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MALAGASY RICE-FISH FARMING

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1. Introduction

Some integrated aquaculture and agriculture systems (IAA) such as Chinese rice-fish farming are possibly as old as 2000 to 8000 years (MacKay, 1995; Edwards, 2019) and overtime, other integrated systems also emerged in both marine and freshwater environments, in temperate or tropical countries. Eventhough some gradually fell into disuse to make room for intensification and monoculture, IAA systems are nowadays rediscovered for their benefits that contribute to many of the sustainable development goals. Indeed, IAA systems are designed to decrease the farmers' dependence on external inputs, and to increase the whole system efficiency by optimizing the use of nutrients, energy and water. IAA systems also permit to diversify farm production and to generate a more resilient source of income, less dependent on mono-product marketing. Finally, they also generate and use different types of ecosystem services. In rural areas with low input availability and incomes, IAA systems bring the opportunity for farmers to extensively produce fish when intensive aquaculture is not within their technical reach. This is particularly the case in Madagascar where integrated rice-fish farming has been promoted by FAO since 1985 and by the non-governmental organization APDRA since 2006 (Dabbadie and Mikolasek, 2017).

Madagascar is an island country, located off the southeast coast of Africa. Frequently ranked among the poorest and most vulnerable nations, it faces several critical challenges (The World Bank, 2019). Food security and nutrition is one of them. Indeed, whereas rice is locally the main staple and main crop, the national production is insufficient to meet the demand, despite a mean yield of 2.5 t/ha and an estimated production area of 1.2 million hectares (Andriamparany, 2010). Malnutrition is another recurring issue in Madagascar, especially for children, as low household incomes limit access to a diversified diet (Razafiarisoa *et al.*, 2009). For example, fish consumption is reported to be as low as 1.3 kg/capita/year according to official statistics (Rakotomalala *et al.*, 2017), whereas the global average is now higher than 20 kg/capita/year (FAO, 2018).

To cope with these issues, the integrated production of fish with rice in paddies appeared as a promising technology, as it allows to harvest a double crop from the same field, and to benefit from synergies between them. Integrated rice-fish farming increases diet diversity, food security and nutrition, improves farmers' income and, overall, improves livelihoods in the rural areas through diversification and intensification of crop productions (Tsuruta *et al.*, 2011). However, given the low availability and accessibility of production inputs to farmers, rice-fish farming in Madagascar needs to focus on improving the productivity of both rice and fish by minimizing inefficiencies and effectively recycling wastes or by-products.

2. Ecological basis of rice-fish farming

Irrigated rice fields are ecosystems favorable to the growth and production of aquatic organisms. They can even play a major role in feeding and nutrition of local communities as a source of self-recruiting species. Flooded rice fields are composed of several trophic compartments, the main ones being rice, water and sediment (Figure1). But insects, snails and weed are also commonly encountered in flooded rice fields as a result of the abundance of natural food and nutrients. They are often considered pests for rice, resulting in the intensive use of pesticides in modern rice crops. But self-recruiting species or stocked fish for aquaculture purpose, freshwater prawns or crabs also give value to these organisms by consuming them and recycling the nutrients they contain.

On the other side, the use of pesticides, fortunately limited in IAA, can affect the survival of most organisms encountered in the rice fields and on the overall trophic foodweb. Fish, crabs and prawns rely directly and indirectly on phytoplankton and zooplankton produced in the water column. Sediments also host a multitude of invertebrates such as freshwater mussels, bacteria, biofilms and many other macro- and micro-organisms, all contributing to the trophic functioning of the flooded rice fields. Lastly, frogs, tadpoles, birds, snakes and rats are also not uncommon as they are looking for shelter or forage on the food resources of the rice fields.

