TOPIC AREA:
WATERSHED AND INTEGRATED COASTAL ZONE MANAGEMENT

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Estimating Carrying Capacity for Aquaculture in Cambodia

Watershed and Integrated Coastal Zone Management/Study/13WIZ01UC

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ABSTRACT

We conducted a pilot project on Aquaculture Carrying Capacity (ACC) in Cambodia. The objective of the study was to plan for sustainable aquaculture development in Cambodia by training Cambodian scientists, staff of the Inland Fisheries Research and Development Institute (IFReDI) in the use of models to estimate the amount of aquaculture waste and therefore to estimate ACC. Stung Chinit Reservoir, located in Kampong Thom province, was selected as the pilot study site. The results showed that the best scenario with acceptable phosphorus concentration ([P]) at 200 mg/m^3, farmers could produce 895 tons of snakehead in the dry season or 467 tons in the wet season. Setting acceptable [P] at 200 mg/m^3 and just varying FCR demonstrates that an FCR of 2.0 allows only 790 tons of snakehead production during the dry season and 412 tons during the wet season, whereas lowering the FCR to 1.0 will allow 1918 tons of snakehead production during the dry season and 1000 tons during the wet season. Holding FCR constant at 1.8 and setting acceptable [P] at 150 mg/cubic meter means that aquaculture will not be allowed in Stung Chinit. On the other hand, setting acceptable [P] at 350 mg/m^3 means that 2138 tons will allowed during the dry season and 14,448 tons during the wet season. Using P mass-balance modeling to project acceptable snakehead production levels in Stung Chinit Reservoir provides the policy makers, and especially farmers, to see the impacts of different scenarios on potential snakehead production in Cambodian reservoirs and in Southeast Asia region.

INTRODUCTION

Cambodia has plans to expand freshwater aquaculture, including in reservoirs (Fisheries Administration, 2011). Lakes and reservoirs represent commonly owned or used water bodies and are therefore subject to the “tragedy of the commons”, in which too many users can destroy the quality of the resource (Hardin, 1968). It is not unusual in Southeast Asia to see reservoirs in which aquaculture has grown beyond reasonable limits, with subsequent declines in water quality (e.g., the Cirata and Jatiluhur reservoirs in Indonesia, with tens of thousands of fish cages).

Aquaculture carrying capacity (ACC) refers to the limits to aquaculture in a common water body, as defined by the environment’s ability to assimilate aquaculture wastes. McKindsey et al. (2006) reviewed the topic and discussed different entities that one might consider protecting (the farms themselves, the entire ecosystem, human society) in the calculation of ACC. Various kinds of models exist for calculating ACC, depending on what is to be protected and how much data one has available to use in the models.

For freshwater bodies with relatively little data available, mass-balance modeling of phosphorus (P) is often used, since P is normally the limiting nutrient for freshwater primary production. The basic P mass-balance model is rooted in the work of Vollenweider (1968) and Dillon and Rigler (1974), relating P levels and primary production in studies of eutrophication. That is, eutrophic waters eventually result in lowered dissolved oxygen (DO) levels due to decomposition of organic material. The aquaculture of fish in cages is usually based on feeding of some diets (chopped trash fish or formulated feed pellets) that add substantially to the organic load of the water.

OBJECTIVES

The objective of this activity was to plan for sustainable aquaculture development in Cambodia by training Cambodian scientists, regulators/managers, and officers in the use of models to estimate the amount of aquaculture waste that an ecosystem can assimilate.

METHODS

The Lead PI provided training workshops and seminars at IFReDI to educate the staffs of relevant regulatory agencies on the problems behind unregulated aquaculture development and the uses of modeling to estimate aquaculture carrying capacity. He further worked with selected IFReDI scientists to learn simple mass- balance models for calculation of aquaculture carrying capacity.

Stung Chinit Reservoir, located in Kampong Thom province, was selected as the pilot study site. It has a surface area of 2,530 ha, and can store up to 38 million m^3 of water. The reservoir is used for irrigation of 22,000 ha during the rainy season and 5,000 ha during the dry season.

