Integrated multi-trophic aquaculture: freshwater IMTA analysis

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Master in Fisheries and Aquaculture Sciences
Aquaculture zootechnics and algae culture course

1. Technical characterization of the system

The freshwater IMTA (FIMTA) consists in raising a production in freshwater by eliminating waste and increasing the productivity of the food production system. The carp polyculture in open ponds was chosen here because it is currently the oldest and most developed FIMTA system in the world (Kestemont, 1995). As the Integrate project is European, carp polyculture is also one system applicable to our latitudes. Many FIMTA tries have been conducted with tilapia (*Oreochromis niloticus*) (Bakhsh and Chopin, 2012) but they are not applicable in Europe without changing the water temperature.

The carp polyculture in open ponds is today widely practiced (Woynarovich, *et al.*, 2010). It is based on the principle that each species stocked has its own feeding niche that does not completely overlap with the feeding niches of other species (Petrea and Mogodan, 2017). A pond is an earthen structure that is built for storing water and/or for fish purpose and has a depth usually around one meter (Woynarovich *et al.*, 2010). Ponds naturally produce worms and plants that can be used by the reared fish and therefore only the main species in the pond must be fed. As the utilization of the "natural food" is far better and more efficient when there are many species, polyculture can produce more fish in the same area than monoculture (Woynarovich *et al.*, 2010).

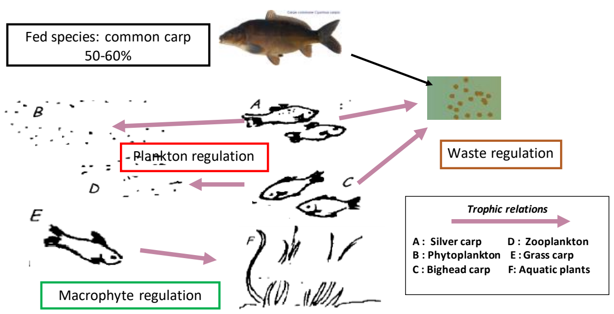

Figure 1. Pond with carp polyculture: a multi-trophic system

The system presented (Figure 1) is based on four carp species: Common carp (*Cyprinus carpio*) that is the main and fed species. Silver Carp (*Hypophthalmicthys molitrix*) is a filter feeder and eats phytoplankton. Bighead Carp (*Hypophthalmicthys nobilis*), that is also a filter feeder but eats zooplankton, and finally Grass Carp (*Ctenopharyngodon idellus*), herbivorous fish that regulates the production of macrophytes in ponds. The two filter feeder species are able to filter common carp waste to increase their growth. This is the main asset of polyculture in term of nutrient reduction.

2. Environmental analysis

2.1. Nitrogen, Phosphorus and organic matter releases

In a FIMTA system, the main driver that influences the impact of Nitrogen, Phosphorus and organic matter is the quantity of feed. The PISCEnLIT project conducted by INRA (Institut National de la Recherche Agronomique) to study environmental impacts of extensive freshwater multi-trophic aquaculture on Lorraine (East of France) ponds showed that the potential eutrophication led by these aquacultures is negative, it extracts Nitrogen and Phosphorus off the environment (-6.8 to -101.2 kg eq. PO_4/yr.). Other studies in Romania, show that IMTA practices lead to a lowest impact of Nitrogen and Phosphorus in comparison with traditional system of production (Favalier, 2019). Moreover, Knosche *et al.*, (2000) report that 1 ha pond in a year retains 3.8-8.4 kg Phosphorus, 96 – 560 kg Nitrogen and 1100 – 1600 kg Suspended Solids Hence, FIMTA reduces the environmental impacts directly through the uptake of dissolved nutrients by primary producers (e.g. macroalgae) and of particulate nutrients and organic matter by suspension feeders (e.g. Bighead carp), and through removing the nutrients from the pond (Cheng 2014).

2.2. Water consumption

Studies carried out in Romania on different systems with carp culture show that water consumption closely depends on either it is a FIMTA or a traditional system. Each system leads to different impact per kg of fish produced but not per surface use (Favalier, 2019). Meaning, water use in a FIMTA to produce a kg of fish biomass (35 $m^3.m^{-2}$) is lower than that of traditional system (50 $m^3.m^{-2}$). So the quantity of water for rearing fish is more efficient in a FIMTA than a traditional system. (Favalier, 2019, Aubin *et al.*, 2014)

2.3. Energy consumption

Few data on FIMTA energy expenditure are available today, it is known that the impact of energy often depends on feed, production system and species (Hornborg and Ziegler, 2014). Moreover, considering the fact that carps are fish with low trophic level (Cheng, 2014) and FIMTA rely on natural production (Yeo *et al.*, 2004), we hypothesised in the present study case that there is the same level of energy consumption with those reported by Troell *et al.* (2004): 1-25 J/J (energy use per protein energy output) for various carps pond.

