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Load models support sustainable aquaculture planning for Brazil's reservoirs

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Risks include eutrophication due to nutrient loads from fish feces, feed losses

Brazil has hundreds of thousands of hectares of reservoir area in which fish cages could be established.

Most of the large rivers in Brazil's upper Paraná River basin, which drains the most industrialized and populated portion of South America, have been transformed into cascades of hydroelectric reservoirs during the past 50 years. This caused losses of aquatic biodiversity and interruption of migratory fish routes that resulted in low fishery production. Several attempts at stock enhancement were carried out, although these artificial ecosystems have persisted as relative biological deserts. On the other hand, the impoundments have enhanced the water quality of the resulting lakes.

No solution for food production in these large ecosystems emerged until cage aquaculture was shown to be feasible. In spite of great biodiversity in local freshwaters, no competitive, native option has yet emerged, and cage aquaculture has been mainly based on tilapia farming.

Farming potential

The total area of reservoirs in the upper Paraná basin is over 500,000 ha and has a potential for annual fish production of more than 2 million metric tons (MT) by using only 0.5 percent of the area.

Cage aquaculture in hydroelectric reservoirs has great potential for expansion in Brazil, but there are concerns of negative environmental impacts, particularly the risks of eutrophication due to nutrient loads derived from fish feces and feed losses. Continuous impacts from agriculture runoff and urban sewage are critical issues for many southern Brazilian rivers, and any new source of nutrient loads would be problematic. However, properly planned and located aquaculture could enhance fishery production in reservoirs.

The preservation of strategic public water resources requires government planning to set limits on any activity with the potential for causing eutrophication. Government and private stakeholders agree on the risks of pollution from cage aquaculture, and regulations limited the cage facilities in hydroelectric reservoirs to 1 percent of the area of each site, but no objective evaluations proved this limit suitable.

Harmonization required

The environmental sustainability of cage aquaculture depends on harmonization between farming practices and the hydrological peculiarities of the proposed site. Natural resources must be used without causing drastic, deleterious changes in the structure and function of the ecosystems in which cages are sited.

The main risks are associated with eutrophication processes. In freshwater reservoirs, phosphorus emission is a key factor. To quantify the amount of fish that can be produced at each site, engineers must determine how much phosphorus is loaded per ton of fish produced to establish the carrying capacity of the site – the amount of phosphorus that can be loaded in a given period without surpassing the threshold of eutrophication. The phosphorus load can be calculated by considering feed conversion ratios and the phosphorus content of feed, while carrying capacity is much more complicated to assess.

Water quality conditions were excellent at the studied sites.

Carrying capacity

Carrying capacity is determined by the intrinsic limnological characteristics of each site. Its estimation demands field surveys that examine detailed bathymetry, hydrodynamics, water conductivity, profiles of dissolved oxygen and temperature, turbidity, chlorophyll and other factors.

The main factors considered in determining the carrying capacity of a given site are:

- Mean depth. Deeper depths allow more intensive production.
- Flushing rate is calculated as the theoretical time needed to fully exchange the water volume of a site. Low flushing times allow more intensive production.
- Initial water nutrient content. Cleaner water with less nutrients can handle a higher aquaculture load.
- Sedimentation rate. More intense sedimentation keeps water clean, allowing more intensive production.

These assessments are made using mass balance models to estimate the amounts of nutrients that can be loaded without triggering eutrophication. If the nutrient load related to the production of a ton of fish is known, the maximum allowable production at a given site can be calculated.

Load modeling

For instance, in Table 1, the simulated carrying capacities for tilapia cage culture in two sites with similar 31-square-kilometer areas but different water retention times and mean depths were very different – 3,982 versus 7,768 MT/year in the Pantano River and Ponte Pensa River areas, respectively. This resulted even though the more productive site displayed a higher initial phosphorus level (12.7 versus 16.1 mg per cubic meter).

David, Simulated carrying capacity, Table 1

Site	Area (km^2)	Mean Depth (m)	Volume (m^3)	Flushing Rate (days)	Initial Total Phosphorus (mg/m^3)	Phosphorus Limit (mg/m^3)	Sedimentation Rate	Maximum Annual Phosphoru Load (mg/m^2)
Pantano River	31.61	6.0	189,660,000	33.01	12.7	30	0.335	1,700.82
Ponte Pensa River	30.88	10.4	321,152,000	21.61	16.1	30	0.290	3,396.16

Table 1. Simulated carrying capacity for two tilapia cage culture facilities with similar areas.

