Approach and conceptual framework of smallholder fish farming intensification: example of dam pond fish polyculture based on all-male tilapia culture (*Oreochromis niloticus*) in Cameroon

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Abstract

This study examines intensification of low-input tilapia farming in large dam ponds and identifies innovative practices that farmers can use for this purpose. More broadly, we consider mechanisms for expanding development of smallholder fish farming and corresponding research requirements to increase the efficiency and dissemination of fish farming. The analysis examines several levels at which innovations are produced: fish, pond population, fish rearing system, watershed, farm and territory. We also examine the choice of the level and time horizon analyzed. Based on existing smallholder practices, further research about effective practices that farmers have and could adopt is proposed and discussed. The history of local smallholder fish farming in Cameroon, the development approach carried out by non-governmental organizations and the reference fish polyculture system based on all male tilapia are presented. Regarding the current situation, innovative practices must be considered, particularly smallholder initiatives for water management or floating rice production in fishponds. At each level, relevant practices are emerging to increase fish yields or intensify lowland production while respecting the social and economic dimensions of fish farming. It is important to recognize that the agroecological principles and associated technical solutions are appropriate and that decreased conflict among stakeholders can provide a consistent response. This positioning of research for rural development favors the emergence of innovations and allows for intensification of smallholder fish farming while taking its complexity into account. Low-input fish farming should not be considered as only a subsistence activity of smallholders to alleviate smallholder poverty. On the contrary, rural fish farming can generate sustainable development that is complementary with commercial fish farming.

Keywords: smallholders, farming systems, extensive fish farming, tilapia, polyculture, dam ponds, intensification, sustainability, Cameroon

Introduction

The place of fish farming in agriculture, especially in tropical agriculture, remains a classic debate topic. In Africa, the small place it occupies is controversial: the supporters of purely commercial fish farming oppose those who aim to integrate fish farming into small household farms as a means to alleviate poverty (Belton et al., 2012; Little et al., 2012; Brummett et al., 2011; Moehl et al., 2005).

Commercial farming is successful; however, it requires the use of many imported resources (inputs, expertise). Purely commercial farming supplies the large African city markets, which are most likely to generate profits. Integrated and more extensive fish farming is often considered inefficient because of the perceived waste of subsidies (i.e., spending without subsequent development). For fish farming integrated into small household agriculture, many realities exist in humid West Africa. Many such systems have proven both their efficiency and resilience over the past 20 years (Oswald, 2013; Simon and Benhamou, 2009; El Sayed 2006; Oswald et al., 1997a). Fish farming practiced in dam ponds is extensive or uses low levels of inputs. The main species used in polyculture is *Oreochromis niloticus*, which, when sexed and grown in association with a predatory fish (to control fry invasion), can reach sizes that facilitate its sale in rural markets. Indeed, fish is the most important source of animal protein, and locally farmed fish are preferred to imported fish because of their low cost and because their size and freshness are attractive to consumers (Grosse, 2009).

A new fact of these developments is that fish farming satisfies the main food expenditure of local communities: buying fish for consumption, which appears an excellent motivation for solving technical problems. Due to other aspects of these contexts, fish farming offers many advantages in tropical forest areas: pond construction is easy and accessible to many smallholders in villages where animal protein is often scarce.

It is necessary to identify whether extensive fish farming progressively degrades natural resources, reducing agricultural performance, or plays a role in agricultural intensification, increasing available resources (Vergez, 2011). In other words, does it indicate that extensification seems the best solution to guarantee the survival of smallholders – thus signifying a general tendency to decrease agricultural production – or does it increase production and revenues despite its extensive nature?

This question is linked to the global issue of how to feed humanity (Griffon, 2013). Outside a normative approach, investigation of intensification of extensive fish farming (Belton et al., 2012; Brummett et al., 2008) has to be treated in a relative and dynamic way. Does creation of these fish farms contribute to intensification of the surrounding agriculture? Ultimately, does its evolution allow for sustainable intensification of this agriculture?

This generates a number of methodological issues about what to measure (yield per unit area seems inadequate) and at what spatial level (e.g., fish, pond, fish rearing unit, farming system, watershed, local territory) and temporal scale (e.g., day, production cycle, a growing season) to assess intensification. Intensification needs to be addressed at different levels, while paying specific attention to risks and vulnerability. We consider that intensification is included in the dynamics of global improvement of the production of various goods and services, taking into account their consequences on food security and the livelihood of rural populations, returning to the definition of Pretty and al. (2011).

