Open sea Cage culture: carrying capacity and stocking in the grow out system

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Developing open sea cage farming is a new way of providing employment to fishermen transferring from fish capture to aquaculture. It will also create significant socio-economic influences in the future. The near target of cage culture is that marine fish farming will become a main force in aquaculture sector. The open sea cage culture has been expanding in recent years on a global basis and it is viewed by many stakeholders in the industry as the aquaculture system of the millennium. The Asian seabass, *Lates calcarifer,* known as "Kaalangi" in Kerala is an important candidate finfish species for sea cage farming.

Carrying capacity

A major consideration in the site selection process should be the carrying capacity of the site which indicates the maximum level of production that a site might be expected to sustain. Intensive cage fish farming results in the production of wastes which can stimulate productivity and alter the abiotic and biotic caracteristics of the water body, whilst less intensive methods can result in over croppping of algae and a fall in productivity. Hence profitability or even viability may be seriously affected. Therfore it is extremely important for all concerned with cage fish farming to have an accurate evaluation of the sustainbale levels of production at a particular site before culture.

The *carrying capacity* of a biological species in an environment is the population size of the species that the environment can sustain indefinitely, given the food, habitat, water and other necessities available in the environment. In ecological terms, the carrying capacity of an ecosystem is the size of the population that can be supported indefinitely upon the available resources and services of that ecosystem. Living within the limits of an ecosystem depends on three factors:

- the amount of resources available in the ecosystem
- the size of the population, and
- the amount of resources each individual is consuming.

A simple example of carrying capacity is the number of people who could survive in a lifeboat after a shipwreck. Their survival depends on how much food and water they have, how much each person eats and drinks each day, and how many days they are afloat. If the lifeboat made it to an island, how long the people survived would depend upon the food and water supply on the island and how wisely they used it. A small desert island will support far fewer people than a large continent with abundant water and good soil for growing crops. In this example, food and water are the natural capital of the island. Living within the carrying capacity means using those supplies no faster than they are replenished by the island's environment: using the 'interest' income of the natural capital. A community that is living off the interest of its community capital is living within the carrying capacity. A community that is degrading or destroying the ecosystem on which it depends is using up its community capital and is living unsustainably. So, in the context of sustainability, carrying capacity is the size of the population that can be supported indefinitely upon the available resources and services of supporting natural, social, human, and built capital.

Within the context of aquaculture, environmental carrying capacity is defined as the maximum number of animals or biomass that can be supported by a given ecosystem for a given time. This is particularly important to aquaculturists who seek to optimize the economic value or yield per unit area, or regulatory authorities who are interested in minimizing the negative impacts aquaculture can have on the natural environment through the issuing of permits or granting concessions.

Estimation of Carrying capacity

In semi-intensive and intensive systems the number of fish that may be stocked will be limited by the "carrying capacity" of the water. This can be calculated using standard methodology. Before considering how to model the impact of cage fish culture on the environment, the rationale behind using this method to increase fish production should be understood. The modeling is based on the assumptions that algal population densities are negatively correlated with water quality in general and growth and survival of fish stocks in particular, and that phosphorus (P) is the limiting nutrient which controls phytoplankton abundance in the water bodies. Phosphorus and, occasionally, light are the principal factors limiting production, and thus the net addition or uptake of P or materials which greatly influence the light climate will alter productivity. Phosphorus is an essential element required by all fish for normal growth and bone development, maintenance of acid-base regulation, and lipid and carbohydrate metabolism. Diets deficient in P can suppress appetite, normal food conversion and growth, and under extreme circumstances affect bone formation and lead to death.

Feed losses are inevitable during fish culture for a number of reasons; but the left over food that is not be eaten is actually not a loss in the culture systems; instead contribute to the wastes from the operation. Manufacturers estimate that 2% of feed is 'dust', due largely to the crumbling of pellets during packing and transport and thus at least 2% of commercial feeds will be uneaten and contributes to the water body.

In order to determine the potential of a water body for intensive enclosure, the productivity of the same prior to exploitation must be assessed through measurement of the steady-state total-P concentration, The development capacity of a lake or reservoir for intensive cage and pen culture is the difference between the productivity of the water body prior to exploitation, and the final desired level of productivity. As stated above, [P] can be used as a productivity indicator. However, it must be decided whether it is then mean annual algal biomass, or the peak annual algal biomass, as measured by chlorophyll levels [ch1] and $[ch1]^{max}$ respectively, that we wish to predict. Since fish are usually held in cages throughout the year, it is the latter parameter which should be considered.

The capacity of a water body for intensive cage and pen fish culture is the difference, Ä [P], between [P] prior to exploitation, $[P]_i$, and the desired/acceptable [P] once fish culture is established, $[P]_f$.

I.e. Ä [P] = $[P]_f$ - $[P]_i$

Ä[P] is related to P loadings from fish enclosures, L_{fish}, the size of the lake, A, its flushing rate, ñ, and the ability of the water body to handle the loadings (*i.e.* the fraction of L_{fish} retained by the sediments, R_{fish}):-

$$\Delta[P] \qquad \frac{L_{fish}\ (1-R_{fish})}{\bar{z}\rho}$$

$$L_{fish} = \frac{\Delta[P]\bar{z}\rho}{1-R_{fish}}$$

The acceptable/desirable change in [P], Ä [P] (mg m^{-3}), is determined as described above, and z can be calculated from hydrographic data obtained either from literature or survey work:-

$z = \frac{V}{A}$ Where V = volume of water body (m^3) and A = surface area (m^2) the flushing rate, (y^{-1}) is equal to Q_o/V, where Q_o is the average total volume out flowing each year. Q_o can be calculated by direct measurement of outflows, or in some circumstances can be determined from published data on total long-term average inflows from catchment area surface runoff (Ad.r), precipitation (Pr) and evaporation (Ev), such that

Q_o = Ad.r + A(Pr - Ev) (see Dillon and Rigler, 1975, for further details).

