Measuring aquaculture sustainability

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Sustainability has been defined in many ways by different authors and institutions. However, there is an agreement concerning some fundamental points that cannot be excluded. We can define sustainability as the management of natural, financial, technological and institutional resources, ensuring the continuous satisfaction of human needs for the present and future generations. This is an anthropocentric concept, which considers the human needs above everything, excluding the other ways of life, unless they interfere with the human species. Moreover, it involves perennially in time. Time scale is the generations. Therefore, a venture is not considered sustainable unless it survives throughout human generations. Every generation must inherit a stock of natural resources, equal or larger than the one inherited by the previous generation. Sustainability requires a human life style within the limits imposed by nature; we must live within the capacity of the natural capital.

Sustainable aquaculture may be defined as the cost-effective production of aquatic organisms, which keeps a harmonic and continuous interaction with the ecosystems and the local communities. It must be productive and profitable, generating and distributing benefits, which may or not be monetary gains. It must use the natural resources in a rational way and must not degrade the ecosystems int which it is inserted. It must generate employment for the local community, increasing quality of life and respecting local culture. The environmental or social impacts caused by aquaculture may be quantified monetarily and included in the production costs. It is called the externality of a project. These duties may be collected by public institutions and be reverted to the involved communities. Projects may be designed in a way to ensure profitability, considering all the production costs, including externalities.

Responsible aquaculture is a different concept. It is the production of aquatic organisms according to the codes of ethics established by social institutions, such as associations of producers, government agencies, consumer associations among others from civil society. Normally, these codes of ethics aim to establish best management practices to reduce environmental impact, labor mistreatment, prejudice for local communities and animal suffering. Boyd (2003) presented an overview of the Best Management Practices used to reduce environmental impacts from aquaculture. Generally, responsible aquaculture is closer to sustainable aquaculture, but using best management practices does not mean that a system is sustainable. We must keep in mind that to be sustainable, it must be perennial in time, at least for more than one generation.

Fig. 1. Rice-freshwater shrimp culture in Brazil. There is a large potential to integrate aquaculture with rice culture in the West Hemisphere with a very low investment. This will improve the use of land and enhance the economy. (Photo: Marcello Villar Boock)

Most high technology aquaculture systems in the Occident are based on monoculture of species intensively fed with commercial diets. These systems are very inefficient because less than 20 percent of the material provided in the diet is converted to biomass of the target species. This means that more than 80 percent of the diet – which normally is the major production cost – is lost, transformed into a pollutant or incorporated into nontarget biota. This fact is overlooked because only the apparent feed conversion rate is determined in aquaculture projects. Formulated commercial diets normally contain about 90 percent dry matter, while live aquatic organisms contain 20-25 percent. Therefore, an apparent conversion rate of 1.6:1, in fact is about 6-7:1. These systems are clearly non-sustainable and they arise because normally only productivity, weight gain and survival of the farmed organism are evaluated. In addition, intensification of aquaculture systems is generally considered unsustainable, regardless of whether or not it promotes more efficient use of facilities and natural resources. Therefore, it is necessary and urgent to establish reliable indicators and indexes to measure sustainability in aquaculture.

Measuring Sustainability in Aquaculture

The major difficulty in evaluating sustainability is the challenge to explore and analyze a system in a holistic way.

It is essential to contemplate all dimensions of the production process and compare measurements of variables from a very different nature. A few papers have been published using ecological footprint (Folke *et al.* 1998, Gyllenhammar and Häkanson 2004), life cycle analysis (Aubin *et al.* 2006, 2009; Gronroose *et al*. 2006) and energy analysis (Cavalett *et al*. 2006, Vassallo *et al.* 2007, Vassallo *et al*. 2009) to assess the sustainability of aquatic production systems. These methods give an integrated overview of the systems. However, all of them require a vast amount of data that is difficult to obtain. In addition, the first two focus mainly on the environmental dimension. On the other hand, aquaculture sustainability may be divided into parts that may be evaluated using sets of indicators. Recently, groups of indicators have been proposed to evaluate aquaculture sustainability (Consensus 2005, Pullin *et al*. 2007, Boyd *et al*. 2007, EVAD 2008).

In this article, we approached aquaculture sustainability in three dimensions or scopes: economic, environmental and social. For each, we propose the computation of some indicators based on data obtained according to methods and units defined in the relevant field. In addition, we present some suggestions to approach animal welfare, a very important feature of the productive process for niche markets.

Fig. 2. Pen culture of marine shrimp in south Brazil. This artisanal system creates many jobs with a small investment (Photo: Wagner Valenti).

Fig. 3. Family company in Thailand specialized in harvest for hatcheries. The activity is possible in a region dominated by family farms with high social sustainability. (Photo: Wagner Valenti).