First, by analysing practices of fish farmers at different levels, we analyze the intensifying character of fish farming. Then, based on the data collected, we evaluate its technical efficiency (production and environmental impact indicators) using life cycle assessment (LCA). Finally, by considering attempts to improve this type of fish farming and the innovative practices that have appeared, we evaluate the potential of these systems.

Based on these results, we assess the current contribution of fish farming and its potential to intensify smallholder agriculture (in contexts similar to that of the Centre Region, Cameroon) and analyze factors limiting its development in this environment.

1. Materials and methods

1.1 The fish farmers who benefitted from this approach

The material is made up of fish farming units previously established from a project-based approach. It is thus a process with a before and after situation.

1.1.1 Critical points of the approach

Producers are targeted by an investment approach based on empowering actors in the project (Halftermeyer, 2009) by:

- transferring skills at both technical and organizational levels to producers with continuous in-situ training and learning by doing
- training fish farming facilitators-advisors (FFAs) of a non-governmental organization (NGO)
- supporting establishment of a local socio-professional network that can offer the services needed to develop the fish farm social network

The project does not give direct subsidies for investment or fish farm functioning to producers, a key point of the approach. Only training and advice are free. "The inability to obtain financial or material assistance guarantees the participation of producers who are truly motivated by the activity, making them responsible members of the project and spurring them to sustainably make the investment profitable. […] The NGO works on the assumption that an owner's management of pond planning is much more efficient if he finances himself entirely. On the other hand, the profitability of the investment enables him to convince other candidates to begin fish farming, even in villages not covered by the project" (Halftermeyer, 2009). The smallholder (and the group of fish farmers) has freely chosen to invest in fish farming; so, if he develops this activity, it is because he finds it as profitable as other potential activities. In compensation, the project must produce results for fish farmers. Reciprocal commitments are thus created between the project and producers who accept the approach and want to invest in fish farming.

The standard fish rearing system proposed is constituted of fish polyculture based on a population of all male tilapias (*O. niloticus)* in dam ponds with low input levels (low fish density and little or no trophic supply). However, this extensive system can be intensified with proper water management and a supply of fertilizers or feed supplements. This system addresses the main constraints of rural producers, who face high transport costs and little cash flow.

Principal components of the hypothetical system proposed are:

- Production of large fish (tilapia with an individual mean weight > 300 g).
- One or several service ponds which have multiple functions: fry and fingerling production, broodstock management, and stocking and which represent about 15% of the surface area of the growing pond. These service ponds have to meet smallholder needs for stocking the dam pond and those of the fish farmer group (especially for tilapia).
- Large dam ponds (> 2000 m^2) for growing fish that minimize the quantity of earth moved as a proportion of pond area and which are equipped to guarantee water control and total drainage with a concrete monk and a flood spillway.
- A fish population composed of male tilapias (*O. niloticus*) and *Heterotis niloticus,* accompanied by a strict predator (*Hemichromis fasciatus).* Secondary species such as catfish (*Clarias jeansis* or *Heterobranchus isopterus*) can be associated.
- A minimum yield of 600 kg/ha/year that can reach 1 t/ha/year or more depending the control of water flow, the location of the lowland (and its watershed) and the duration of fish rearing cycles.

Performances of the fish farming unit have to meet producers' expectations: adequate quality and quantity of harvests to contribute significantly to the household economy. This means decreasing fish purchases and increasing gifts of fish and monetary incomes. This implies that an FFA discusses a candidate's fish farming investment proposal with him. FFAs have to check that a candidate's lowland has enough potential to guarantee harvests that can satisfy his objectives and induce a social dynamic at individual and collective levels. Then diversification can continue via new construction in available lowlands and new optimization of inputs via better water and fish management.

The approach relies on self-sufficiency of the fish farmer for pond stocking requirements of the fish rearing unit or at least of smallholder groups. Production of male tilapia fingerlings occurs mostly within individual fish rearing systems, while production of *Heterotis* juveniles and *Hemichromis* relies on group exchanges.

