Focus

Aquaculture

Searching for footprints

The concept of an ecological 'footprint' is a worthwhile tool for analyzing different aquaculture production systems

The useful 'ecological footprint' approach is not new. In 1967, Bergstrom used the term 'ghost acreage' to reflect the area of agricultural land required for food consumption. Using the concept of energy density (the amount of energy consumed per unit of area per year), Odum in 1989 estimated that cities and industrial areas occupy 6 per cent of the continental US, but when their ecosystem shadow area is included, they appropriate about 35 per cent.

It was Rees and Wackernagel in 1994 who introduced the term 'ecological footprint' to reflect the land area necessary to sustain current levels of resource consumption and waste discharge by a given human population. They estimated that the population of Lower Fraser Valley, Vancouver, B. C., depends for *food*, forestry products, carbon dioxide assimilation and energy, on an area 19 times larger than that contained within its boundaries.

Based on this result, and a similar result for the Netherlands, they argued that it would not be possible to sustain the present human population, of close to six billion, at the same material standard as an average North American. That would require two additional planet Earth's.

In our work, we have used the footprint concept when trying to develop concepts and management tools that take into account the support ecosystems needed for different aquaculture production, systems. By doing so, it is more easily realized that aquaculture relies on many resources and must, therefore, be viewed in a broader context and not as an isolated sector. Aquaculture needs nature, both for the supply of resources (water, feeds etc.), and ecosystem services (waste assimilation, etc.).

If aquaculture development is to be ecologically sustainable, efforts must be directed towards methods that make use of the natural environment without severely or irreversibly degrading it. These systems should require fewer resources, use them morn efficiently and emit wastes which do not exceed the assimilative capacity of the environment.

We have analyzed the area of coastal and marine ecosystems (and freshwater) that is required to sustain the yields of fish, shrimp, shellfish and seaweed from various fisheries and aquaculture, and have compared the ecological footprints of intensive production systems with semi-intensive and extensive systems.

In 1988, C. Folke estimated the amount of primary production in the North Sea and Baltic Sea ecosystems that is required to harvest salmon by fisheries, and to produce the fish exploited by fisheries to feed salmon farmed in cages. The estimate was based on existing data on the relationships between the trophic levels of these seas.

He found that production of the fish content of dry pellets fed to cage-farmed salmon demands a "supporting marine production area about 40,000-50,000 times the surface area of the cultivation. He also found that the area of marine support—the marine footprint—is similar, or about 1-2 km per tonne of salmon produced, irrespective of whether the salmon is harvested by fisheries, ranched at the coast, or farmed in cages.

Life support systems

The results indicate that although new technologies change the pattern of exploitation, they do not seem to make economic activities less dependent on the work of life-support ecosystems.

By far the largest support system is the mangrove nursery for shrimp post-larvae. which may be as much as 160 times the size of the cultivation pond, if a large proportion (half) of the post-larvae used are caught wild and post-larval density in the mangrove nursery is low (0.3 individuals per sq in).

If, on the other hand, only 10 per cent of post-larvae are caught wild, and seed are more abundant (one per sq in), then the mangrove nursery need be no larger than 10 times the size of the pond area. The sea area required to support the fish catch for pellet manufacture was estimated to be 14.5 sq m per sq m of pond, while agricultural ecosystems vegetable component in occupy 0.5 sq m per sq m of farm area.

The amount of water pumped yearly into the ponds is equivalent to a lagoon 3m deep and 7.2 sq in area for every sq in of pond. The adjacent mangrove area needed to produce a sufficient litterfall to fulfil the hypothetical 30 percent shrimpdietary requirement for mangrove detritus was estimated at 4.2 sq in per sq m of pond.

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On the other hand, the forest area necessary to sequester the carbon dioxide released directly and indirectly (by energy use in producing industrial inputs to the farms) by shrimp farming was estimated to range between under one sq m and 2.3 sq m per sq m pond. In all, external support ecosystems were estimated to be between 35 sq m and 190 sq m of shrimp pond area.