1. Economic sustainability indicators

For the economic dimension, we can use indicators that show if the capital is efficiently used and the activity can generate enough wealth to retain the producer in that activity. The well-known economic feasibility indicators may be used for large projects and for investors. Therefore, the Internal Rate of Return, Payback Period and Benefit-Cost Ratio may be computed for real or simulated projects using the relevant technology to be tested. However, for small family farms, it is more important to know if the activity can support a good life style for the producer and his family. The proposed indicators are:

- **Net income.** This corresponds to the profit summed to the opportunity cost. The opportunity cost includes farmer remuneration, interest over investment and operating capital, and land leasing. If it is negative, the project does not have economic sustainability. If it is positive, it is an indication that the project may be sustainable. But, that is not sufficient. It must ensure the permanence of the farmer in the activity, getting from it his maintenance or a substantial part of it. Summing profits + opportunity costs, it must obtain an annual value enough to give to the farmer and his family an acceptable life style in the region in which the enterprise is situated.
- **Proportion of the invested capital that has been generated by the activity itself.** Sustainability of each aquaculture sector (e.g. tilapia culture, freshwater shrimp culture, etc.) may be evaluated by the proportion of the investment that has been generated by the sector itself. Sectors that grow with the capital generated in other sectors of the economy or with governmental subsides are not sustainable. This analysis must be done on a local, regional or country basis, considering each sector separately, or aquaculture as a whole.
- **Minimum enterprise size**. The minimum enterprise that ensures income for the livelihood of one family with a good quality of life. A four member family is used as a base. Lower enterprises would be more sustainable.
- **Net income/ initial investment:** Enterprises with lower initials that generate the same liquid income would be more sustainable, inasmuch as they correspond to a more adequate use of the capital resource.
- **Traditional indicators of economic feasibility.** Includes Internal Rate of Return, Payback Period, Benefit-Cost Ratio, Net Present Value and Profit (Shang 1990, Jolly and Clonts 1993). These indicators should include the externality costs. Traditional indicators are useful for enterprises that involve investors. For small farmers, the time that the capital returns or the profitability investments make may be irrelevant. They are really interested in keeping the family in a good life style with that business.

Fig. 4. Production of Brazilian coconuts in the vicinity of freshwater shrimp ponds. This is a good way to improve the use of land and other natural resources. (Photo: Wagner Valenti).

Fig. 5. Freshwater shrimp are frequently sold along the roads in Thailand. This is a way to increase profits and increase the number jobs in family companies. (Photo: Wagner Valenti).

2. Environment sustainability indicators

For the environment dimension, we have to consider three major aspects: the quantitative use of natural resources, the efficiency of using natural resources and the waste generated, which can potentially damage the environment. Water, land, total energy and the total amount of phosphorous (P), nitrogen (N) and carbon (C) used per ton of target organism produced are good indicators for the use of resources. Non-renewable materials (such as P) are most important. The percentage of energy and key materials provided by the farmer (as P and N), which is effectively incorporated into biomass of the target species are indicators of the efficiency of resources use. The amount of P, N, total suspended solids, biochemical oxygen demand and chemical oxygen demand generated in effluent water and the total amount of greenhouse gas emissions to the atmosphere per ton of target organism produced may be used as indicators of pollution.

The following indicators are proposed to measure the use of resources:

- Space (S): S = area used/production
- Water (W): W = consumed volume/production
- Energy (E): E = energy consumed/production
- Materials (M): M= material applied/production
  - ◊ N = mass of nitrogen applied/production
  - ◊ P = mass of phosphorus applied/production
  - ◊ Protein = mass of protein applied production
  - ◊ C = mass of carbon applied/production

A higher weight should be attributed for resources that are not renewable at the same rate it is used by man. For example, phosphorus that is lost to the ocean.

The following indicators are proposed to measure the efficiency in the use of resources:

- Energy: E= energy applied/energy recovered in production
- Materials: M= material applied/the same material incorporated in production
  - ◊ N = mass of nitrogen applied/mass of nitrogen recovered in production
  - ◊ P = mass the phosphorus applied/mass of phosphorus recovered in production
  - ◊ Protein = mass of protein applied/mass of protein recovered in production

Again, a higher weight should be attributed to the resources that are not renewable in the same rate of used by man.

The following indicators are proposed to measure pollutants released to the environment:

- Load of N: mass of N released in the effluents/mass of aquatic food produced;
- Load of P: mass of P released in the effluents/mass of aquatic food produced;
- Load of organic matter (OM): mass of OM released in the effluents/mass of aquatic food produced;
- Load of total suspended solids (TSS): mass of TSS released in the effluents/mass of aquafood produced;
- Load of BOD_5: BOD_5 caused by the effluents/mass of aquatic food produced;
- Load of greenhouse effect gases: mass of CO_2 + CH_4 (measured in equivalents of CO_2) released to the atmosphere/mass of produced aquatic food.