Fish farmers adopt fish management by forming their own frame of reference through experiences that they gather during the initial rearing cycles. They learn to define pond stocking requirements according to expected final mean weights and pond productivity (Glasser and Oswald, 2001). Thus, step by step, fish farmers define optimum density according to their knowledge of how their ponds function and their objectives. In this way, fish farmers accumulate empirical knowledge based on an understanding of the essential principles of fish farming to ensure results that they can foresee. In other words, they become able to manage their fish farms on their own.

1.1.2 The fish farmers studied

The study site in Cameroon is located in the Centre Region (Fig. 1), which has an area of 69,000 km^2 and a population density up to 45 inhabitants/km^2 (Bucrep, 2010). This region has hills with a mean elevation of 700-800 m. Its equatorial climate is marked by two dry seasons (December-February and July-August) and two rainy seasons. Mean annual rainfall is 1700 mm and the temperature ranges from 19-28°C. Vegetation is secondary forest, in which smallholders practice slash-and-burn cultivation. The main cash crop is cocoa associated with food crops such as plantain, maize, beans, groundnut, cassava or cocoyam. Fruit trees are numerous, and palm trees are expanding in the area.

In approximately 12 villages in the Centre Region, more than 100 farmers invested in pond construction in lowlands. An assessment of the project performed in 2011 revealed that the rate of construction slower than that in other countries such as Guinea (Fig. 2), where the same approach was applied. The thick vegetation of the lowlands and the relatively low availability of family labor in rural Cameroon could partly explain the delay. To a smaller extent, the slower speed is also due to the inherent trial-and-error process caused by the complexity of setting up the approach, centred on fish farm investment, in new contexts.

1.2 METHODOLOGY

Intensification of small household fish farming has a large literature and a long tradition, particularly in Asia. All sources agree on its importance in world fish production and many raise questions about its future. Starting from a population of reared fish, choosing a species likely to be improved by genetic selection is a frequent way to intensify, but it always hinges on the availability of fingerlings and feed, which often hinder development (Brummett et al., 2008). Other authors (Milstein, 1992, 2005, 2012) emphasize the remarkable performance of polyculture and its ability to improve many existing situations. Increasing pond productivity by adding fertilizer (mineral or organic) is also commonly practiced (Mischke, 2012; Knud-Hansen and Batterson, 1994; Knud-Hansen et al., 1993), sometimes by housing animals above the pond (Little and Edwards, 2003). This solution is remarkably efficient from a technical point of view, but in some environments in Africa, it induces high pressure on cash-flow, which makes the fish farmer more vulnerable to financial shortage (APDRA-F, 2002). Currently, this solution only has limited development in Africa. Improving production by distributing small amounts of supplementary feed is also suggested, but this faces two major constraints: feed availability and ability to distribute feed at the right time to optimize profitability (Tacon et al., 2011; Tacon and De Silva, 1997; Diana et al., 1996). Liti et al. (2005) observed that better profitability is obtained in Kenya with rice bran than with high performing feeds. At another level, fish farming is frequently seen as a tool for integrating irrigation with agriculture; its performance is then analyzed at a larger scale (Karim et al., 2011; Dey et al., 2010). Many examples have been described, such as rice–fish culture or ponds forming the heart of farm-product circulation (Brummett and Noble, 1995). The latter is limited by the availability of by-products at the farm level (Azim and Little., 2006). More recently, the principles of IMTA (Chopin, 2013) and bioflocs (Avnimelech, 2012) added new mechanisms for improving the performance of household fish farms.

This wide technical set (Azim and Little, 2006) raises questions about how to assess the contributions of each technique to the overall production performance of fish farming. Given the increase in competition between fish farming and other agricultural production, a comparative and dynamic approach is required to assess its evolution and compare it to that of other crop or livestock systems. For example, transferring organic matter to ponds to intensify their production can reduce the fertility of agricultural fields. It is necessary to estimate the balance between the benefits of increased fish production and the cost of decreased cereal production. This led some authors to consider the change in farm incomes as a global indicator of the profits or losses induced by fish farming (Prein, 2002). Here, we give preference to the technical dimension, while bearing in mind the need to consider economic and environmental dimensions. It is therefore easy to understand the difficulty in measuring the quality of the intensification performed by fish farmers. However, we have to consider both before and after situations and compare them to other opportunities. Although the logic of producers has been recognized for several decades (Pillot, 1987; Collinson, 1981), the level at which to investigate where the consistency of choices can be explained fluctuates. Sometimes it is found during crop cultivation or fish rearing, while at other times it is located at the community level for social issues (e.g., guaranteeing access to land or profitable markets). The most frequent level used is that of the farming system.