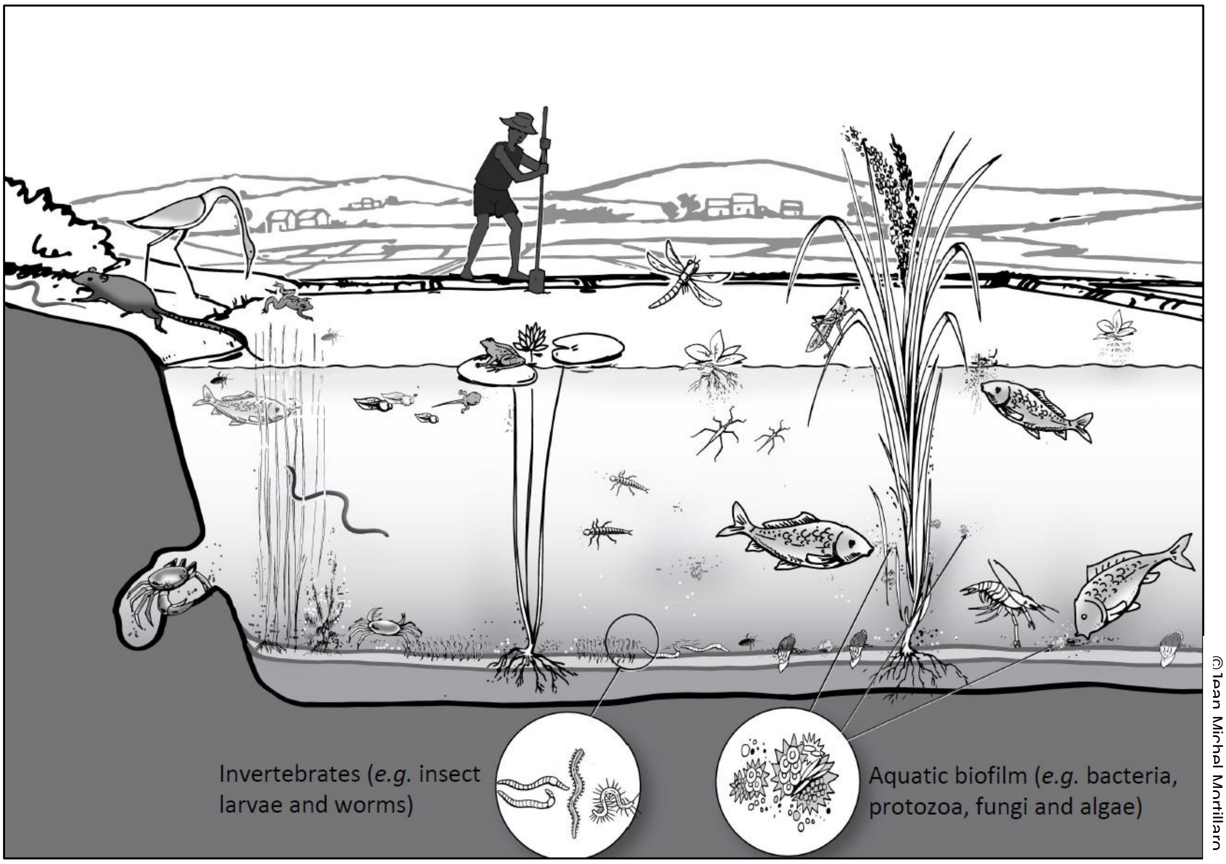

Figure 1: Schematic representation of the food web in a flooded rice field.

If wild fish, mostly consisting of various species of tilapias, have been traditionally harvested in Madagascar rice fields, technologies introduced since the middle of the 1980s were aiming at intensifying the rural fish production by promoting improved rice-fish farming practices and stocking common carp fry (*Cyprinus carpio*) in the irrigated rice fields. Besides the interest of this fast-growing species for its adaptation to the water temperature of Madagascar highlands (14 to 26°C), common carp also feeds through bioturbation on the bottom, which has been demonstrated to increase the oxygen supply to a greater depth in fishpond soil, thereby improving its quality (Ritvo *et al.*, 2004). Furthermore, common carp have been considered as ecosystem engineers affecting the water transparency and community composition (phytoplankton, zooplankton, macroinvertebrates and submerged macrophytes; Matsuzaki *et al.*, 2007). Matsuzaki *et al.* (2007) also demonstrated the effect of common carp on nutrient dynamics through excretion as a primary mechanism. Nutrient excretion by common carp should occur, as stated previously, while foraging on macro-invertebrates and weeds thus fighting against rice pests. Also, common carp can limit the growth of phytoplankton and submerged macrophytes (weeds) that compete with rice for nutrients, by affecting water transparency. Therefore, common carp are particularly adapted to the IAA context of rice-fish farming in Madagascar.

