant topic of research because they dangle the possibility of procuring sea proteins and seaweeds for human consumption in intentional ecologies in an environmentally sustainable manner. Shellfish and seaweed operations which have improved water quality have been covered extensively in the literature, cultivating fish might take pressure off wild fisheries, and cultivating indigenous species in these operations might serve to bulwark indigenous wild populations. For kelp and shellfish, genetic escape of cultivated species into the surroundings is nearly inevitable, posing potential risks, and opportunities for ecological engineering.  
Along with identifying ecologically responsible practices for an IMTA operation, and analyzing the environmental impacts of it, the matter of profitability is central to this thesis.

By developing spatially specific hypothetical IMTA operations, and modelling their potential risks, impacts, and profitability as rigorously as possible, this thesis will provide a valuable contribution to aquacultural research centered on the Strait of Juan de Fuca and Pacific Northwest. This thesis will gather data for IMTA operations in the Strait of Juan De Fuca, so that future experimental analyses can be used to authoritatively establish the profitability and ecological responsibility (or lacks thereof) of IMTA operations in the Strait.

**6) Summarize your study design2. If applicable, identify the key variables in your**   
**study. What is their relationship to each other? For example, which variables are you considering as independent (explanatory) and dependent (response)?**  
The study will consist in part of a literature review, establishing conceptual frameworks and practical workflows for the following steps:

* Collecting data on a hypothetical site using remote sensing, NOAA bouies, publicly available models of water quality and water kinetics such as the Salish Sea Model, conversations with Northwest Fishery Science Center research station staff, existing literature, and/or other sources to provide variables to feed into an IMTA model and establish background information on the hypothetical site.
* Modelling cultivated food species population dynamics within an integrated multitrophic aquaculture (IMTA) operation
* Modelling nutrient and particulate inflow and outflow, in the context of establishing potential productivities of cultivated species as well as potential water quality impacts from nutrient discharge.
* Assessing the market value of modelled harvestable aquacultural product.
* Assessing the costs involved in the hypothetical operation.
* Identify sources of future funding for field-testing and refinement of the model.

And a practical element, in which the conceptual frameworks and modelling workflows developed and documented through the literature review are put into practice to create rigorous models of potential IMTA operation productivity, cost, and profitability.

The objective is to create a conceptual framework complete with models which can be calibrated against future (outside of the thesis project) experimentation on organism growth and harvest metrics in small scale aquacultural operations.

**7) Describe the data that will be the foundation of your thesis. Will you use existing data, or gather new data (or both)? Describe the process of acquiring or collecting**   
**data3.**   
  
I will utilize existing models and conceptual frameworks to inform, educate and assist in the construction of my own spatially specific and organism-specific models. I will utilize existing data on cultivated shellfish, finfish, and seaweed population dynamics wherever possible. This population data will be coupled with current and historical NOAA data on the abiotic characteristics of the Strait of Juan De Fuca, as well as spatially specific characteristics of potential sites for offshore aquacultural operations.

Finally, marketable cohort of finfish, shellfish, and seaweeds will be evaluated against the costs of hypothetical IMTA operations in a profitability analysis.

The operation will be profitable if it can produce fish, shellfish, and seaweeds at prices set by the market sufficient to compensate the operation for all operating costs. Regardless of the profitability of the operation, the thesis will attempt to speculate on future conditions which can increase (rising population and seafood/seaweed demand) or decrease (climatic inhibition of shellfish/seaweed/finfish growth) profitability.

**8) Summarize your methods of data analysis. If applicable, discuss any specific**   
**techniques, tests, or approaches that you will use to answer your research question.**  
I will use models of aquacultural species productivity alongside available information on the growth rates of indigenous species suitable to an aquacultural operation in the Strait of Juan De Fuca to model the growth and environmental impacts of an IMTA operation consisting of at least one finfish, shellfish, and seaweed species. The model will be complemented by a second model, which assesses labor, infrastructure, feed, fuel, and regulatory costs for an IMTA operation. The model of cultivated organism population dynamics will be complemented with assessments of the market rate of the (or comparable) cultivated shellfish, finfish, and seaweed food products.

**9) Address the ethical issues raised by your thesis work. Include issues such as risks to anyone involved in the research, as well as specific people or groups that might benefit from or be harmed by your thesis work.**

While this face of the research is not concerned with handling animals, it aims to lay the groundwork for future research which aims to model animal growth to assess the profitability of their harvest under an IMTA. Ethical issues related to aquaculture include the ethics of raising animals in captivity versus harvesting them from the wild, predator management, piscivory and the environmental impacts of the operation.