In consequence, we discuss our results at the scales used most often: the fish population with the specific contribution of each species, the pond plot, the fish rearing unit (combining ponds and water management structures), the farm, and, beyond that, the watershed or local territory.

In situ observation of fish farming has many difficulties. First, we examine the intensifying character of fish farming by analyzing effective fish farmer practices at different levels. Collecting data about on-going practices allow techniques to be identified. This widespread approach aims to associate observations of how a smallholder manages his farming system with the decoding of how he determines on-going management and describes the main constraints that he faces; the latter is mainly collected through interviews. Ultimately, the analysis attempts to provide the most coherent explanation for the scales studied.

2. Results and evaluation of the process

2.1 Initial results by analyzing practices of existing fish farming

2.1.1 At the territory level: complementary diversification of household farms specialized in agro-forestry

Traditionally, crops and plantations are planted on hills, though some cocoa plantations are planted near wetlands. The lowlands have little production; the few vegetable crops are mostly grown during the dry season by young men who do not have a stable income. A landscape study shows the complementarity between fish farming and other activities. In the Centre Region of Cameroon, fish farming uses areas that are currently less exploited. Fish farming therefore spatially diversifies production, contributing to agricultural intensification at the territory level (Ruf and Schroth, 2013).

Occasionally, higher ground water increases the water available for agriculture. Small vegetable plots or tree nurseries for new plantations around dams show this effect. Thus, the development of pond fish farming is complementary to other agricultural production and tends to improve water use.

Making good use of knowledge acquired through the project (notably prospecting lowlands and planning water management), some pioneer groups volunteer to help construct fish farms for farmers from villages not covered by the project. At the request of the groups, these initiatives are assisted by FFAs when possible, who work to guarantee the quality of construction planning. These confirm the increasingly important role that fish farming has to smallholders, despite the risk of eroding the social knowledge necessary for the approach to work.

2.1.2 Fish farming as an investment project at the farm level

As previously discussed, physical investment uses farmer resources (mainly labor and capital). Two facts can help to determine the importance that farmers give to this new production. First, they practice fish farming effectively, which they describe as routine; fish farming labor is included in farm work planning. Secondly, some do not hesitate to begin building a second dam.

The fact that smallholders chose to invest in dam construction highlights its potential advantages compared to other activities (notably, planting new plantations). It also signifies that fish farming is perceived as a way to improve the performance of their farming systems at least as efficiently as other opportunities. By improving functioning of the farming system, it represents an alternative way to intensify than to rely on cocoa, palm or rubber plantations.

For the smallholders, extensive fish farming in dam ponds can generate income. Many of them have assimilated the principles of fish farming and are self-sufficient at the individual and group levels. It is not necessarily the same for those who are new fish farmers and who still depend on their elders for access to the minimum skill required. Similar to this situation, some have negotiated the support of fish farmer pioneers on their own and do not exactly know what support they need; this could degrade the technical frame of reference.

2.1.3 Service ponds at the level of the fish rearing system

In Cameroon, service ponds constitute a "local revolution" compared to the situation prior to implementation of the project. It allows the fish farmers to become self-sufficient in producing male tilapia fingerlings and simultaneously to intensify production of the fish rearing unit. The service ponds are small, have water supplied by deviation, and generally flank the side of the dam pond. The size of these ponds and their good control of the water inlet and outlet simplify addition of fertilizer or food. They simplify management of the fish and that of the fish farm. These skills generally lead farmers to practice almost two growing cycles per year, in line with their personal objectives.

Fish farmers usually start fry production by stocking broodstock inside the service pond that has been previously drained and refilled while preventing the entry of invasive fish. Then, broodstock are removed (after reducing the water level) after 1-2 months; the number of fingerlings is then reduced to facilitate their growth for easy hand-sexing and to provide enough tilapias to stock the dam pond. The self-sufficiency of the fish farmer in rearing the tilapias relies mainly on the service pond.