3. Malagasy rice-fish farming study case

Rice-fish farming has been carried out traditionally in the irrigated rice plots of Madagascar highlands (Kutty, 1987), which consist of four major ecosystems:

- Swamps, where rice is cultivated by farmers without modification of the landscape.
- Rainfed hillsides, where poor water management may lead to flood and drought (Fujisaka, 1990).
- Floodplain rice, where rice plots are characterized by more than 10 consecutive days of medium to deep flooding (50 cm flood to more than 300 cm) during the production cycle (Greenland, 1997) and where the water supply depends on rain and river flow.
- Irrigated leveled rice terraces, where fields are bunded with water control systems.

Fish can be found in all these ecosystems except in the rainfed hillsides. Nonetheless, floodplain rice and swamps are not appropriate for fish farming considering the risk of fish escapees during flood episodes. Eventhough the harvest of wild fish trapped in paddy fields during rice culture is widely practiced, intensifying the production through improved rice-fish technologies and stocking of farmed fish, faces several technical and social problems:

- One is the fear of fish theft, often associated or even confused with mortality through predation on fry (e.g. by birds, aquatic insects, snakes).
- Another one is the poor rearing or fish handling/transport conditions due to the lack of technical knowledge.
- The water management is also frequently questioned. This is particularly the case for the plots with raised bunds built to increase the water level for fish and that use new technologies that promote periodic drainage and drying to fight weeds and oxygenate soils.
- The use of refuge channels dug inside the plots to shelter fish in case of heat or drought, is also often seen as problematic because it leads to a loss of cultivable surface for rice. However, the loss of area is assumed to be offset by the increased rice yields observed with IAA, according to the FAO technical manual for dissemination of rice-fish culture (Kutty, 1987).

The technologies allowing an improved water management through raised bunds and refuge channels were therefore evaluated and compared to traditional practices in rural areas. The objectives of the case study were to characterize the agronomic performance in traditional (rice + self-recruiting species) and integrated systems (rice+carps). This was achieved by measuring the weight of commercial and self-recruiting species, as well as the yield of rice at harvest.

Farm experiments were conducted twice during a dry (2016-2017) and a wet (2017-2018) campaign. During the dry campaign, the first experiment consisted of six rice plots of 467 to 863 m^2 (total of 3 882 m^2) randomly distributed in two treatments: traditional (rice + self-recruiting species; n=3) and integrated systems (rice+carps; n=3). The rice plots were located near the village of Tsiafahy, Antananarivo (-19.06, 47.61; Figure 2) and investigated during a 100 days cycle, beginning on the 11 January 2017 with fish stoking in integrated systems plots. Eight additional plots located in the village of Fihaonana, Antananarivo (-18.66, 47.17; Figure 2) were added during the wet season. These rice plots measuring 270 to 655 m^2 (total of 3 552 m^2) were receiving two treatments: integrated (rice+carps; n=3) and fed systems (rice+carps+feed; n= 5). Feed provided to the fish in the last treatment consisted of food remains, cow dung and termitary collected locally.

The second experiment started on the 04 December 2017 in Fihaonana and on the 28 January 2018 in Tsiafahy, and lasted for 98 and 89 days, respectively. Fish in each rice field were sorted by size and weighed at stocking and harvesting. Survival rate was calculated. Rice yields were also evaluated through three replicates, with a surface of 0.25 m^2, sampled randomly in each plot.