The following indicators are proposed to measure pollutants accumulated inside ponds:

- Load of N accumulated in sediments: mass of N accumulated in the sediment/mass of produced aquatic food;
- Load of P accumulated in sediments: mass of P accumulated in the sediment/mass of produced aquatic food;
- Load of OM accumulated in sediments: mass of OM accumulated in the sediment/mass of produced aquatic food.

3. Social sustainability indicators

Projects that generate more inputs for the local community and distribute wealth are more sustainable. Therefore, the percentage of breakeven price spent as labor, the ratios of labor cost:gross income and labor cost plus other social benefits/profit and the number of jobs created per ton of product may be used as social indicators.

- Proportional cost of labor: percentage of the "breakeven price" that corresponds to labor remuneration. Cost of labor (includes familial labor)/cost of production. For example:
  - ◊ Cost of production ("breakeven price"): US$64,000.
  - ◊ Labor + remuneration of familiar labor US$28,500.
  - ◊ Proportion of labor = (28,500/64,000)x100 = 44.5 percent.
- Labor required per unit of area occupied: man-hours per year/occupied area (ha). Note that this indicator should be analyzed combined with the next indicator.
- Income distribution: value paid with salaries + social fees + social benefits. Example - health insurance paid by the company/profit generated.
- Remuneration of labor per unit of production: value paid in remuneration of labor, including owner/1,000 kg of production.
- Required labor per unity of production: man-hours per year, includes owner, if working/1,000 kg of production.
- Generation of direct employment: number of jobs generated/investment cost.
- Generation of total employment: number of employments and auto-employments generated, direct + indirect/ investment cost.
- Percentage of auto-employments: number of auto-employments generated/ total number of labor post generated.
- Use of local labor: number of labor posts generated that permits the recruitment among local population/ total number of labor post generated.
- Development of local economy: costs that are paid in the local market/total costs, measures the proportion of acquisitions that are made in local markets.
- Local consumption of production: kg of feed sold in the local market/total production. This indicator measures a possible improvement in the food availability for the local community.

Projects with these indexes that are higher would have more social sustainability. But, there are important items that are not contemplated here, such as adaptation of technology to local culture.

Welfare Measurement

Because welfare is a characteristic of the animal, we can attempt to measure its quality. Although it has been discussed, little has been defined about this issue because of its complexity of interactions. Some proposed indicators to measure it are presented here.

- Lifetime reproductive success: length of successful reproductive performance. This indicator may be used even for growout animals, inasmuch as it may indicate delay in the onset of reproduction. For breeders, it may include life expectancy as well.
- Proportion of body damage: number of damaged animals/total animals.
- Proportion of sick animals: number of diseased animals/ total animals;
- Stress hormone level: proportion of stressed animals (according to hormone readings)/total animals.
- Percentage of abnormal behavior: proportion of animals in abnormal behavior/total animals.
- "Painless slaughter" use: considering that there is an ongoing discussion on whether or not animals feel pain, we are assuming here that animals may feel pain. Therefore, if methods are used during slaughter to prevent animals of feeling pain, it must be given a higher value.
- Environmental characteristics: the animal must be reared within the range defined as adequate for its development. Then we can define the indicator as: the number of water variables suitable for the farmed species/total measured variables. The measured variables may be dissolved oxygen, temperature, ammonia, nitrite, pH, salinity and trace elements.

Fig. 6. Trial to control daily feed consumption in ponds in Thailand. This management may optimize feed supply decreasing costs, wastes and increasing labor. It may increase economic, environmental and social sustainability. (Photo by Wagner Valenti)

Conclusion

The above indicators can be converted to a performance scale according to criteria scientifically defined to estimate the endpoints, Example: we may attribute zero for the worse score and 100 for the best one. Then, we can combine the indicators and obtain a sub-index for each dimension. The arithmetic average among the three sub-indexes will generate the sustainability index.

Selected sustainability indicators and/or sustainability indexes may be used by scientists to evaluate different treatments of an experiment, by investors and policy makers to evaluate different projects to be supported or by farmers to move their farming systems toward sustainable production. To develop technology for production, low sustainability systems have no validity, nor attend to the desires of society. To utilize them for production is wasteful.

It is evident that the proposed indicators need to be tested and may be improved to obtain a cluster of comparable indicators that reflect the sustainability of aquaculture in its all dimensions.

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Notes

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