THE FATE OF NITROGEN AND PHOSPHORUS DISCHARGED FROM OPEN-OCEAN AQUACULTURE FACILITIES

A PhD DISSERTATION PROPOSAL
(Abbreviated Version)

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PROBLEM STATEMENT

Anthropogenic discharges of nitrogen (N) and phosphorus (P) have been implicated in a wide range of marine environmental problems including eutrophication (Rabalais et al. 2002a), harmful algal blooms (Heisler et al. 2008), and fish kills (Dybas 2005). In the northern Gulf of Mexico, for example, a hypoxic dead zone is created every summer by the nutrients flushed out of the Mississippi river (Goolsby et al. 2001; Rabalais et al. 2002b; Dybas 2005) and Diaz and Rosenberg (2008) report that similar dead zones affect more than 245,000 km^2 in hundreds of locations around the world. Places like the Sea of Cortez (Lluch-Cota et al. 2007), the Taihu Lake region in northern China (Tian et al. 2007), and the Baltic Sea (Dybas 2005) all suffer from persistent nutrient related eutrophication events. As such, there is justifiable concern about the increase in N and P discharges into the ocean that will result as aquaculture operations expand both in the U.S. and abroad.

The discharge of N and P is not, however, *ipso facto* pollution. N and P are naturally excreted by almost all living organisms and are necessary nutrients for the phytoplankton that drive the primary production that sustains all marine fisheries (Chassot et al. 2010). In fact, it is theoretically possible that N and P from fish farms could stimulate primary productivity in ways that are beneficial to marine ecosystems and fisheries if discharged in appropriate environments and in appropriate amounts. In these circumstances, N and P would be more aptly described as a fertilizer than as a pollutant. Unfortunately, the conditions under which N and P discharges might have beneficial effects have not been rigorously investigated.

RESEARCH APPROACH

The University of Miami (UM) Aquaculture Program has been at the forefront of the move to open-ocean aquaculture for more than a decade. Program director Dr. Daniel Benetti and his team have developed technologies that have become industry standards throughout Latin America and the Caribbean (Benetti et al. 2010a, Benetti et al. 2010b, Benetti and Welch 2010). This proposal represents the next stage in the evolution of that work – ensuring that open-ocean aquaculture is integrated into the marine environment in a seamless fashion.

The goal of this research is to define the conditions under which N and P can have a beneficial impact on ocean ecosystems and translate that information into usable models that help stakeholders improve site selection decisions for aquaculture. The cobia (*Rachycentron canadum*) industry will be used for modeling purposes due to its recent growth worldwide and the University of Miami's access to various cobia production sites in Latin America. Research will proceed according to the following plan:

1. Quantify the N and P excretion rates of cobia fed traditional (fishmeal-based) and alternative (vegetable-based) feeds. N and P discharges in aquaculture result largely from feeding fish. Nutrients that are not assimilated via the digestive process are excreted across lamellar surfaces and in the urine, as well as in dissolved and solid fecal matter (Xu et al. 2007). Feeds that substitute soy meal for fishmeal have been shown to significantly reduce N and P discharge in all forms (Cheng et al. 2003) and vegetable- and soy-based feeds are an increasingly feasible alternative to traditional feeds (Naylor et al. 2009, Benetti and Welch 2010, Salze et al. 2010, Welch et al. 2010). This indicates that the N and P discharges associated with aquaculture operations could be reduced by moving away from fishmeal and towards vegetable and soy based diets. To quantify potential N and P savings associated with alternative feedstuffs we will test different feeds and their effects on cobia excretion rates and composition. Juvenile cobia will be fed conventional and vegetable and/or soy based diets. The N and P excretion rates associated with these different feeds will be characterized using the procedures described in Cheng et al. (2003) and Feeley et al. (2007). This data will be linked to real-world cobia husbandry information (feed types and amounts, FCRs, growth rates, etc…) provided by commercial operators to generate an accurate estimate of the N and P discharged by farms using both traditional and vegetable based feeds.

2. Develop an open-ocean aquaculture NPZ-Ocean Circulation model. Techniques for modeling nutrient cycles and associated plankton community dynamics in the marine environment are well known and have been in use since the 1970s (Franks 2009). These platforms are known generically as Nitrogen-Phytoplankton-Zooplankton (NPZ) models and can be linked to high-resolution coastal ocean circulation models to produce spatially explicit forecasts and hindcasts of plankton community responses to variability in nutrient loading. In the second phase of this research, an existing NPZ model will be adapted for use in open-ocean aquaculture scenarios and then linked to an appropriate coastal ocean circulation model developed by the University of Miami. The data generated in Part 1 of this research project will be fed into the model and the resulting work product will be used to help understand the fate of N and P generated by open-ocean aquaculture facilities and the conditions under which those discharges would be beneficial for marine ecosystems and fisheries.

3. Investigate the Implications of the Models for Marine Spatial Planning. The findings of this research will be of interest to U.S. policy makers interested in marine spatial planning. Marine spatial planning (also known as "marine zoning") has become a hotly debated topic in recent years. A number of schemes have been proposed by academics, environmentalists, and regulatory agencies (e.g. Eagle 2006). Potential and existing aquaculture operators in the United States will be greatly impacted by any scheme that ultimately becomes law even if that scheme only codifies the existing status quo. The final phase of this research project will involve a thorough analysis of existing and potential regulatory schemes for open-ocean aquaculture and will use the open-ocean aquaculture NPZ-Ocean Circulation model developed here to propose principals for optimizing siting decisions within those schemes.

EXPECTED RESULTS

This research has the potential to fundamentally alter the way fish farms and the environment interact and, in the process, to change the public perception of open-ocean aquaculture for the better. If it proves possible to affirmatively link aquaculture operations to improved fisheries via nutrient discharge and plankton fertilization, the societal and environmental cost-benefit analysis that attaches to open-ocean aquaculture will change radically. It will no longer be possible to paint open-ocean aquaculture operators as simply the least bad polluters. Instead, aquaculturists will be able to assert with confidence that they are providers of positive ecosystem benefits and effective stewards of the ocean environment.

The results of this research will be publicized through a series of papers released in the scientific literature, presentations to interested environmental and policy making/government groups, presentations at annual meetings of the World and US Aquaculture Societies, and outreach via the mainstream press. This research will also be the focus of a PhD dissertation by a UM graduate student. All work will be completed in 2 years.

RESEARCH PERSONNEL

Aaron Welch, J.D., M.Sc. Mr. Welch is a PhD Student at the University of Miami. He has an extensive background in environmental law and aquaculture and has been a first or co-author of five papers published in the peer-reviewed scientific literature in the last three years. This research will constitute the bulk of his Ph.D. dissertation.

Jorge Arturo Suarez, Ph.D. Dr. Suarez is a fish and shrimp nutritionist with more than a decade of research experience. He holds a post-doctoral research position at the University of Miami. He will assist with part II of this project.

Daniel Benetti, Ph.D. Dr. Benetti is the chair of Mr. Welch's PhD committee and will supervise the research proposed here.

Kenneth Broad, Ph.D. Dr. Broad is the co-chair of Mr. Welch's PhD committee and will help supervise the research proposed here.

Additional Support. A University of Miami oceanography graduate student will be recruited to assist with the mathematical modeling required in part 2 of this project.

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