Aquaculture 497 (2018) 174–183

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Review

Application of open water integrated multi-trophic aquaculture to intensive monoculture: A review of the current status and challenges in Korea

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ARTICLE INFO

Keywords:
Integrated multi-trophic aquaculture
Intensive monoculture
Coastal zone management
Seaweed
Shellfish
Sea cucumber

ABSTRACT

Intensive fish aquaculture has raised serious environmental concerns, including eutrophication, harmful algal blooms, fish kills, etc. Integrated multi-trophic aquaculture (IMTA) may be the most suitable aquaculture technology to achieve environmental and economic sustainability. The objectives of present study are to review the status of aquaculture and IMTA in Korea; and to determine the challenges to apply the principles of IMTA to intensive monoculture in Korean coastal waters. Korea has been one of the leading countries in aquaculture. Like other advanced countries in aquaculture, such as China and Japan, most aquaculture practices in Korea are intensive monoculture and farms are highly concentrated in bays or estuaries with restricted circulation. In intensive open water aquaculture in these waters, nutrient producers (finfish) are cultured mostly in southeastern Korea whereas extractive organisms (seaweeds) are farmed in the southwestern Korea. There are relatively small areas of overlap between these monocultures, causing environmental issues and reduction in the quality of aquacultured products. Recent attempts of IMTA in Korean coastal waters suggest that IMTA can be a good management tool for improving Korean aquaculture although there are still challenges to overcome. These challenges include development of temperature tolerant species/strains of extractive organisms such as seaweeds and sea cucumbers. Most aquacultured seaweed and sea cucumber species in Korea do not grow well during the summer months, when the release of finfish effluent is at its peak. It is essential to the future success of aquaculture in Korea that a coastal zone management (CZM) be developed that reflects coordinating fed and extractive organisms in coastal bays and estuaries rather them keeping them isolated from one another. The importance of a new regulatory framework advocating IMTA solutions will be essential for environmental protection and continued success of aquaculture in Korea. Although this review is a case study in Korea for IMTA, it will also provide critical information for coastal managers, aquaculturists and regulators in other countries where there are intensive monocultures of fed and extractive organisms.

1. Introduction

The world population will increase by over 50% by 2050, reaching 11 billion (Melorose et al., 2015). Considering this rapid growth of population, as well as climate change, economic and financial uncertainty, and reduction of natural resources, it will be challenging to provide sufficient high quality food for humans. In 2013, approximately 17% of animal protein and nearly 7% of all protein consumed by humans, were provided by fish. Worldwide per capita fish consumption was over 20 kg per year (FAO, 2016). Since the 1980s, growth of the capture fishery production has declined while aquaculture production has increased to meet consumer demands. In 2014, aquatic animal production from aquaculture was over 76 million tons, with nearly US $160 billion of economic value (FAO, 2018). Global fish production is expected to be 181 million tons by 2030, and aquaculture is expected to provide over 60% of the fish by that time (World Bank, 2013). However, intensive fish aquaculture has raised serious environmental concerns. For example, eutrophication due to excess nutrients by fish effluents can cause harmful algal blooms (HABs) (Buschmann et al., 2008; Chopin et al., 2012; Ridler et al., 2007). The sediments underneath or nearby intensive fish aquaculture have accumulations of organic matter providing a good breeding ground for parasites (Alonso-Pérez et al., 2010; Richard et al., 2007; McKindsey et al., 2011; Molloy et al., 2013; Lunstrum et al., 2018). With environmental degradation caused by intensive finfish aquaculture, these wastes can kill or diminish the fish production systems. Therefore, it is critical to develop

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https://doi.org/10.1016/j.aquaculture.2018.07.051
Received 9 May 2018; Received in revised form 26 July 2018; Accepted 27 July 2018
Available online 30 July 2018
0044-8486/

Fig. 1. Intensive seaweed (*Pyropia*) farm in Wando, Jeonnam, Korea.

sustainable aquaculture systems for the long-term aquaculture expansion. Integrated multi-trophic aquaculture (IMTA) is a practice that will achieve environmental and economical sustainability.

Integrated multi-trophic aquaculture is a farming technology growing aquaculture species from different trophic levels in one system with fed-aquaculture and extractive aquaculture components. More specifically, in IMTA systems, deposit feeders and suspension feeders (shellfish) can consume the organic particulate waste from the fed-aquaculture (finfish or shrimp). Seaweeds can take up the inorganic wastes. Many studies have shown that IMTA technology increases the biomass yield of aquacultured animals and seaweed while reducing the waste stream (Barrington et al., 2009; Chopin et al., 2008; Hughes and Kelly, 2011; Ren et al., 2012; Wang, 2001; and references therein).

IMTA is not a new concept. IMTA-like practices have been conducted in China for centuries possibly as earlier as 470 BCE by Fan Li (Yang et al., 2000), but the modern IMTA concept was originally described by Ryther and his colleagues at Woods Hole Oceanographic Institution in 1970's (Ryther, 1977; Ryther et al., 1979). Since then, many IMTA practices have been described worldwide, principally in western countries (McVey et al., 2002; Abreu et al., 2009, 2011; Buschmann et al., 2008; Chopin et al., 1999; Corey et al., 2014; Neori et al., 2004; Ridler et al., 2007). Although Shangou Bay in China is known to be the world largest IMTA practice (Fang et al., 2016; Mahmood et al., 2016; and references therein), IMTA has not been well developed in other Asian countries. Consequently, these aquaculture practices in most Asian countries are still focused mostly on intensive monocultures, leading to a plethora of environmental problems (e.g. eutrophication, HABs, disease, etc.).

Most Korean IMTA practices have conducted in small land based systems (Chung et al., 2002; Kang et al., 2008, 2013, 2014). The first open water IMTA practice began in 2012 (Park et al., 2016). In Korea, intensive fish aquaculture has been practiced for many decades in highly congested bays and estuaries, causing severe environmental problems. Recently, the open water IMTA has received a lot of attention by aquaculturists and coastal managers to reduce the environmental impact of intensively farmed areas. However, there is scant information available about the status of IMTA in Korea. This review will provide critical information about the status of aquaculture and IMTA in Korea and to determine the impediments to apply the principles of IMTA in Korean coastal waters. To achieve these goals, we reviewed several different perspectives, including: 1) current status of aquaculture in Korea; 2) challenges of intensive open water monoculture; 3) IMTA as a potential solution for the issues of intensive aquaculture; 4) summary of open water IMTA practices in Korea to date; and 4) the challenges to the acceptance of IMTA. Although this review focuses mostly on the cases in Korea, this study will provide critical information for global perspective of sustainable and IMTA development.