IFReDI staff received training in P mass-balance modeling and collected information about Stung Chinit reservoir to be used in the modeling. As described by Beveridge (1996), the modeling procedure is quite simple and requires relatively little input data. One needs to know the volume of the water body, area (A) and average depth (z) of the water body, the turnover rate (number of volume replacements per year, ρ), initial P concentration before aquaculture $[P]_i$, and some acceptable final P concentration $[P]_f$, and the fraction of P that is lost to the sediments (R). In addition, one needs to know about the fish being proposed for rearing: species, P content of their feed, feed conversion ratio (FCR, which is a measure of how much feed must be provided to achieve desired growth of the fish), and the amount of P retained by the fish at harvest. The critical quantity is $\Delta P = [P]_f - [P]_i$, which is the amount of new phosphorus that aquaculture can add to the system and still allow the system to be at or below the acceptable P level.

Clearly, if $[P]_i$ is already greater than $[P]_f$ (due to nutrient runoff, etc), then no aquaculture can be allowed.

Average volume of Stung Chinit reservoir is 35.6 million m^3. During the dry season (November to April) flow in the Stung Chinit River is 460 million m^3 (for the whole season), whereas during wet season (May to October) flow is 1586 million m^3 for that season. [P] in the reservoir in 2008 (the last year for which we have an annual data set) averaged 92 mg/m^3 in the dry season (range = 40-150) and 195 mg/m^3 in the wet season (range = 50-520). The area of the reservoir is 16,720,000 m^2 in the wet season and 5,140,000 m^2 in the dry season, and the average depth is 1.5 m. In the absence of specific data, we are assuming that R = 0.5. With this information, one can use the relationship described by Beveridge (1996) $\Delta P = [L_{fish}(1-R_{fish})]/z\rho$, where L_{fish} is the amount of P that can be contributed by fish aquaculture, by rearranging it to solve for $L_{fish} = [\Delta P z\rho]/(1 - R_{fish})$.

One can then calculate the number of tons of fish that be produced to achieve L_{fish}. That is accomplished by multiplying the P content in a ton of feed times the FCR (to determine how much P is provided to the aquaculture operation, P_{feed}) and subtracting from that the amount of P that is retained in a ton of fish, P_{fish} (and therefore removed from the system). In other words, the amount of P lost to the environment, $P_{env} = P_{feed} - P_{fish}$, expressed as P loss per ton of fish produced.

RESULTS

In the current best scenario with acceptable [P] at 200 mg/m^3, farmers could produce 895 tons of snakehead (dry season) or 467 tons (wet season). Since the growth cycle for snakehead lasts for more than one season, the annual production will be limited to 467 tons. Setting acceptable [P] at 200 mg/m^3 and just varying FCR demonstrates that an FCR of 2.0 allows only 790 tons of snakehead production during the dry season and 412 tons during the wet season, whereas lowering the FCR to 1.0 would allow 1918 tons of snakehead production during the dry season and 1000 tons during the wet season (Figure 1). Holding FCR constant at 1.8 and setting acceptable [P] at 150 mg/m^3 means that aquaculture will not be allowed in Stung Chinit. On the other hand, setting acceptable [P] at 350 mg/m^3 means that 2138 tons will be allowed during the dry season and 14,448 tons during the wet season (Figure 2).

DISCUSSION

One of the interesting things about this exercise is that there are some things that fish farmers and feed manufacturers cannot control (volume, area, depth, flow rate of the water body) and some things that they can (FCR, P content of feed). In addition, stakeholders of the water can decide on the acceptable level of P for that water body. For example, if stakeholders desire oligotrophic (clear, very low nutrient water) for tourism, then aquaculture production is unlikely, but if they really want to promote aquaculture, the higher levels of P would be permissible. Beveridge (1996) suggested that P levels up to about 250 mg/m^3 are permissible for tropical culture of tilapia, carp and milkfish, although lower levels of 50-75 mg/m^3 would be more protective of fisheries production.

We followed the above approach to calculate ACC for fish culture in Stung Chinit. Since this effort was part of a project to bring about the reintroduction of snakehead culture in Cambodia, we used that as our model species, although one could clearly model other species as well. We began by calculating ACC with the best current data available and an assumed acceptable [P] of 200 mg/m^3. However, as part of the exercise, we also calculated ACC under different scenarios of FCR and $[P]_f$. We were faced with the additional challenge that Stung Chinit has very different flow rates and $[P]_i$ values for the wet and dry seasons, but snakehead require about one year to grow to market size, thereby encompassing both wet and dry seasons. We therefore decided a priori that we would calculate ACC separately for wet and dry seasons, but that we would finally choose the lower of the two values for tons of fish production, so that production would be protected in the worst-case scenario.