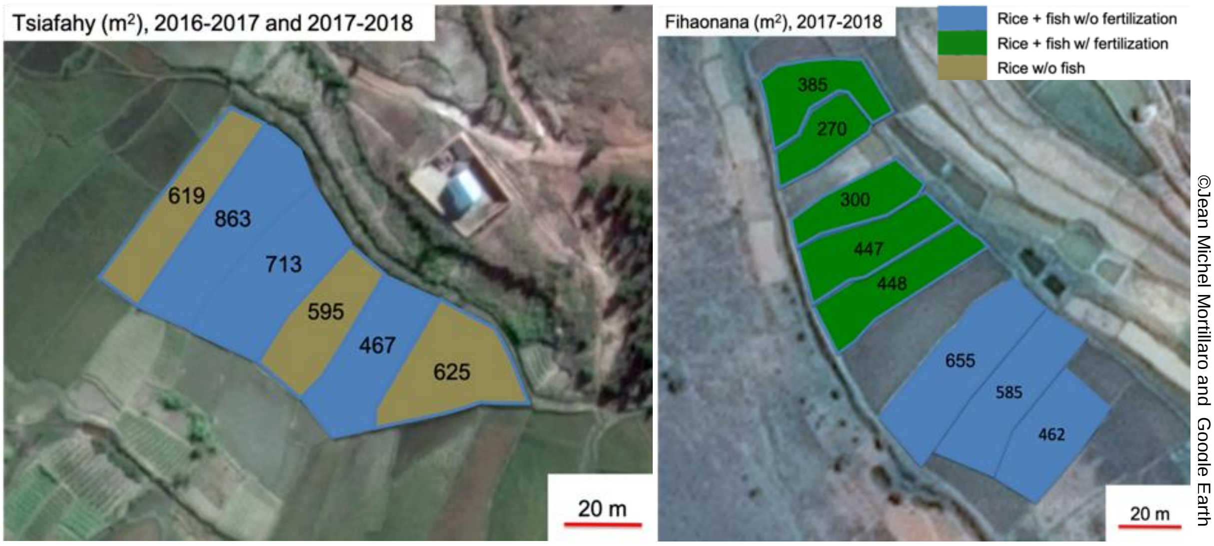

Figure 2: Experimental setup of the rice-fish farming (left: Tsiafahy; right: Fihaonana)

The efficiency of rice-fish farming and the benefits brought by fish were demonstrated from these on farm trials (Mortillaro *et al.*, 2018, Raminoharisoa *et al.*, 2018). Indeed, despite a refuge channel covering about 10 percent of the rice plot surface (Kutty, 1987), the rice production increase reached 19 percent after a dry, unfavorable, season (2016-2017) and up to 31 percent after a wet, favorable, season (2017-2018; Figure 3), thus largely compensating for the 10 percent surface loss. However, in Fihaonana, the fish feeding had no significant impact on rice, despite a seemingly high rice yield (Figure 3).

New insights on the integration of aquaculture with agriculture came up from the use of crop residues and raw materials from the agroecosystem. From a 30 farms survey, no correlation between the amount of zebu manure and rice productivity was recorded (Raminoharisoa *et al.*, 2018). Such findings highlight the diversity of practices (e.g. Intensive Rice System-SRI, traditional rice culture and off-season rice systems), soils quality and agro-environmental conditions, where standardization of inputs and techniques do not provide the expected results.

