**NOAA National Sea Grant Symposium Presentation**

October 29, 2021

Title: Economic and environmental sustainability decision-support tool for fish-free aquafeed

**Slide 1: Title slide**

**Slide 2: Road map**

We’ve organized the talk into three sections as outlined in the road map. We’ve included the roadmap on each slide to communicate where we are in the presentation.

**Slide 3: Sustainability: Business as usual**

Among global food production systems, aquaculture is the fastest growing food sector and has recently outpaced wild seafood. The explosive growth of global aquaculture (shown in the yellow line in the panel on the left side) has been accompanied by a diminishing supply of fishmeal which the aquaculture industry relies on as a feed ingredient. For these reasons, concerns about the finite supply of marine resources have been cited as one of the barriers to the sustainable development of the aquaculture industry.

**Slide 4:** **Sustainability: Environmental and economic impacts of aquafeeds**

We also know that the environmental impact and the high cost of feeds are also barriers to the sustainable development of the aquafeed industry. For example, as shown in the left panel, feed has the largest overall global warming potential, and in the panel on the right, aquafeeds have the largest overall variable costs along the aquaculture supply-chain. Against this backdrop, there is a critical need to find alternatives to fishmeal and fish oil that minimize the economic costs and environmental burden of aquafeeds.

**Slide 5: Sustainability: Terrestrial ingredients**

Resource constraints have led to a shift away from proteins and oil sourced from seafood to terrestrial sources such as soybeans and corn. However, there are concerns that we could be shifting the environmental burdens from the sea to land. Plant-based substitutes for wild fish ingredients are also constrained by nutrient and performance limitations. Soybean and corn meals have imbalanced amino acids, low levels of long-chain polyunsaturated fatty acids, and high levels of anti-nutritional factors that limit their suitability as a replacement for fish meal. Furthermore, the replacement of high-quality fish oil with vegetable oils can result in a decline of performance indicators such as growth, fish health, and fatty acid profile. As shown in our schematic, the more we replace fish meal and fish oil with terrestrial crop ingredients, the lower the omega-3 fatty acids EPA, and DHA in the fish, and this results in less health benefits to humans from eating farmed fish. These data have prompted researchers to investigate alternative sources of protein and oils.

**Slide 6: Sustainability: Alternative ingredients**

The effect of replacing fishmeal and fish oil with conventional substitutes like soybean and corn meals and oils has been carefully researched. However, the environmental and economic impacts of alternatives sources are largely unknown. A few alternative ingredients are shown in this image, such as insect meals from mealworm and soldier fly larvae, meal from single cell protein, and meals and oils from marine microalgae.

**Slide 7: Open-source aquafeed decision-support tool**

To address these critical knowledge gaps, we are developing an open-access decision-support tool that allows users to assess if alternative aquafeed ingredients meet nutritional requirements and promote growth of the farmed organisms, ensure high quality of the final edible product, have low environmental impact, and compete with costs of conventional aquafeed ingredients. As inputs to the decisions support are developing a meta-model database with three components: (1) life-cycle assessments data; (2) economic data; and 3) growth performance data. We are developing a user-friendly interface that provides data visualizations of the economic and environmental impacts.

**Slide 8: Project objectives**

Here, we present the objectives grouped with the downward arrows showing the major project deliverables, the meta-model database and the open-access software tool. This slide is also a good transition from the project overview to progress-to-date. The orange boxes show the tasks under each objective that high levels of completion, and the light blue boxes show activities that have yet to be completed.

**Slide 9: Communication with industry advisors**

We convened a group meeting with several industry advisors and a California Sea Grant Extension Specialist. After our group meeting, we learned that we would get better feedback from the advisors if we met with them individually. In these individual meetings, we presented detailed process models with material and energy flows that represent our best estimates. The industry advisors provided as much feedback as they could while protecting their proprietary information. We then changed our models until they are more aligned with industry practices. This has been iterative and time-consuming process, but an important step in assuring the model is commercially relevant.

