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Abstract

Aquaculture faces a double challenge produce more to sustain growing demand for aquatic products and respect the environment. For several years, Integrated MultiTrophic Aquaculture (IMTA) has gained worldwide attention. IMTA is based on integrated cultivation of aquatic organisms from different but complementary trophic levels. The objective of this study was to assess environmental performances of pond-IMTA systems based on freshwater polyculture experiments in earthen ponds conducted in Romania, France and Indonesia that explored different ways to combine fish and plants. In each experiment, the IMTA system was compared to a conventional or traditional system for the country (carp polyculture in Romania, intensive polyculture in France and gourami monoculture in Indonesia). Environmental impacts of IMTA systems differed among case studies. In Romania, environmental impacts also differed between years: IMTA system had higher impacts than the traditional one in 2016 but has lower impacts in 2017. In France, conventional system had lower cumulative energy demand, eutrophication and NPPU than semi-intensive and IMTA system, the latter had the highest values of these impacts. However, for climate change the conventional system has higher impact than IMTA and semi-intensive system. In Indonesia, IMTA system had lower impacts than the tradional one. The environmental impacts estimated in this study illustrate the variability in the responses of IMTA systems. Impacts of agricultural systems depend on system productivity and the amounts of inputs embodied in the system. IMTA is expected to provide improvements such as a decrease in input use such as feed, increase in fish yields, and/or decrease in emissions per unit mass of fish produced. Depending on the practices, increasing the number of species or their organization through IMTA practices can decrease environmental impacts, especially local impacts such as eutrophication, compared to classic practices. Production and use of fish feed is one of the main causes of environmental impacts. Based on our results, IMTA practices can improve resource use and decrease the overall impact of aquaculture. Any increase in inputs used to improve nutrient recycling must also increase productivity to ensure a decrease in impacts per unit mass of fish. Certain impact categories that can describe consequences of IMTA systems more completely are lacking, especially those related to diversity, particularly biodiversity.

Keywords: aquaculture, ponds, multi-trophic

Introduction

Market demand for seafood products and stagnating production volume from fisheries have combined to increase aquaculture production for the past several years (FAO, 2018). Consequently, aquaculture faces a double challenge: i) produce more to sustain growing demand for aquatic products and ii) respect the environment. Freshwater pond aquaculture remains the main system worldwide for producing fish (FAO, 2018). Nonetheless, intensification of practices in these systems has had increasing drawbacks, and new perspectives must be sought. Although the number of aquatic species used in aquaculture increased from ca. 72 in 1950 to more than 500 at present (of which fish species increased from 43 to 219 in 2005), 90% of global aquaculture production depends on only 20 fish species (Teletchea, 2019). For several years, Integrated MultiTrophic Aquaculture (IMTA) has gained worldwide attention. IMTA is based on integrated cultivation of aquatic organisms from different but complementary trophic levels. Inorganic and organic wastes from fed aquaculture organisms are assimilated by autotrophic and heterotrophic species, respectively, that are co-cultured with the fed organisms (Neori et al., 2004). IMTA systems are designed to i) decrease dependence on external inputs and increase system efficiency by optimizing use of nutrients and energy in production, ii) decrease impacts of waste and bio-deposition by decreasing nutrient loss (to water, sediments and air), iii) diversify aquaculture products and generate a more robust source of income (less dependent on single-product markets) and iv) generate and use different types and levels of ecosystem services. The objective of this study was to assess environmental performances of pond-IMTA systems based on experiments launched at a commercial scale.

Material and methods

a) System design: The study was based on freshwater polyculture experiments in earthen ponds conducted in Romania, France and Indonesia that explored different ways to combine fish and plants (Figure 1). In Romania, experiments compared two systems of common carp and four species of Chinese carp (bighead, grass, crucian and silver) in 2016 and 2017. A traditional extensive polyculture (TEP), with all five species fed a cereal mixture, was compared to a semi-intensive monoculture of common carp fed the cereal mixture and seprated by nets in the same pond from a polyculture of the Chinese carp (IMTA_EP). The Chinese carp relied solely on the natural productivity of the pond, which was sustained by emissions from the common carp monoculture.In France, experiments compared a classic unfed extensive polyculture (CEP) to i) a semi-intensive polyculture using formulated feed (SEF) and having double the fish density and ii) a SEF connected to a planted lagoon with the same area (IMTA_SEF). The polyculture was composed of common carp, perch and roach. The ponds had the same water area, and pumps were used in SEF and IMTA_SEF to increase water circulation. In Indonesia, experiments compared a giant gourami monoculture (GM) fed artificial feed to the same giant gourami culture with the added culture of a floating plant (red Azolla) in the same pond separated by nets (IMTA_G). The Azolla produced in the pond was used to supplement the Gourami diet.