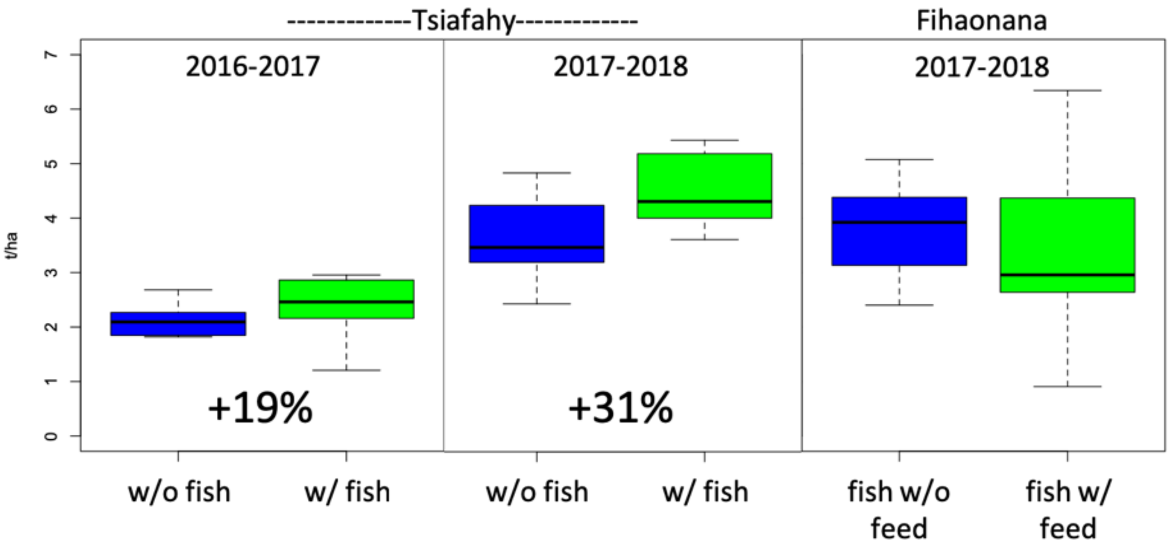

Figure 3: Rice yields from Tsiafahy (2016-2017 and 2017-2018; left) and Fihaonana (2017-2018; right).

Fish reared in extensive condition are generally not fed and it is also common that no fertilizing input is applied. Therefore, fish rely on their natural feed in the rice field, especially the insects that can be harmful for rice as well as algae and weeds that compete with rice for nutrients (Moreau, 1972). In extensive conditions, fish production remains small (39 to 59 kg/ha/cycle; Table 1) and no difference was recorded in fish weight and yield from Tsiafahy experiments (Figure 4, Table 1). However, feeding fish with qualitative inputs of termitary, cow dung and food remains, has significantly improved fish weight and yield, reaching 97 kg/ha/cycle (Figure 4, Table 1).

Survival is also quite low, with a maximum of 40 percent in Fihaonana fed plots (Table 1). Similar results in fish weight, yields and survival in Tsiafahy suggest that fish carrying capacity of rice plots was reached in such extensive conditions. It can be suggested that stocking density in such depleted systems was too high, leading to low survival, but it is also locally acknowledged that the size of stocked fish and the stocking/transport practices could be improved to increase fish survival.

Table 1: Fish productivity of integrated rice fish farming in Tsiafahy (2016-2017 and 2017-2018) and Fihaonana (2017-2018; without or with feed)

Site	Campaign	Cycle (days)	Fish yield (kg/ha)	Survival (%)
Tsiafahy	2016-2017	100	39	38
	2017-2018	89	48	39
Fihaonana w/o feed	2017-2018	98	59	32
Fihaonana w/ feed	2017-2018	98	97	40