This research is not an environmental impact analysis, but it does seek to model waste streams of the hypothetically cultivated organisms with the hopes of quantifying nutrient-pollution of surrounding waters of the hypothetical operation.

Positive findings of the research should not be taken out of context, as they will not have been field-tested, nor would they constitute an environmental impact analysis if they were.

Markets, seafood enjoyers, and potentially wild populations of native aquatic organisms in the Pacific Northwest stand to benefit from this research, as profitable IMTA ventures in the PNW could be an effective method of generating seafood and seaweed for humans and increasing food security while taking demand away from wild fisheries.

**10) List specific research permits or permissions you need to obtain before you begin collecting data (e.g. landowner permissions, agency permits).**

I intend to procure an Amateur Radio License to assist with communications when surveying in the field. A nearby licensing exam is available January 28th. While much of the data will be gathered from public datasets, I will also be actively corresponding with various NOAA-funded research stations which do work in managing the Salish Sea Model and other relevant aquacultural yield models. These contacts will include:

1. Doctor Barry Berejikian, Manchester Station Chief and Fisheries Enhancement and Conservation Program Manager [barry.berejikian@noaa.gov](mailto:barry.berejikian@noaa.gov)
2. Tarang Khangaonkar, Program Manager of Coastal Ocean Modelling at Pacific Northwest National Laboratory [tarang.khangaonkar@pnnl.gov](mailto:tarang.khangaonkar@pnnl.gov)

<http://www.arrl.org/exam_sessions/poulsbo-wa-98370-8573-52>

**11) Reflect on how your positionality as a researcher could affect your results and how you will account for this in the research process.**

My topic is focused heavily on the profitability of IMTAs in the Strait of Juan de Fuca, and this is not random happenstance. I have reached a stage in my life where I am desperately seeking stability and aiming to actively accumulate capital, so enterprise is naturally appealing to me. This means that I have a desire to see my research yield favorable results, both in terms of the profitability of a site, as well as in terms of its environmental impacts. Everyone wants to hear good news, and any civically-minded entrepreneur would like to believe that their enterprise is a public good. If the results of my research are promising, it is likely that I would seek funding from private enterprise or government grants which support food resiliency and economic development, including those offered by the National Oceanic and Atmospheric Association, and the US Department of Agriculture and US Department of Commerce.

It will be essential that I actively seek to critically interpret my results, actively attempting to determine if they accurately represent reality, are in line with the best scientific practice, and if the ways in which they could have been shaped by what I had hoped to find.

Honestly conveying my findings, critically interrogating the methods used to establish my model and the results the model produces, and earnestly seeking to serve as a custodian of the marine environment will be pivotal to performing ethical research.

**12) Provide at least a rough estimate of the costs associated with conducting your research, if any. Provide details about each budget item so that the breakdown of the final cost is clear.**

* Proprietary modelling software and data sources $61.49 - $600
  + ShellSim software costs £50 ($61.49 at 12/4/22 conversion rate)
  + Other valuable water-dynamic modelling and organism population modelling tools may be procured to assist in development of a spatially specific IMTA model
  + Some useful remote sensing software or oceanic datasets may be behind paywalls
* HAM Radio License $35
* HAM Radio and supporting equipment $40-$200
* Water-appropriate clothes and flotation device ~$150
* Small craft or charter of small craft for near-shore sampling $400-$1000
* Total estimated costs: $646.49 - $1985

**13) Provide a detailed working outline of your thesis.**

1. Gather spatially specific data on a site in the Strait of Juan de Fuca. Data should contain as variables relevant to the IMTA as possible, such as
   1. Average Tidal Current Speed
   2. Salinity
   3. Temperature
   4. Dissolved oxygen
   5. Nitrogen
   6. Carbon
   7. Turbidity
   8. Total Particulate Matter
   9. Particulate Organic Matter
   10. Chlorophyll
   11. PH

The data will be obtained through buoys, publicly accessible water quality and water kinetic models such as the Salish Sea Model, and through correspondence with fishery research stations such as the Manchester Research Station of the Northwest Fisheries Science Center.

