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Review

Aquaculture environment interactions: Past, present and likely future trends

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ABSTRACT

The two-way interactions of aquaculture and the environment are diverse and complex. Three major questions are addressed: what happened in the past, what are today's trends, and what may the future hold? Traditional aquaculture is mostly environmentally compatible as it mainly uses on-farm and locally available wastes and by-products such as crop residues and animal or human manures for nutritional inputs or natural food in open water culture-based fisheries and mollusk and seaweed farming systems. Wastes, by-products and natural food were the only sources of nutritional inputs for most farmed aquatic organisms in the past before the relatively recent and increasing use of pelleted feed in modern aquaculture, leading to major environmental concerns. Environmental aspects of intensification of aquaculture and their relation to ecosystems and agro-ecosystems in inland terrestrial and aquatic, and coastal/offshore, land- and water-scapes are reviewed. Aquaculture is increasingly being adversely impacted by pollution from agricultural, domestic and industrial pollution. Environmental issues are illustrated by case studies of traditional and modern aquaculture farming practice in temperate and tropical inland and coastal areas. Promising technologies that employ the principles of traditional aquaculture to contribute to the sustainability of modern aquaculture are outlined. There does not appear to be a panacea for environmentally sustainable aquaculture on the horizon to meet the increasing demand for aquatic food. This is more likely to be met through improvements in existing technology, including combining aspects of traditional with modern practice; better management practices (BMPs); better site selection so that aquaculture remains within the carrying capacity of inland and coastal water bodies; and the most efficient use of land and water, which is more likely to be aquaculture than farming terrestrial crops in relatively poor agro-ecosystems. Inland aquaculture, especially in ponds, is likely to continue to dominate global aquatic food production.

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1. Introduction

Three major questions are addressed regarding the development of environmentally sustainable aquaculture: what happened in the past, what are today's trends, and what may the future hold? Traditional aquaculture is mostly environmentally compatible as it uses on-farm and locally available wastes and by-products such as crop residues, animal or human manures or natural food in open water bodies as nutritional inputs for farmed aquatic organisms. Wastes, by-products and natural food were the only sources of nutritional inputs for farmed aquatic organisms in the past before the relatively recent and increasing use of pelleted feed in modern aquaculture which has led to major environmental concern. Traditional integrated fisheries aquaculture systems fed low-value/trash fish fed may have adverse environmental impact but open water culture-based fisheries and mollusk and seaweed farming systems based on naturally occurring food are environmentally compatible.

The past and present are contrasted in terms of traditional and modern aquaculture production systems, in natural ecosystems and human-made agro-ecosystems, with emphasis on type of nutrient inputs. Aquaculture is discussed in relation to natural ecosystems and human-built agro-ecosystems in inland terrestrial and aquatic, and coastal/offshore, land- and water-scapes. A major change has been the decline of traditional integrated aquaculture with increasing concerns about environmental sustainability. The two-way impacts of aquaculture on the environment, and the environment on aquaculture, are outlined, with environmental issues illustrated by selected case studies of actual traditional and modern aquaculture practice of inland and coastal aquaculture in temperate and tropical regions. The adverse impact on aquaculture of agricultural, domestic and industrial pollution is discussed. The treatment of pond effluents and examples of how promising technologies employing the principles of traditional aquaculture may contribute to the sustainability of modern aquaculture effluents are presented.

Widely held views on perceived differences in philosophy and action of the Orient and the West towards the environment are discussed. A call is made for more efficient use of nutrients, land and freshwater through aquaculture and the likely future contributions of freshwater and marine aquaculture practice, including open ocean aquaculture, are discussed.

2. Changes over time

2.1. From traditional to modern aquaculture

Aquaculture was entirely 'traditional' up to less than 30 years ago in Asia as locally available resources were the only sources of nutritional inputs available to the farmer before the relatively recent agro-industrial manufacture of pelleted feed (Edwards, 2009a). Traditional aquaculture is mainly integrated with other human activity systems. Major types of traditional aquaculture are integrated agriculture–aquaculture systems (IAAS) with on-farm or local agricultural by-products, manures and/or vegetation; integrated peri-urban-aquaculture systems (IPAS) using domestic sewage and wastes/by-products from local agro-industry; and integrated fisheries–aquaculture systems (IFAS) with carnivorous fish fed with trash and low-value fish. The farming of mollusks and seaweeds, so-called 'extractive species' because they depend for nutrition on usually naturally occurring organic detritus and plankton, and dissolved nutrients in the water column, respectively, may also be considered as traditional aquaculture systems.

There has been a relatively recent rapid increase in aquaculture production based on the development of 'modern' aquaculture through the application of science and technology, with the de-linking of aquaculture from agriculture (IAAS) and sanitation (IPAS). For the purpose of this article modern aquaculture is considered as fed with agro-industrially manufactured feed although it also includes relatively recently developed technologies such as hormonally-induced breeding, genetic improvement and use of diverse chemicals for various purposes. A major issue is the greater adverse environmental impact of modern aquaculture causing eutrophication because of intensification through increasing use of pelleted feed as well as expansion of the aquaculture area. Although there are considerable environmental impacts related to the production of feed ingredients as shown by several recent life cycle analyses (LCA) studies, this paper considers only the direct impacts of the fish farm with the immediate surrounding external environment. Most feed nutrients consumed by fish are released into the immediate environment in which they are farmed as only about 1/3 of the nutrients in the feed are removed in the harvest of the fish with 2/3 voided by fish during growth (Edwards, 1993). The potential adverse environmental impacts of aquaculture effluents increase from rice/fish culture, through pond, and to raceway and cage culture, essentially in direct proportion to the degree of intensification through use of pelleted feed and the exchange of water between the internal environment of the culture system and the external environment.

The main driving force behind the major trend to intensify production is increased farmer profitability through increasing the yield per unit area (Hepher, 1985), made possible by increasing demand for fish through expanding domestic and international markets, and availability of new technologies. The total production of pelleted feed increased more than three times from 7.6 million tonnes in 1995 to 27.1 million tonnes in 2007, with pelleted feed production growing at an average annual rate of 11.1% and expected to continue at a similar rate to 70.9 million metric tonnes by 2020 (Tacon et al., 2011). Even herbivorous and omnivorous species that are traditionally considered to be relatively low-input species such as most carps, catfish and tilapia are increasingly being fed pellets rather than being raised in semi-intensive integrated farming systems (Edwards, 2009a).