b) Environmental assessment: Life Cycle Assessment (LCA) was performed according to the main recommendations of ISO (2006 a & b) but applied at the farm gate. The functional unit was 1 kg of total fish biomass produced during one production cycle.The processes included covered the production of feeds, fingerlings, equipment and buildings. The electricity mix was adapted to the contry, if necessary. The ecoinvent v3.4 database was used for background data and the Ecoalim data set (Wilfart et al. 2016) for feed ingredients. Impact categories were selected based on previous studies and recommendations for aquaculture LCA (Aubin et al., 2009; Bohnes & Laurent, 2019; Papatryphon et al., 2004; Wilfart et al., 2013): climate change (kg CO_2-eq), potential eutrophication (kg PO_4^--eq), Net Primary Production Use (NPPU, kg C) and cumulative energy demand (MJ) according to CML IA v3.05 and cumulative energy demand v1.10. Impacts were estimated using SimaPro ® software v8.5.4.0. Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

Results

Environmental impacts differed among case studies (Figure 2). In Romania, environmental impacts also differed between years: IMTA_EP had higher impacts than TEP in 2016 (except eutrophication), but lower impacts than TEP in 2017. In France, CEP had lower cumulative energy demand, eutrophication and NPPU than SEF and IMTA-SEF, the latter of which had the highest values of these impacts. However, CEP had higher climate change than IMTA_SEF and SEF. In Indonesia, IMTA_G had lower impacts than GM.

Discussion

The environmental impacts estimated in this study illustrate the variability in the responses of IMTA systems. Impacts of agricultural systems depend on system productivity and the amounts of inputs embodied in the system. IMTA is expected to provide improvements such as a decrease in input use (especially feed), increase in fish yields, and/or decrease in emissions per unit mass of fish produced. In Indonesia, the giant gourami culture associated with Azolla decreased consumption of formulated feed per unit mass of fish and nutrient emissions to water by recycling them into Azolla production, which also feeds the fish. This “virtuous” system decreased all selected impacts by ca. 70%.

In Romania, the IMTA-EP system decreased eutrophication by increasing recycling of the nutrients from the common carp monoculture. However, the associated Chinese carp polyculture did not grow sufficiently in 2016 due to the initially low weight of individual fish. Consequently, since the use of formulated feed did not decrease, the lower yields resulted in higher per-kg energy demand, climate change and NPPU compared to those of TEP. In contrast, better management of the Chinese carp in 2017 generally increased their yields and consequently decreased impacts compared to those of TEP.

In France, the CEP system had the lowest impacts because it used biomass produced naturally in the pond. Its higher climate change impact was due to natural methane emissions from the pond itself, which were compensated by high fish yields in the SEF and IMTA_SEF systems. In the IMTA_SEF system, the planted lagoon captured some nutrients, which decreased the natural biomass available for fish and thus decreased fish yield. The decrease in yield was not compensated by a significant decrease in nutrient emissions in the water when ponds were drained. Moreover, since the plants were not considered as co-products of the lagoon, the increase in inputs was not compensated by an increase in production, which increased the impacts.

This should explore the significance of the results of the work, not repeat them. A combined Results and Discussion section is often appropriate. Avoid extensive citations and discussion of published literature.

Conclusions

Depending on the practices, increasing the number of species or their organization through IMTA practices can decrease environmental impacts, especially local impacts such as eutrophication, compared to classic practices. Production and use of fish feed is one of the main causes of environmental impacts. Based on our results, IMTA practices can improve resource use and decrease the overall impact of aquaculture. Any increase in inputs used to improve nutrient recycling must also increase productivity to ensure a decrease in impacts per unit mass of fish. Certain impact categories that can describe consequences of IMTA systems more completely are lacking, especially those related to diversity, particularly biodiversity.

Moreover, IMTA covers a broad spectrum of practices based on the complementarity of productive compartments and can involve many groups of species from different ecological niches. Combining LCA with another assessment method, such as Emergy Accounting or food-web models, could improve understanding of these promising aquaculture systems.