Model calculations assumed a standard phosphorus emission of 13.5 kg/mt of produced tilapia based on an average 1.5 feed-conversion ratio (FCR) and 1.5 percent total phosphorus feed content, although feeding management may drastically affect total allowable fish production.

Simulating a 20 percent FCR shift from 1.5 to 1.8, phosphorus emission would increase 25 percent, resulting in a 25 percent reduction in the compatible production according to site carrying capacity. Accordingly, a 6.7 percent change in phosphorus feed content from 1.5 to 1.6 percent would result in a 9 percent decrease in total allowable production at the farm site. Total production can be almost tenfold lower when low-quality feed and high FCR are associated (Fig. 1).

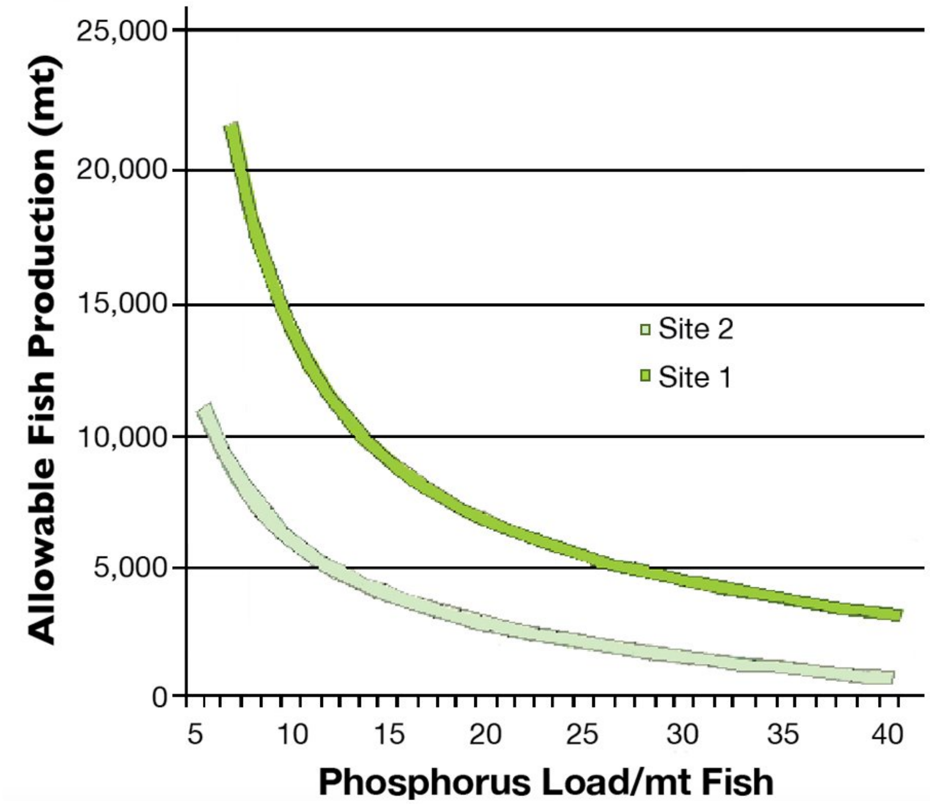

Fig. 1: Total allowable fish production is strongly affected by phosphorus loads.

Some reservoir sites register significant nutrient increases related to cage farming, but not enough to reach the eutrophication threshold due to the limited scale of farming operations. Seasonal variations in hydrological features are also relevant, with reduction in the carrying capacity related to massive nutrient influx from agricultural and sewage runoff, especially in summer, when water temperatures are more favorable for tilapia farming.

Water temperatures during winter months are frequently below 20 degrees-C, when tilapia cultivation is less profitable due to reduced growth and potential increases in diseases and parasites. Under these conditions, the efficiency of nutrient use by fish may be lower, with potential higher nutrient emissions to the environment. Careful climate zoning for tilapia cultivation could assist proper planning of cage siting.

Environmental planning

In the last four years, carrying capacity studies have been carried out by the authors’ research group at 19 sites in the upper Paraná River basin with a concentration on the Ilha Solteira and Chavantes reservoirs. Fish production at most studied sites seemed compatible with local carrying capacities for assimilation and recycling of nutrients derived from farming. Water quality conditions were excellent, with no signals of surpassing eutrophication thresholds – probably due to the limited scale of the farming operations.

Specific models are needed for the further management of aquaculture in the ecosystems considered. Effective planning for farming public waters will require further discussion and guidance at various governmental levels to reach a truly sustainable aquaculture.

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