With the exception of the agricultural support area, the ecosystem support areas are all larger than the pond area, ranging from only a few times the size of the pond area to twice the magnitude, as is the case for the maximum estimated post-larval nursery area. The implication of the size of the supporting mangrove nursery area becomes clearer when shrimp farming is looked at a national and regional level. The total pond surface area of Colombia's shrimp farms in 1990 was 29 sq km, which implies that the size of the mangrove support system supplying pest-larvae for Colombian shrimp farming was between 874 sq km and 2,300 sq km. This accounts for 20 to 50 per cent of the total mangrove area in the whole country, estimated at under 4,400 sq km, not all of which is suitable habitat for shrimp post-larvae.

The largest support ecosystem, mangrove nurseries for post-larvae, thus extends far beyond the physical locations of the shrimp farms and is a vulnerable link in the farming operation. Other support areas, although being minor in size, are of special importance since they must be located in close vicinity of the farms (except the agricultural support system and the carbon sequestering system). If the local area around the farm is depleted of clean water or if the environment is polluted, this may immediately hit back on the cultivation.

It is notable that the calculated mangrove support area for detritus production (4.2 sq m/sq m) closely matches the area of existing mangroves draining into lagoons from which the Bay of Barbacoas shrimp farms draw their water (approximately 3.6 sq m/sq m). This suggests that further construction of ponds using the same water resource could cause a decline in productivity in the existing ones, and that new farms should be better located elsewhere.

Since transportation costs are a major expense, there is a great incentive to locate new farms as close as possible to roads or existing farms (since these already have the necessary facilities, such as boats and jetties). This could lead to crowding and degradation of the necessary lagoon and mangrove support system and would also transfer disease from one farm to another, with potentially very serious results.

As a basis for deciding how aquaculture could be developed to improve the chances for sustainable resource use and long-term maximized fish production in Lake Kariba, Zimbabwe, we estimated the economic and ecological resource demand, expressed in industrial and solar energy units, respectively, for semi-intensive pond farming and intensive cage farming.

Also estimated were the ecosystem areas appropriated by the two farms for production of feed, oxygen and phosphorus assimilation. The results showed that intensive cage farming would require about 17,800 million joules (mj) of solar energy (gross primary production) to produce one kg of fish. The industrial energy input would be more than one and a half times higher (about 85 mj/kg) compared to semi-intensive pond farming (about 50 mj/kg).

Intensive cage farming must also be supported by ecosystem areas that are all substantially larger than the area of the farm itself. The aquatic ecosystem area for producing feed is the largest (21,000 sq in / sq m cage area), but the areas required for daily oxygen production (compensating for fish respiration and biological oxygen demand or BOD) (160 sq in lake area / sq m cage area) and nutrient assimilation (115 sq m area / sq in cage area) are of special importance since these areas must be located close to the *farm*.

For semi-intensive pond farming, oxygen production and nutrient assimilation could probably be provided within the pond system, and no external life support from Lake Kariba would be needed, since waste from harvested fish could be used in the ponds. This waste does, of course, also originate from a support area, but it is not accounted for, as the waste would otherwise be thrown away.

From an ecological point of view at least, semi-intensive pond farming is more sustainable than intensive cage farming because it needs a smaller input of external resources to survive. However, from our study, it was also concluded that a moderate level of intensive cage farming could exist beside the pond farming systems, giving the pond farmers access to a functioning support and transportation network.

We are aware that ecosystems are complex, with non-linear thresholds and discontinuities, but the ecological footprint is a static measure. Although static, the footprint eliminates the ‘bidden’ requirement for ecosystem support, and puts the scale of aquaculture within an ecosystem framework.

There are some important aspects of ecological footprints that we are in the process of analyzing. One is to compare several activities using a mutual ecosystem and to establish the extent to which their footprints overlap and if so, whether they compete or supplement one another. Another critical issues concerns ecosystems as multifunctional systems. Several resources and services are produced by the same ecosystems. To address this properly requires a knowledge of the internal relationships of the ecosystems.

Further, besides relating the size of a footprint to the resource appropriated, the permanency of the footprint has to be taken into account as well. This means that we have to separate between activities appropriating only a minor part of the supporting system and those appropriating larger parts, and also between short-lived effects from the footprint on the ecosystem and more permanent effects.

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