3. Productivity gains

Carp is a benthivorous fish that browses the sediment to find its food. This behavior leads to the release of nutrients from the benthos to the upper water layers. Soluble phosphorus (PO4-P) in particular, is important because it is a limiting nutrient for phytoplankton growth. This “bottom-up effect” boosts the primary production of the pond and nutrient fluxes to other trophic levels (Rahman et al, 2008; Rahman, 2015a).

A moderate density of carp (0.5 carp/m²) added in rohu (*Labeo rohita*, herbivorous cyprinids) ponds increases substantially the primary production (total zooplankton and phytoplankton is almost doubled) but at higher density (1 carp/m²), it starts to be less advantageous. Rohu growth is significantly higher with 0.5 common carp/m² added (Rahman, 2015b).

Nevertheless, fish productivity in Lorraine ponds (Aubin *et al.*, 2014) ranges from 0.16 to 0.72 t/ha/yr., and is low compared with intensive carp monoculture that can reach 5 to 30 t/ha/yr. in Asia, depending on food, oxygenation and density of fingerlings first stocked per hectare (Woynarovich *et al.*, 2010). In central Europe, yields of carp monoculture are estimated between 0.7 and 2 t/ha/yr. (EUFOMA, 2016). Polyculture can be as effective as certain low fertilized monocultures, with the environmental advantages, and with very low use of feed, but cannot reach the extremely high yields of Asian intensive monocultures. However, using diversity of fishes can enhance the overall food efficiency and primary production of the pond.

4. Economic analysis

As very few data are available on the economic impact of FIMTA, it is difficult to establish precise and comparable figures. However, one of the main economic assets of this system is the diversified production, that makes it more resilient in case of environmental or economic changes (climate change, seasons, price fluctuations…) and allows a stabilized income from different resources. Petrea *et al.* (2017) have shown that for the same feeding and the same period, a better biomass of carp in a polyculture system were harvested compared to a monoculture system. The study shows that there is a better food optimization in a polyculture system. Therefore, it is economically beneficial to have polyculture ponds rather than monoculture ponds.

5. Balance sheet

Carp polyculture, our FITMA model (Figure 2) is here compared to carp monoculture that has 0 as score awarded for every issue (Nutrients, Energy, Economy, Employment and Water). For issues Energy and Employment, data were absent or unavailable to evaluate the differences between the two breeding systems, therefore we set the score to 0 with a “?”.

The economic issue seems a little bit better for the carp polyculture because of the diversified production that allows more resilience for prices and environment concerns. As mentioned before there is also a better food optimization in polyculture and therefore less use of food. However, due to the lack of precise figures and comparison, we cannot put a score over 1. Then, as the quantity of water to produce one kilogram of product in a polyculture system is less important than in a monoculture system, and more efficient, the score of 2 is awarded for the water issue.

Finally, FIMTA is a system were the nutrients (Nitrogen, Phosphorus and organic matter) are the less concerned issue because of filter feeders presence in the pond (Bighead Carp and Silver Carp) that reduces the quantity of particulate nutrients and organic matter but also because of the uptake of dissolved nutrients by primary producers (plankton, algae). Therefore, the main asset of carp polyculture is the reduction of nutrients in the system with a score of 4.

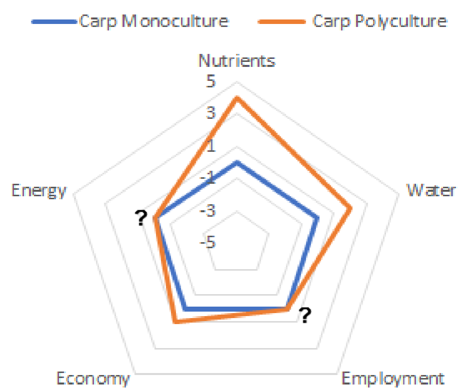

Figure 2. Radar diagram on environmental, social and economic aspects of freshwater IMTA (carp polyculture) compared to carp monoculture

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