Available online at www.sciencedirect.com
SCIENCE DIRECT®
Marine Pollution Bulletin 50 (2005) 48–61
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development

Md. Shahidul Islam *

Division of Applied Biosciences, Faculty of Fisheries, Graduate School of Agriculture, Kyoto University, Kyoto 606-8502, Japan

Abstract

Being an essentially open system, cages are usually characterized by a high degree of interaction with environment and cage systems are highly likely to produce large bulk of wastes that are released directly into the environment. Therefore, large-scale cage aquaculture development has been put into question and concerns have been raised that cage aquaculture produces large bulk of wastes that are rich in organic matter and nutrients and are released into coastal and nearshore environment. Recent information on cage aquaculture nutrient budget is scarce and most published reports are dated. This paper reviews cage aquaculture nutrient budget and nutrient loadings and propose a model for nutrient (nitrogen, N and phosphorus, P) budget in a hypothetical cage aquaculture farm with values of feed loss, FCR (feed conversion ratio) and nutrient contents in feed and fish taken from published literature in order to calculate the amount (kg) of N and P produced and released to the environment for each ton of fish produced. The paper proposes, in addition, a critically analyzed nutrient budget based on the dry matter conversion rate instead of the usual feed conversion rate. The conceptual model shows that 132.5 kg N and 25.0 kg P are released to the environment for each ton of fish produced; these values are as high as 462.5 kg N and 80.0 kg P when calculated on the basis of dry matter conversion rate instead of usual feed conversion rate. Thus, the annual global N and P loadings from cage aquaculture (10,000 tons fish and 3000 tons dry matter) are 1325 tons N and 250 tons P and 1387.5 tons N and 240.0 tons P based on usual feed conversion rate and dry matter conversion rate respectively. The paper also proposes, by analyzing the existing data, an FCR-based regression model for predicting nutrient loadings for a given diet. Finally, attempt was made to calculate the annual global loading and release of N and P from cage aquaculture to the coastal and marine environment, the potential impacts of nutrient loading on the ecosystem were discussed and critical points to be considered for minimizing nutrient output in cage aquaculture were suggested.

Keywords: Nutrient budget; Effluent nutrient loading; Cage aquaculture; Nitrogen; Phosphorus; FCR; Mariculture

1. Introduction

The production of fish in cages has been practiced for years in various countries worldwide and still expanding in many parts of the world; some examples of cage aquaculture expansion in terms of the number of cage, area and production tonnage in Asia are shown in Fig. 1. Similar trends have been reported in other parts of the world such as in Asia (Liao and Lin, 2000; Menasveta, 2000; Sharif and Gopinath, 2000; Takashima and Arimoto, 2000) and in Europe (Enell, 1995; Piedrahita, 2003). For example, Enell (1995) reported that over the last few decades there has been a steady development of the fish farming with regard to the feeding and farming technology and to the increase in production quantities. For example, during the period 1974–1994 the production increased from 15,800 to about 250,000 tonnes per year in the Nordic countries (Enell, 1995). Over 50 commercially important fish species have been

* Tel.: +81 075 753 6225; fax: +81 075 753 6229.
E-mail address: msi@kais.kyoto-u.ac.jp