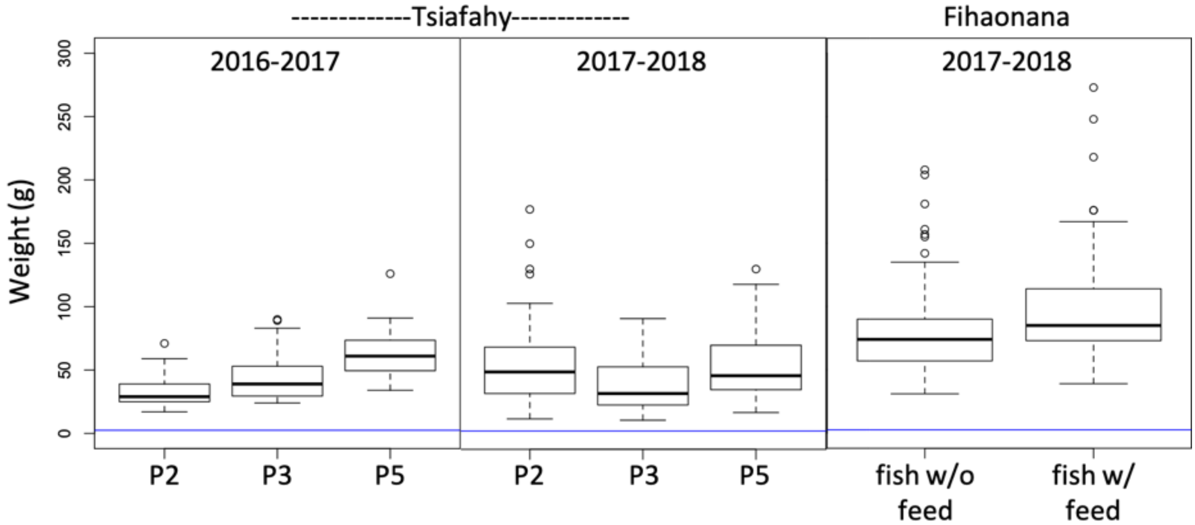

Figure 4: Fish weight (g) from Tsiafahy (2016-2017 and 2017-2018; left) and Fihaonana (2017-2018; right); P2, P3 and P5 refers to the three rice plots stocked with fish (Figure 2). Blue line refers to stocking weight which was of 2.5 g on average.

Although small yields were recorded in these experiments, intensification with fertilizers and feeds can improve yields up to 500 kg/ha/cycle (avg. 100 days). In that context, trophic characterization of rice-fish systems will be needed to improve the knowledge on ecosystem dynamics as well as on fish and rice yields determinants, by considering the whole diversity of situations encountered in the Malagasy highlands: rice culture practices, climate, environment, soils, feed and/or fish quality.

Finally, although traditional rice-fish farming has been practised in Madagascar for more than a century, the low adoption rate of improved technologies will need to be better understood through socio-economical surveys. In such extensive systems, the fish density should be adapted and kept to a minimum for the model to remain economically viable (less than 1 fish / 4 m^2).

For an average 400 m^2 rice plot, raising bunds and digging a fish refuge channel cost EUR 16, while the price of a 2 cm-long common carp fry is EUR 0.05 per unit (EUR 6.25 at a 1 fish / 4 m^2 density), leading to an initial investment of approximately EUR 22 for 400 m^2 (Randrianetsy, personal communication, 2019). Considering that the average monthly income for a 5 people household is EUR 21 (Andrianantoandro, 2015), and that the daily income for an average farmer is EUR 1, the initial investment to start rice-fish farming is greater than one month of labor. Moreover, because of the climate seasonality in the highlands, this investment is needed at the beginning of the lean season.

Furthermore, fry is often difficult to access for farmers, given the remoteness of rice plots and the poor road infrastructure. Aquaculture development projects have therefore focused part of their activities on giving farmers autonomy in fry production by promoting and supporting small-scale hatcheries (APDRA, 2016). This proved quite successful as many small-scale hatcheries can now be observed in the different regions were projects had interventions, but fry production remains low with an average of 2 000-3 000 individuals from a single female. The development of rice-fish and overall aquaculture production in Madagascar, is therefore limited by the access and high cost of fry as well as the limited availability inputs such as the high-quality feeds and fertilizers.

Further development of rice-fish farming and aquaculture in Madagascar will have to focus on reducing costs for farmers to encourage adoption and facilitate risk taking. Many pathways are available to achieve these goals, in particular the improvement of the breeding techniques to increase the survival and quality of early stage fry (use of feed for breeders and fry, improve breeding ponds, avoid predators etc.). New approaches will also have to focus on the integration of rice-fish farming within the agroecosystem and on the evaluation of the organic resources allocation trade-offs.

Optimization of rice-fish farming practices will also need to consider polyculture systems by combining fish species that have supplementary feeding habits and making use of organic inputs. Finally, ecological slope continuum within rainfed hillsides and irrigated leveled rice will have to be characterized, given the similarity of the ecological processes (bioturbation, soil dynamics, pest control) between both and opportunities to recycle nutrients between one and the other one through runoff.