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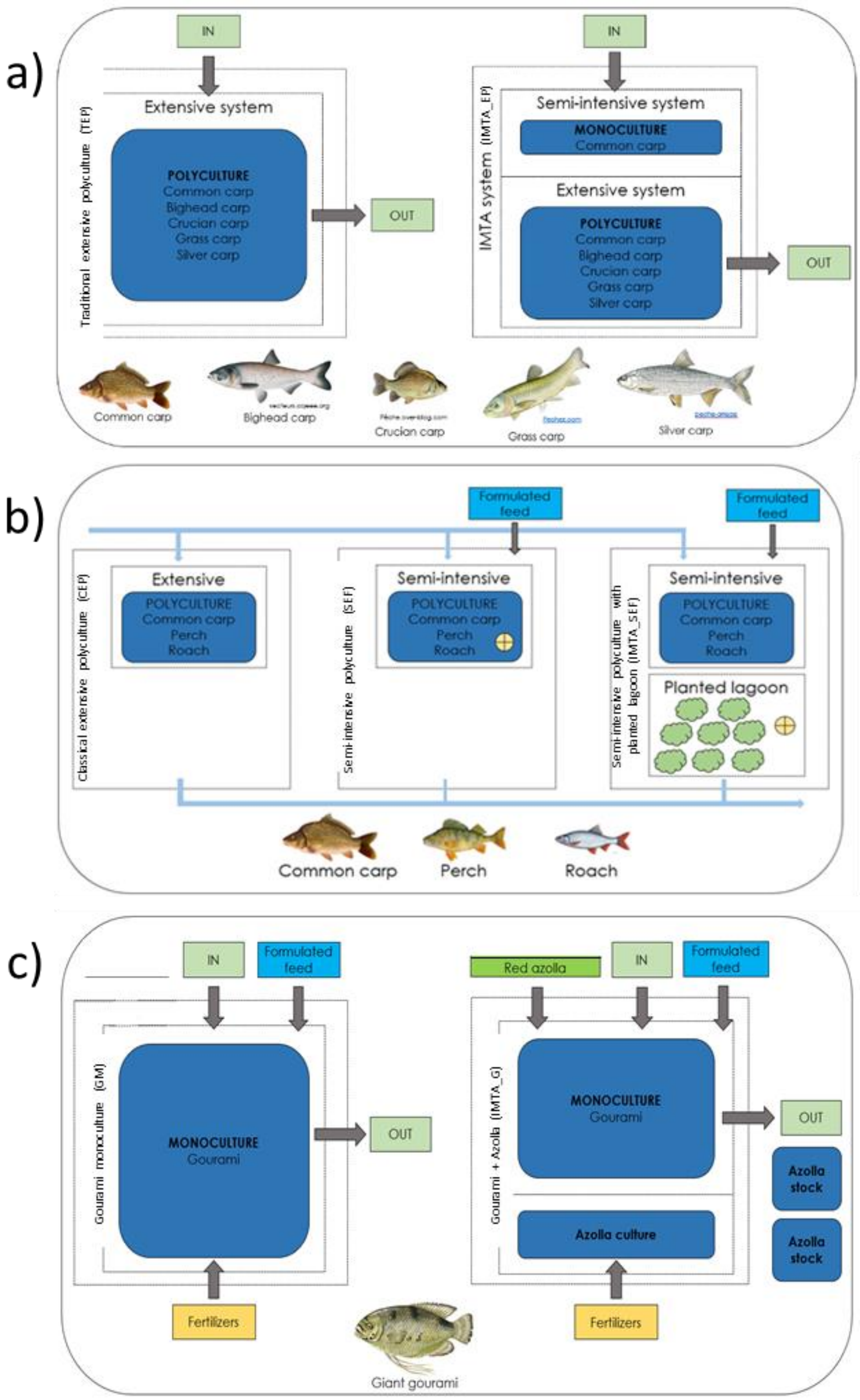

Figure 1. Experimental design of (a) Romanian experiments for a traditional system (TEP) and the IMTA system (IMTA_EP); (b) French experiments for a classic extensive polyculture (CEP), a semi-intensive polyculture using formulated feed (SEF), and a SEF coupled with a planted lagoon (IMTA_SEF) and (c) Indonesian experiments for a classic giant gourami monoculture (GM) and a IMTA system based on co-culture of gourami and azolla (IMTA_G). In (b), the crossed circle indicates the use of a pump, and the three ponds with fish had the same water area.