For our current best scenario with acceptable [P] at 200 mg/m^3, farmers could produce 895 tons of snakehead (dry season) or 467 tons (wet season). Thus, the annual production would be limited to 467 tons, the lower of the two values. As we examine other scenarios, we see that FCR is a powerful regulator of allowable tons of fish production. Setting acceptable [P] at 200 mg/m^3 and just varying FCR demonstrates that an FCR of 2.0 allows only 790 tons of snakehead production during the dry season and 412 tons during the wet season (so we choose 412 tons for year-round production to be safe), whereas lowering the FCR to 1.0 would allow 1918 tons of snakehead production during the dry season and 1000 tons during the wet season (so again we choose 1000 tons to be safe) (Fig. 1). Similarly, holding FCR constant at 1.8, setting acceptable [P] at 150 mg/m^3 would mean that aquaculture would not be allowed in Stung Chinit (481 tons during the dry season but a negative number during the wet season), whereas setting acceptable [P] at 350 mg/m^3 would mean that 2138 tons would be allowed during the dry season and 14,448 tons during the wet season (so 2138 tons to be safe) (Fig. 2). It is interesting that the wet season production levels are always lower than the dry season production levels and therefore determine the year-round production at all FCR levels, but that, when FCR is held constant and acceptable P varies, the wet season production levels are higher and the dry season production levels determine the year-round production.

Some final issues must be considered regarding the introduction of aquaculture to Stung Chinit. First, we must be sure that the P levels do not violate Cambodian national standards for water quality. Those standards appear to allow P levels from 50-1000 mg/m^3, so that should not be a problem. Because the water leaving the dam is only used for irrigation of agriculture, elevated nutrient levels will be considered something positive. Second, we do not want to endanger the fish community that already exists in Stung Chinit and contributes to fishery catches. Monthly measured P values in Stung Chinit in 2008 ranged from 40-150 mg/m^3 during the dry season and from 50-520 mg/m^3 during the wet season. It is therefore likely that the fish community is already adapted to a wide range of P conditions in the reservoir and can cope with somewhat elevated average P values due to aquaculture. Finally, Stung Chinit averages only 1.5 m in depth, but has some deep areas that reach 10 m in depth. Whatever tonnage of fish production is allowed in Stung Chinit must also be consistent with good aquaculture practices of siting cages in deeper water. Thus, sufficient deep water areas must be shown to be available as part of the decision to allow aquaculture operations.

CONCLUSION

Using P mass-balance modeling to project acceptable snakehead production levels in Stung Chinit Reservoir provides us, policy makers, and especially farmers to see the impacts of different scenarios on potential snakehead production. It can serve as a template for modeling allowable levels of aquaculture in other Cambodian reservoirs and perhaps throughout the Southeast Asia region.

QUANTIFIED ANTICIPATED BENEFITS

One Master's student has been involved in this investigation. Four IFReDI researchers have received training in P mass-balance modeling and collected information about Stung Chinit reservoir to be used in the modeling. Two-thousand IFReDI/FiA staff, scientists, researchers, and government officers have an improved understanding of environmental carrying capacity through sharing research result findings such as policy brief, technical report, and meetings and workshops; and about 100 scientists and researchers can apply models to the calculation of carrying capacity for specific bodies of water.