1. Interrogate the literature to determine modelling methodologies most suitable for assessing the hypothetical yields of waste streams of multiple organisms in an IMTA.
2. Build the model, interrogating the literature and corresponding with industry, state and academic representatives who have information they are willing to share on the characteristics of organisms in the model.
3. Document the model’s methodology, limitations, and benefits.
4. Identify funding sources for field-testing, refinement, and calibration of the model.

**14) Provide a specific work plan and timeline for each of the major tasks in the work plan. Be as realistic and specific as you can at this point, including deadlines for Spring quarter.**

1. Break weeks – practice HAM radio
   1. Take regular practice HAM tests on my smartphone to prepare for my January test.
   2. Study literature to get a head start on January if I have the inclination and time.
2. January – Deep review of literature
   1. Explore NOAA buoys and document remote sensing options
   2. By the 16th, Complete Farm-scale models in fish aquaculture – An overview of methods and applications (Chary et al., 2021) and identify most promising modeling methods for your subject
   3. By the 23rd complete US Department of Commerce’s Offshore Aquaculture in the United States: Economic Considerations, Implications & Opportunities
   4. On the 28th complete and pass my HAM licensing exam
3. February – Continued Literature Review, Data Collection
   1. Complete most relevant sections of Shumway’s excellent text Shellfish Aquaculture and the Environment (2012) (Chapters 2 – 9, 15)
   2. Draft of which organisms the model will be assessing.
4. March – Data collection, nearshore proxy data collection
   1. Continue using remote sensing, NOAA, and other available sources for data collection, correspond with state, academic, and private enterprise experts on the topic to help uncover data sources and information about modelled organisms.
5. April – IMTA Model Design and Documentation
   1. Produce the model, document its production, and document the results for various organisms under various conditions, comparing to existing literature.
   2. Begin development of fiscal feasibility framework by estimating costs and researching potential pricing scenarios for modelled organism biomass yields
6. May – Final Stretch
   1. Polish model and documentation
   2. Identify and document potential funding sources for further research
   3. Present research to date

**15) Who (if anyone) beyond your MES thesis reader, will support your thesis (in or outside of Evergreen).**

My thesis will be largely independent, but I will be actively utilizing NOAA data, as well as numerous other data sources. Additionally, I will be corresponding with members of the Department of Ecology such as Melissa Glidersleeve of the Water Quality division of the Department of Ecology, and other state servants such as Laura Butler, the Aquaculture Coordinator & Policy Advisor the Washington Department of Agriculture. I may reach out to local private industry (Taylor Shellfish) and Tribal entities (Jamestown S’Klallam Tribe) involved in aquaculture. I will also be in correspondence with Doctor Barry Berejikian, the Manchester Station Chief and Fisheries Enhancement and Conservation Program Manager and Tarang Khangonkar, Program Manager of Coastal Ocean Modelling at Pacific Northwest National Laboratory.

**16) Provide the 5 most important references you have used to identify the specific**   
**questions and context of your topic, help with issues of research design and analysis, and/or provide a basis for interpretation. Annotate these references with notes on how they relate to/will be helpful for your thesis. For any other sources cited in your prospectus in other answers, provide a complete bibliographic citation here as well.**

1. Rubino, Michael (editor). 2008. Offshore Aquaculture in the United States: Economic Considerations, Implications & Opportunities*. U.S. Department of Commerce*; Silver Spring, MD; USA. NOAA Technical Memorandum NMFS F/SPO-103. 263 pages.
2. Klinger, D., & Naylor, R. (2012). Searching for solutions in aquaculture: Charting a sustainable course. *Annual Review of Environment and Resources*, *37*, 247–276. <https://doi.org/10.1146/annurev-environ-021111-161531>
3. Neori, A., Chopin, T., Troell, M., Buschmann, A. H., Kraemer, G. P., Halling, C., Shpigel, M., & Yarish, C. (2004). Integrated aquaculture: Rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. *Aquaculture*, *231*(1–4), 361–391. <https://doi.org/10.1016/j.aquaculture.2003.11.015>
4. Shumway, S. E. (2011). Shellfish Aquaculture and the Environment. In *Shellfish Aquaculture and the Environment*. <https://doi.org/10.1002/9780470960967>
5. Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., & Fang, J. G. (2009). Ecological engineering in aquaculture - Potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture*, *297*(1–4), 1–9. <https://doi.org/10.1016/j.aquaculture.2009.09.010>

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Other references:

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ShellSIM – Modelling Shellfish Growth. 2011. Plymouth Laboratories. <http://www.shellsim.com/Description.aspx>