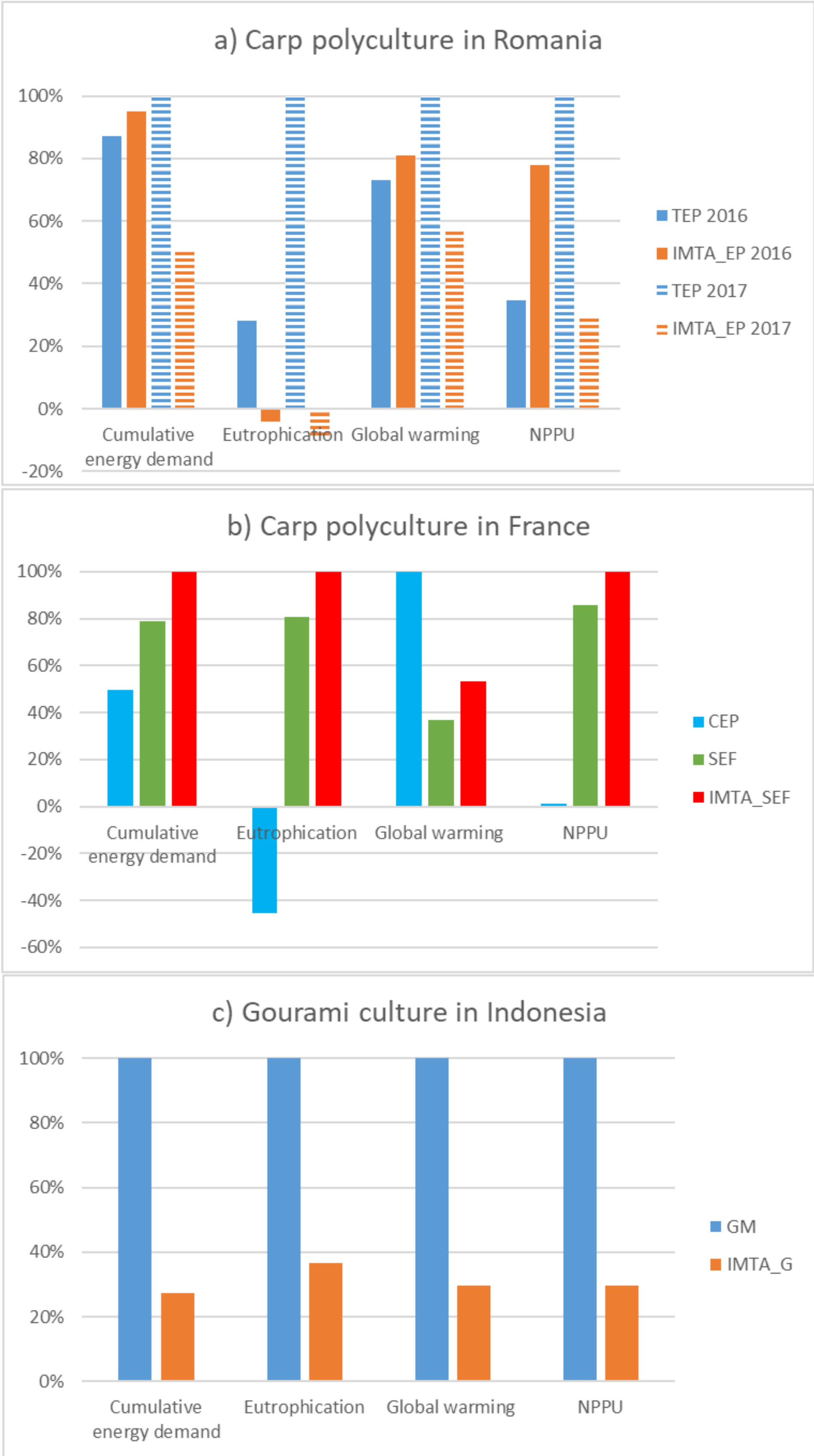

Figure 2. Comparison of environmental impacts of classic and IMTA systems in the case studies from (a) Romania, (b) France and (c) Indonesia. Results are expressed as a percentage of the largest value per impact.