ACKNOWLEDGEMENTS

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FIGURES

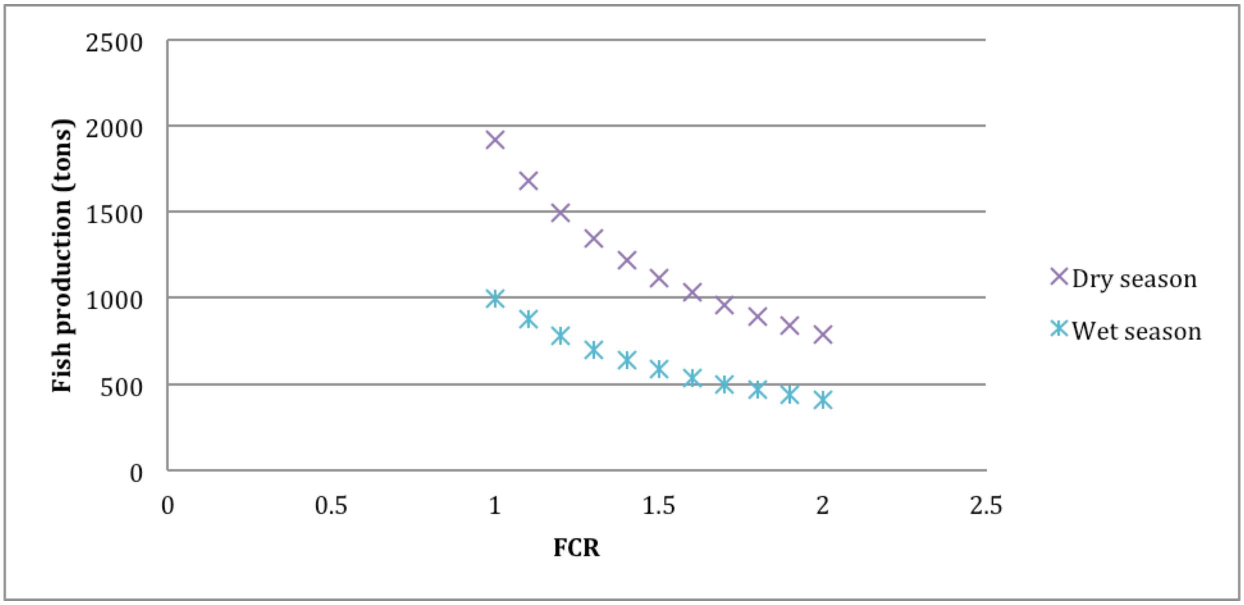

Figure 1. Effect of FCR on aquaculture carrying capacity in Stung Chinit Reservoir.

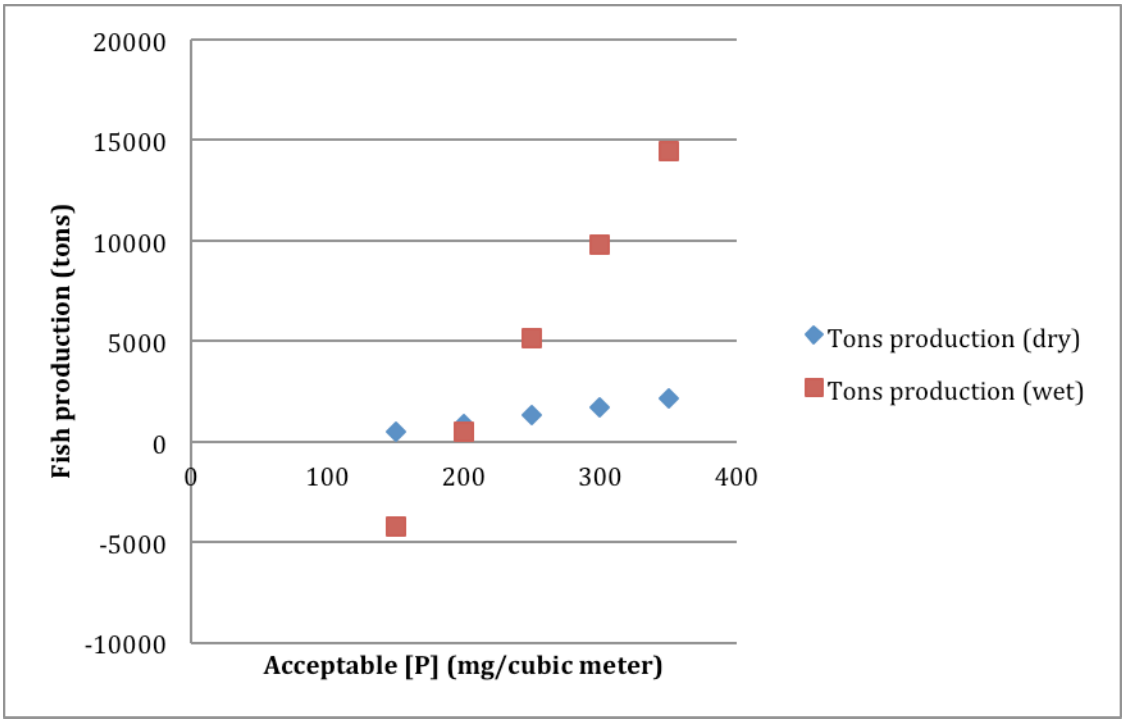

Figure 2. Effect of phosphorus acceptability criterion on aquaculture carrying capacity in Stung Chinit Reservoir.