0025-326X/$ - see front matter
doi:10.1016/j.marpolbul.2004.08.008

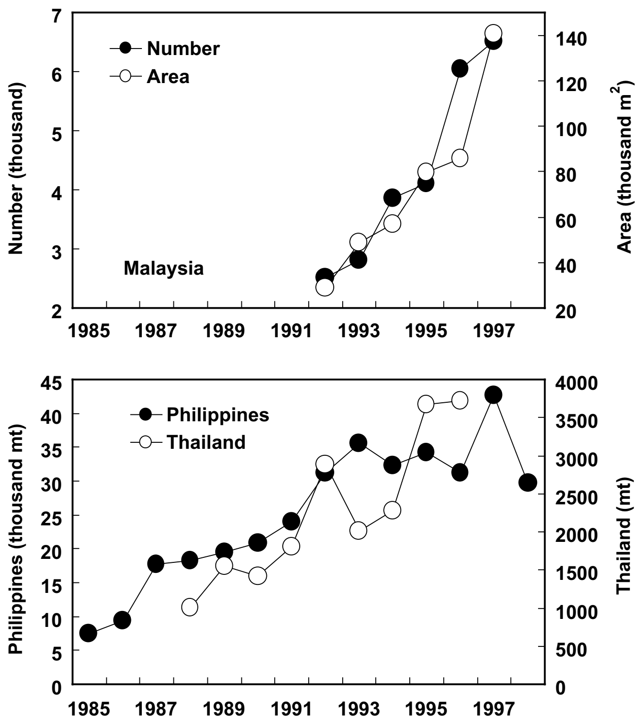

Fig. 1. Trends in cage aquaculture in major Asian countries; upper: increasing number of cage farms and corresponding cage area (m^2) in Malaysia; and lower: production tonnage from cage aquaculture in Thailand and Philippines.

in use for cage aquaculture. Specific production characteristics such as cage design and construction material, stocking rates, feed types and rates and water quality requirements vary greatly depending on the species and water body and the level of technology available.

Cage aquaculture has several advantages over the conventional land-based aquaculture systems (Beveridge, 1984, 1996). Because they use existing water bodies, require comparatively low capital investment and use simple technology, cage aquaculture has been popular among farmers. Unlike the conventional land-based aquaculture systems, cage systems do not use organic and inorganic fertilizers with high N and P contents; however, for the same reason, cage systems usually use diets with higher N content (Ackefors and Enell, 1990). Unlike land-based aquaculture systems, marine cage systems discharge their wastes directly into the environment, the bulk of which are solids or bound to particulate material, and thus subject to sedimentation. Therefore, the expansion of cage aquaculture has led to an increased awareness that fish farming may have considerable impacts on the marine and nearshore ecosystem. In coastal and open sea cage cultures, high organic and nutrient loadings generated from feed wastage, excretion and faecal productions are directly discharged into the environment (Duff, 1987; Hammo, 1987; Waldichuk, 1987; Soley et al., 1994; Wu et al., 1994; Wu, 1995). Therefore, concerns have been expressed that the interaction between a farm and its environment could result in harmful feedback which may have adverse effects on the coastal and marine ecosystems as well as on the farm itself (Gowen and Bradbury, 1987; Wu et al., 1994; Wu, 1995; Leung et al., 1999). Being an essentially ecologically open system, production of high volume of wastes and their release into the environment is obvious and, in general, impacts from these wastes occur over several spatial and temporal scales: internal, local and regional (Silvert, 1992; Beveridge, 1996).

Understanding the nutrient budget of fish farms is useful in mariculture development and management, since information on the loading and forms of nutrients from various sources enable appropriate measure to be devised for the sustainable development of the industry (Leung et al., 1999). The purpose of this review is to quantify nutrient loadings in cage culture farms from reported nutrient loadings and hypothesized nutrient budgets and discuss the pattern and scale of the effects of fish cage effluents on the ecosystem.

2. Cage aquaculture inputs and sources of nutrients

In the semi-intensive land-based aquaculture systems where large amounts of organic and inorganic fertilizers are used to enhance natural productivity, fertilizers provide the major source of nutrient outputs in the system. However, like some forms of intensive aquaculture, cage aquaculture does not use fertilization but requires large amounts of supplied diets which provide the single largest source of nutrient output. Intensive cage culture of fishes is largely restricted to temperate, developed regions, where luxury carnivorous species are grown on expensive, high-protein feeds compounded from fish meal. Intensive feeds are not essential in tropical fish culture, since many of the commercially important species such as the tilapias, carps and milkfish feed readily on natural macrophyte, plankton and detrital production. Supplementary feeds derived from low-cost, low-protein agricultural by-products or wastes, are widely used in order to improve production. However, this scenario has been changing since the last few years in many parts of the tropical cage farming regions. In the Philippines, for example, cage culture of tilapia and milkfish has become semi-intensive to intensive, requiring commercial feeds with 24–30% crude protein which are fed at varying rates (Marte et al., 2000). The trend for coastal aquaculture or mariculture in cages has been increased within the last 5 years due to the greater demand for fish by the ever-growing population in this country. Another example of recent development of semi-intensive and intensive cage culture is the cobia culture in Taiwan which has been heavily relying on commercial feeds