The service ponds enable the farmer to stock some fish from the dam pond harvest for sale or consumption. That allows the fish farmer to quickly drain the pond and shortens its unproductive period. They also facilitate the stocking of *Hemichromis* or *Heterotis* in the dam pond.

The assessment observed that *Heterotis* and *Hemichromis* juveniles were often supplied at the group level. Thus, the local group satisfies other stocking requirements of the polyculture practiced. Stocking with secondary species (such as local catfish) was done by catching them from in the natural environment. Note that frequently some broodstock are supplied from outside the farm (from neighboring ponds or the natural environment). At times, when harvesting the dam pond, any fingerlings caught are also sexed to adjust the needs of the fish farmer or of his neighbor.

In the East Region of Cameroon, another dynamic of extensive fish farming has been shown. For dam construction, farmers often take advantage of the passage of bulldozers from forestry companies. Their fish farming infrastructures do not include service ponds and they practice cycles longer than one year (sometimes 3). Thus, the characteristics of service ponds and dam ponds allow fish production to be intensified.

2.1.4. Efficiency of the fish farming unit, a result of the polyculture

Fish farmers' skills let them harvest large fish of which they are proud and that the market appreciates: tilapias have a mean weight ≥ 300 g and *Heterotis* weigh over 1 kg each. Tilapias constitute 2/3 of the harvest of tilapias and *Heterotis*.

In dam ponds, we did not observe proliferation of wild fish (*Tilapia zilli* in particular) nor of *O. niloticus,* which could be expected, as manual sexing leaves at least 5-10% females, sufficient for colonizing the dam pond in 1-2 generations. Good control of the fish population is due to successful management of *H. fasciatus*: at harvest, its fingerlings are stocked in the service ponds, while the largest ones, and smaller ones that usually do not survive the stress of drainage, are eaten. Generally, and especially in Cameroon, management practices of dam ponds show that fish farmers aim to produce large fish. *Hemichromis* polyculture is therefore managed to produce large fish and not to increase the yield.

Fish farmers' affection for "kanga", the local name for *Heterotis,* is surprising. They appreciate that it grows quickly in ponds. This species is always added to tilapia, as it is perceived as a valuable supplement. Associating *Heterotis* with tilapia requires additional considerations: its fingerlings are relatively expensive, and rearing it requires special care and hence additional labor; it therefore aims to increase the production permitted by tilapia alone (Copin and Oswald, 1993; APDRA-F 2002).

Adding fingerlings of a local catfish *(C. jeansis*) also aims to increase fish production; only a few are stocked to avoid competing with the growth of tilapias, as observed with *H. isopterus* in the Ivory Coast (Lazard and Oswald, 1995). *C. jeansi*s is preferable to *C. gariepinus* (introduced in the Nyong basin, Cameroon), which grows faster, making fish management difficult. One may not be able to control tilapia overpopulation under extensive conditions; alternately, it may eliminate the small predator (*Hemichromis)* or still worse, consume the marketable tilapias at the end of the cycle.

The production of large fish seems the decisive condition for being able to sell most of the production efficiently. Once rearing techniques of tilapia are properly managed, including predator management, other species are added to increase the yield. Once fish farmers improve water management and fish rearing, cycles tend to last for 6 months, and yields can reach 1.5 t/year.

The complex management of extensive systems based on natural productivity justifies the project approach, which is centered on support from advice, on-farm training and learning by doing.

2.2 Using field data collections for evaluation

The technical system proposed has been widely adopted by smallholders who have integrated it in their system of activities. Some farmers have improved on or expanded their fish rearing unit. Monitoring conducted by researchers completes the analysis of fish farming in this particular context.

2.2.1 Environmental evaluation at the pond level

The agro-environmental efficiency of different household fish farming systems was evaluated with life cycle assessment (LCA, ISO 2006) in a doctoral thesis (Efolé, 2011). Twenty production cycles were observed in nine farms and grouped into two semi-intensive types and one extensive type; they were compared to each other and to other systems: trout and "Peixe Verde" of Brazil (Fig. 3). Only the latter corresponds to the system presented here.

