Estimation of aquaculture carrying capacity in Southeast Asia: needs and capabilities for modeling of common water bodies

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Summary
With expansion of aquaculture in Southeast Asia, some water bodies have already exceeded their abilities to assimilate wastes from aquaculture production. The need to determine the maximum amount of aquaculture that can take place in a given water body is great. Resource managers first need to decide what they to protect (farmers, ecosystem, society), then calculate the appropriate carrying capacity (production, ecological or social). A variety of models can be used to predict the impacts of aquaculture wastes in the environment. Use of each depends on needs, available data, and user expertise. Ideally, such models are used before aquaculture production begins, so regulators only permit the appropriate amount of aquaculture and/or properly site the aquaculture operations. Most SE Asian countries have strategic plans that call for substantial increases in aquaculture production, but opinions on what to protect differ. Data available for models are usually sparse and scientists may need training to use more complex models. I recommend a phased approach to modeling of common water bodies, beginning with simple mass-balance models and progressing toward full ecosystem models over time. Because most countries permit aquaculture at the municipality level, an outreach program for municipal officials to prevent aquaculture overcapacity is needed.

Introduction
Five of the world's top ten aquaculture producing countries are in Southeast Asia (SEA). Although their production that goes to Japan, North America and the European Union must normally meet international quality standards, production for SEA domestic consumption need not be held to such standards. The total population of SEA countries is now about 626 million, greater than any of the individual developed-country markets listed above, and they consume about 17 MMT of seafood annually (not all from aquaculture). Tilapia, milkfish and carp are favorites of consumers in megacities like Bangkok, Jakarta and Manila. Furthermore, although China is by far the world's largest aquaculture producer, it is now a net importer of seafood. With abundant coastal waters, SEA has ample space for aquaculture expansion, either by SEA companies or Chinese companies. For the moment, much production occurs in lakes, reservoirs, and estuaries, and some of those are heavily overused, leading to decreasing production per cage and even periodic fish kills.

Responsible aquaculturists in government, industry and academia realize that planning for aquaculture development in SEA will require modeling of aquaculture carrying capacity (ACC). Several definitions of ACC exist (physical, production, ecological and social) (McKindsey *et al.* 2006) and modeling methods have successfully been used for production ACC (Beveridge 1996) and ecological ACC (Jiang and Gibbs 2005; Byron *et al.* 2010). For freshwater cage culture, the Dillon and Rigler (1974) model of aquatic ecosystem responses to phosphorus loading has long served as the basis for modeling production ACC based on phosphorus mass-balance (Beveridge 1996). In marine waters, hydrodynamic and benthic deposition models have been used to predict water quality changes with aquaculture development (e.g., Kishi *et al.* 1994) and Ecopath models to predict ecological ACC (e.g., Xu *et al.* 2011). The purpose of my work in SEA has been to assess the needs and abilities of SEA countries for modeling ACC and to help them begin the modeling process.

Materials and Methods

Beginning in 2012, I have made multiple trips to SEA to meet with regulators and scientists in Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Thailand and Vietnam to assess their SEA needs and abilities. Meetings usually include a seminar by me on ACC and modeling approaches, then follow-up discussions with the regulators, scientists and occasionally stakeholders, along with visits to aquaculture production areas. In 2014, a collaboration among four universities (University of Rhode Island, University of Stirling, Bogor Agricultural University, and Surya University) was funded to study ACC in a spectrum on Indonesian water bodies, from very eutrophic (Lake Cirata) to oligo-/meso-trophic (Lake Toba) to planned (Lake Jatigede, when a large dam is completed). Initial visits to these lakes for information-gathering were completed in summer, 2014.

Results and Discussion

Regulators and scientists in SEA countries want models for lakes, reservoirs, estuaries, coastal waters, rivers, ponds; in short, everything. Unfortunately, regulators in different agencies (e.g., Environment vs. Aquaculture) often have different goals (ecological carrying capacity vs. production carrying capacity). However, in general, they have little capability to use such models and will require training. Even more important, they have very little data to put into the models. Thus, the most useful approach will be to begin with phosphorus mass-balance models in freshwater lakes to demonstrate the efficacy of modeling in determining ACC. We have been training government staff in Cambodia and students in Indonesia in these models this year. Through the use of consulting companies, governments could begin to examine ACC based on hydrodynamics of coastal waters and benthic deposition of feeds and feces therein. Although the end goal would be calculation of ecological carrying capacity, it will take years for the countries to develop the database required for use of a model like Ecopath. An additional problem in SEA is that, in one way or another, much of the aquaculture permitting is done at the local level. It will be critical to develop educational modules for both farmers and municipal officials to understand the relationship between aquaculture production and the ability of the environment to assimilate wastes, and ultimately to understand the rationale for ACC modeling. An encouraging note is that farmers can understand that loss of feed to the environment means loss of money, as does decreased growth and increased mortality of fish in cages; thus, they may accept the argument for aquaculture management by ACC on economic grounds, even if not on ecological grounds.

Acknowledgments

Funding for these projects from the United Soybean Board, U.S. Agency for International Development (via Aquafish Innovation Lab at Oregon State University), and the U.S. Department of State (via the Institute for International Education) is gratefully acknowledged.

References

Beveridge, M. 1996. *Cage Aquaculture, 2nd ed.* Fishing News Books, Oxford, 346 pp.

Byron, C., Link, J., Costa-PierceB. and Bengtson, D. 2011. Modeling ecological carrying capacity of shellfish aquaculture in highly flushed temperate lagoons. Aquaculture 314: 87-99.

Dillon, P.J. and Rigler, F.H. 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. Journal of the Fisheries Research Board of Canada 31: 1771-1778.

Jiang, W. and Gibbs, M.T. 2005. Predicting the carrying capacity of bivalve shellfish culture using a steady, linear food web model. Aquaculture 244: 171–185.

Kishi, M.J., Uchiyama, M. and Iwata, Y. 1994. Numerical simulation model for quantitative management of aquaculture. Ecological Modelling 72: 21-40.

McKindsey, C.W., Thetmeyer, H., Landry, T. and Silvert, W. 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture 261: 451–462.

Xu, S., Chen, Z., Li, C., Huang, X. and Li, S. 2011. Assessing the carrying capacity of tilapia in an intertidal mangrove-based polyculture system of Pearl River Delta, China. Ecological Modelling 222: 846-856.