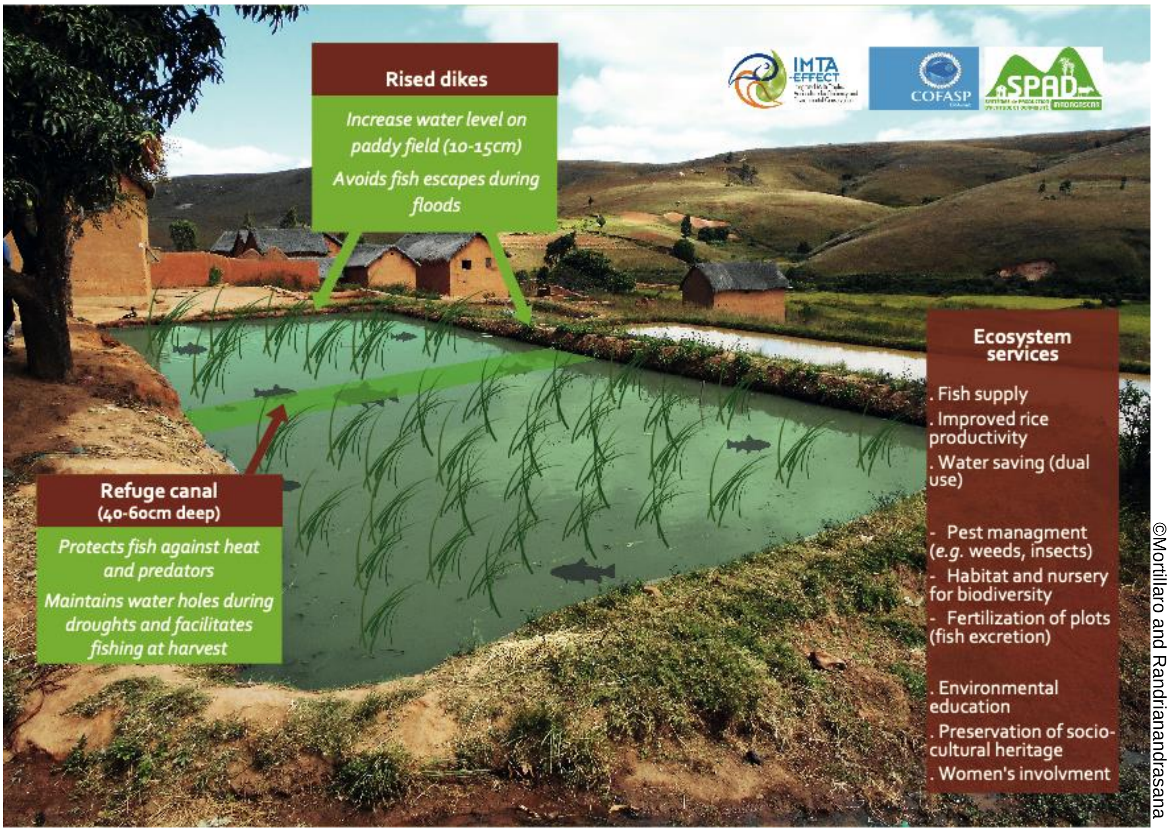

Figure 5: Rice fish farming popularization leaflet

4. Conclusion

Altogether, rice-fish farming promoted through participatory research with farmers can help to diversify farm production and increase the local supply of fish and other aquatic products. This will in turn enhance food security and nutrition, in accordance with the cultural heritage of Madagascar. Rice fish farming improve also farmers' income, but the high investment cost and need to have access to appropriate land areas may lead to the exclusion to some stakeholders, especially the middle-to-lower classes, in particular in peri-urban areas were land availability is a critical issue (Dabbadie and Andria-Mananjara, 2016; Fertin, 2018). Moreover, gender inequities among rural communities with regards to land ownership and access to capacity building remains an issue (Randrianandrasana and Randrianetsy, 2019). This is particularly visible in the fish farming development projects where women beneficiaries represent only for 13 percent of the total, although 80 percent of women are involved in the decision-making at the household level (Vololoharimanana, 2018). Improving tilapia farming in these areas, given the lower investment production cost compared to common carp may help to protect and improve livelihoods, equity and social well-being (Fertin, 2018). However, the building cost of rice-fish plots still represents more than 70 percent of the budget and further prospect will need to reduce it. Increasing the efficiency of the system by improving the knowledge on the trophic dynamics of this aquatic ecosystem and promoting ecosystem services (Figure 5).

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