Initial results show a negative eutrophication potential with highly correlated impact categories (climate change potential, acidification potential and energy use) of the extensive system (0.84 t/ha/year, mean of 6 observations). This confirms the ability of the low-input fish farming system to use natural resources from the environment by stocking (and destocking) nutrients (N and P) in the sediments and their efficient fixation by the fish. This characteristic of the extensive system in Cameroon is comparable to the semi-intensive system "Peixe Verde" in Brazil (6.8 t/ha/year according to Casaca, 2008), which is polyculture based on grass carp (*Ctenopharyngodon idella*) fed with forage (Casaca, 2008). The decrease in quantities of N and P fixed with the semi-intensive systems of Cameroon could be explained by inappropriate water and food-supply management but also by an overestimate of waste due to the method of measurement used, which does consider the role of pond sediments (Efolé et al., 2012).

2.2.2 Technical Evaluation

The two cases presented below concern two fish farmers with below-average pond sizes. This is frequent at the start of a project, when the first fish farmer who joined seek to minimize the risk of overflow by reducing pond water level and thus the pond area. However, these fish farmers have already constructed a second pond.

At harvest of the two ponds, the final mean weight of tilapia is > 300 g for yields of 1.6 and 1.3 t/ha/year, respectively (Table 1), in accordance with the technical reference. Tilapias were not genetically selected, but their growth does not seem to be a major obstacle under effective rearing conditions. Although the two total yields are similar, the growth of the species differs as a function of initial densities and weights, species interactions and productivity of each dam pond. Today, *Hemichromis* is appreciated by the smallholders despite its small size. Its role in the control of tilapia fry production was well understood in association with manual sexing. However, the control of sex ratio during the harvest of marketable fish shows incomplete mastery of this technique, which is considered tedious. It should be noted that one of the fish farmers started fertilizing his ponds with waste from palm oil fabrication.

2.2.3 Socio-economic significance of results

The fish production is considered and developed as a livelihood oriented to and appreciated by the local market. The smallholders express their satisfaction in fish farming because the local market is largely open and pays a fair price for their marketable fish. The food and energy crisis of 2007 has reinforced the interest in production of food crops in villages.

As a result of the LCA analysis, quantities of human labor in the extensive and semi-intensive systems of Cameroon were similar to the 236 h/day/t of fish observed in equivalent systems (Casaca, 2008); all were higher than the 8 h/day/t in intensive trout systems in France (Aubin et al., 2009). This is related to the absence of mechanization for both pond construction and daily management of fish rearing cycles. This indicator measures the distribution of added value to the agents of fish production.

In accordance with the technical process described in Ivory Coast and Guinea, the interpretation of the two-pond cycle results shows a value of daily work of approximately 4000 FCFA (656 FCFA = 1 €), similar to (or higher than) that of cocoa production in the same area (Jagoret al., 2008).

Although the results presented are not the common to all the fish farmers, they clarify the initiative of these two farmers, each of whom constructed a second pond using only their own labor.

A socio–economic analysis able to assess opportunity costs of investing in fish farming when candidates decide to engage themselves could bring further useful information to this technical view.

2.3 What potentials do the innovative practices and development strategies indicate?

The smallholders are free to manage their fish farming and other farm production as they wish. We can therefore hypothesize that the emergence of innovative practices, combined with their explanations of their strategies, enables us to assess how smallholders want their fish farming to develop.

2.3.1. Adoption of irrigated rice in co-culture with fish

After a journey to the forests of Guinea, fish farmers of the Centre Region of Cameroon brought back rice seeds. With the help of a Guinean technician, they set up rice nurseries and carried out the first cycles of floating rice planted in the bottom of the pond. Initial results (Table 2) were interesting enough to spur other producers to jump into this "new" crop. Here, rice had been planted by the farmers' parents and then abandoned for decades.

After the first commitments, diffusion of this innovation encountered two constraints. The first was bird predation, which limits its adoption in some places. In Guinea or Ivory Coast, fish farmers plant rice at the same time as other farmers, which reduces bird pressure on their sites. The second is the lack of rice mills in villages, which makes preparing rice for cooking more difficult.

However, smallholders are continuing these trials, signifying that they have seen advantages in this rice-fish association, one of which is reduction of undesirable plants in the dam pond. Adoption of rice cropping shows that fish farming is an innovation with a systemic character, as it can induce a succession of interconnected innovations.