The retention coefficient, R, can be determined experimentally by measuring the mean annual inflow and outflow [P], $[P]_i$; and $[P]_o$ respectively:-

$$R = .1 - \frac{[P]_o}{[P]_i}$$

Marine cage aquaculture produces a large amount of waste that is released directly into the environment. To effectively manage the mariculture environment, it is important to determine the carrying capacity of an aquaculture area. In many Asian countries trash fish is dominantly used in marine cage aquaculture, which contains more water than pellet feed. The traditional nutrient loading analysis is for pellet feed not for trash fish feed. So, a more critical analysis is necessary in trash fish feed culturing areas. Based on the hydrodynamic model and the mass transport model in Xiangshan Harbor, the relationship between the water quality and the waste discharged from cage aquaculture has been determined. Here corresponding to FCR (feed conversion ratio), dry feed conversion ratio (DFCR) was used to analyze the nutrient loadings from marine cage aquaculture where trash fish is used. The environmental carrying capacity of the aquaculture sea area can be calculated by applying the models noted above. Here nitrogen and phosphorus are the water quality parameters considered for the calculation of carrying capacity. The simulated results showed the maximum nitrogen and phosphorus concentrations were 0.216 mg/L and 0.039 mg/L, respectively. In most of the sea area, the nutrient concentrations were higher than the water quality standards. The calculated environmental carrying capacity of nitrogen and phosphorus in Xiangshan Harbor were 1,107.37 t/yr and 134.35 t/yr, respectively. The results showed that the waste generated from cage culturing in 2000 has already exceeded the environmental carrying capacity.

Unconsumed feed has been identified as the most important origin of all pollutants in cage culturing systems. It suggests the importance of increasing the feed utilization and improving the feed composition on the basis of nutrient requirement. For the sustainable development of the aquaculture industry, it is an effective management measure to keep the stocking density and pollution loadings below the environmental carrying capacity. The DFCR-based nutrient loadings analysis indicates, in trash fish feed culturing areas, that it is more critical and has been proved to be a valuable loading calculation method. The modeling approach for Xiangshan Harbor presented here is a cost-effective method for assessing the environmental impact and determining the capacity. Carrying capacity information can give scientific suggestions for the sustainable management of aquaculture environments. It has been proved that numerical models were convenient tools to predict the environmental carrying capacity. The development of models coupled with dynamic and aquaculture ecology is a requirement of further research. Such models can also be useful in monitoring the ecological impacts caused by mariculture activities.

Fish stocking in the cages

The minimum recommended stocking density for common carp, tilapia, and catfish is 80 fish/m^3. A recommended maximum stock density for beginning farmers is the number of fish that will collectively weigh 150 kg/m3 when the fish reach a predetermined harvest size (Schmittou, 1991). The smallest recommended fingerling size for stocking is 15 g. A 15-g fish will be retained by a 13-mm bar mesh net. Larger fish can also be stocked into cages. Survival rates in well-placed and well-managed cages are typically 98 to 100 %. Unless greater mortality is expected, no adjustment is needed to calculate stocking density. An example of how to calculate the number of fish to stock per cage follows: Assume that a farmer wants harvest fish weighing 500 g from a 1m^3 cage.

Total fish weight at harves t= 150 kg/m^3
Number to stock = 300 fish (300 x0.5kg)
Desired average fish weight = 0.5 kg at harvest
Production = 150 kg/m^3

For a harvest of fish averaging 200 g, the number of fish to stock would be:

Number to stock = 750 fish/m^3
0.2 kg x 750 = 300 kg/m^3

The carrying capacity of a body of water limits the weight of fish that can be cultured. Stocking so many fish that the carrying capacity is exceeded will result in increased stress, disease, and mortality, and reduced feed conversion efficiency, growth rate, and profit. Generally, 1,000 m^2 of water surface area is needed to support 400 kg of fish. A calculation can be used to determine the maximum number of fish which can be stocked into a cage(s) to assure that the weight does not reach the carrying capacity of the water body during culture.

Maximum volume of cages (m^3) = 2.6a*
Where: a = total surface area of water body (1,000s of m^2)

* The constant 2.6 is derived below

$$\frac{\dfrac{400\ \text{kg}}{1{,}000\ \text{m}^2\ \text{pond}}}{\dfrac{150\ \text{kg}}{\text{m}^3\ \text{cage}}}$$

Grow out of the sea bass culture starts as it transfers to the cages from the nurseries. Juveniles of sea bass reared in the nurseries of size 10 - 15 cm in length (25 – 50 g in wt) can be transferred to the cage for the grow-out. The stocking density in the cages varies from 20 – 25 kg/m^3 in the final harvest time. So with a final weight of expectation of 1 kg fishes in harvest time after a period of 6 – 8 months; from the cages the stocking density varies from 25 – 30 fishes / m^3 for the sea bass. Care must be taken to avoid handling stress and other physiological stresses as maximum as possible while transport and stocking.

Once when the carrying capacity is determined in a culture system, and optimum stocking is done accordingly, open sea cage culture can be a successful alternative for any species of high value marine fish.