**Slide 10: Meta-model database: life cycle assessment (alternative ingredients)**

We have developed detailed process models with material and energy flows that represent our best estimates, some of which have been vetted by industry advisors, for ten different novel ingredients used to formulated feeds for salmonids. Our life cycle assessment models include the calculations of the global warming potential, land use, water use, eutrophication potential, and biotic resource use.

**Slide 11:** **Meta-model database: life cycle assessment (conventional ingredients)**

We have also included the environmental impact metrics of 12 different conventional ingredients used to formulate feeds for salmonids.

**Slide 12:** **Meta-model database: economic assessment (alternative ingredients)**

We have synthesized the economic data from the literature for 5 different novel ingredients used to formulate feeds for salmonids.

**Slide 13:** **Meta-model database: economic assessment (conventional ingredients)**

We have also synthesized the economic data from the literature for 12 different conventional ingredients used to formulate feeds for salmonids.

**Slide 14:** **Meta-model database: growth performance**

We have also synthesized the growth performance from the literature for 8 different alternatives to fish meal that are used to formulate feeds for salmonids.

**Slide 15: Demonstration of the software calculator function**

Here, we will demonstrate the software which asks the user to choose between rainbow trout or salmon, and then asks the user to input the amount of ingredient per kilogram of aquafeed, which results in a data visualization of seven different environmental impact metrics and one economic impact metric.

**Slide 16: Data visualization of the software**

In the demonstration, we chose rainbow trout. The data visualization shows the environmental impact conversion ratio and the economic conversion ratio of the user input diet compared to the reference diet. The environmental impact conversion ratio is the product of the life cycle impact metric and the feed conversion ratio. Likewise, the economic conversion ratio is the product of the market price of the formulated feed and the feed conversion ratio. In this example the user input diet was a fish-free formulation that substituted the defatted marine microalga, Nannochloropsis oculata, for fish meal and the whole cells of marine microalga and canola oil as substitutes for fish oil. The data visualization illustrates the tradeoffs of the novel ingredients used in the user input diet compared with conventional ingredients used in the reference diet. For example, the reference diet has a higher economic conversion ratio and biotic resource use per kg farmed fish. Biotic resource use is a measure of the primary production required to sustain marine and terrestrial biomass. However, the user input shows higher global warming potential, land use, water use, and eutrophication potential per kg of farmed fish.

**Slide 17: Publications**

In addition to progress with software development, we have been working on publishing. Last year we published in the Nature journal, Scientific Reports. Much of the economic work we published in that manuscript was used as the economic data for the marine microalgae and conventional ingredients. This figure on the right shows the economic conversion ratio of a reference diet for farmed tilapia compared to different formulations include marine microalgae as replacements for fish meal and fish oil.

**Slide 18: Publications**

We are also working on publishing the meta-model database and the open-access software, in the DRYAD repository. A temporary link is available now on request and we will provide a permanent link when we are ready to publish. And, we recently submitted a manuscript entitled, “Life cycle assessment of the potential of heterotrophic microalgae as sustainable fish oil replacements in aquaculture feeds” for publication in the peer-reviewed journal, Elementa: Science of the Anthropocene.

**Slide 19: Meta-model database**

Next steps for the meta-model database include using the process models we have already developed in the life-cycle assessment models for techno-economic assessments of alternative ingredients. We will also compile protein and amino acid data for conventional and alternative ingredients and add this to the database.

**Slide 20: Software development**

Next steps for the software development include adding an optimization tool so that a user can formulate a least cost formula or a least environmental impact formula subject to nutritional constraints. We also plan to write a user’s manual and to record an instructional video.

**Slide 21: Disseminate results**

Next steps include publishing additional manuscripts. We have work already under way on these additional manuscripts we plan to publish.

**Slide 22: Communication with industry advisors**

We plan to solicit feedback from out industry advisor on the software and to incorporate the feedback in future versions of the software.

**Slide 23: Team acknowledgment**

We would like to acknowledge the Kapuscinksi-Sarker lab. With special thanks to the student interns that have helped with this project.

**Slide 24: Funding acknowledgment**

We would also like to acknowledge funding support from NOAA National Sea Grant and UC Santa Cruz. We would also like to acknowledge helpful feedback from California Sea Grant extension specialist, Dr. Luke Gardner, and the other industry advisors we list here.