From the intensification viewpoint, associating rice in fish dam ponds illustrates a potential for intensification at the plot level. The farmers can practice fish rearing and rice cropping simultaneously, providing synergy between the two types of production. In this way, they could give up the slash-and-burn cropping that destroys forest fallows.

2.3.2. Polyculture to increase fish yield and fish farming efficiency

Smallholders are always ready to test new species; however, those that are potentially available are limited in number. In addition to *Heterotis* and the local catfish (*C. jeansi*s), some tests conducted with the common carp (*Cyprinus carpio*) gave good growth results, but its contribution to the overall yield could not be determined. However, smallholders have not adopted the carp due to difficulties in obtaining its fingerlings. The only two sources of fingerlings are many kilometres away from the fish farming sites of the Centre Region.

Comparison of *Heterotis* and the common carp is interesting; in both cases, the fish reach large sizes that are highly valued by the market. At the stocking density used, their production seems to be added to that of tilapia. This positive contribution is less clear for carp than for *Heterotis*. *Heterotis* fingerlings are expensive, but they are bought from neighbors and have a high survival rate; carp fingerlings are less expensive (excluding costs of communication and fish transportation), and their survival in the grow-out pond varies, depending mainly on their size on delivery. Ultimately, fish farmers are fond of *Heterotis* and did not organize a supply of carp fingerlings. In the present context, this choice shows that the technical reference system must ensure the self-sufficiency of smallholders concerning pond fish stocking.

Beyond research fads for new species, fish farmers are waiting for new fish that will diversify and increase production such as *Heterotis* and that can greatly increase the efficiency of fish farming.

2.3.3. Fertilization attempts with locally available by-products

Some of these fish farmers seek to use available by-products. For example, one of those whose fish cycle was described used residues from the processing of palm nuts into palm oil, which occurs at the farm level. The palm trees bring a high income, but setting up a new plantation is made possible only by the support of one elite of the village by insuring access to quality plants. Another product used is chicken manure, but only occasionally due to its low availability.

Dam ponds with permanent water flow, even if very low, are an obstacle to the use of organic manure or mineral fertilizers. Nevertheless, smallholders are still willing to use locally available by-products (such residues from the extraction of palm oil). This generates the need to better understand how to control water flow through the pond. On the other hand, fish farmers reject the use of high performance feed due to its high cost. Organizing the transportation of by-products from large towns also seems impractical due to bad roads during most of the year and high transportation costs.

Integration of livestock (essentially pigs) is often suggested; however, financial and disease risks are large obstacles. In this region, pig (and also poultry) production is considered the business of elites who often invest, at a loss, in their village and are able to supply inputs for the animals because of incomes from non-agricultural sources. These elites generally practice semi-intensive fish farming, which combines catfish (*C. gariepinus)* with unsexed tilapias (*O. niloticus*). The use of pig excrement by small-scale farmers is more the result of some individual arrangements.

Discussion: Improvement potential of the (ecological) intensification process /scale

3.1. At the level of the tilapia: toward a genetic controversy

For Brummett and Ponzoni (2004), there is a need for genetic improvement programs in face of the genetic degradation of reared Nile tilapia (*O. niloticus*) in African fish farming systems. In a study carried out in Cameroon, Brummett et al. (2004) compared growth of a wild strain with that of a domestic one in a rural environment and an experiment station (Table 3). They observed a significant decrease in growth (up to 40%) of the reared strains. Therefore, they concluded that smallholders cannot ensure correct genetic management of their fish and proposed entrusting it to large farms in a public-private partnership. Moreover, the improved and synthetic tilapia strain called GIFT would be a neutral technology which can meet the expectations of small and large producers regardless of the feed and manure levels used in the fish farming system (Acosta and Gupta, 2010).

However, without any genetic improvement, large fish of 400 g are obtained in 6 months from 30 g fingerlings (at a density of 0.11 fish/m^2) with a daily weight gain of 2 g/day and a water temperature around 26°C during the rearing cycle. An improved strain such as GIFT fed with balanced feed reach this weight in 4 months at a daily weight gain of 3 g/day and a constant temperature of 28°C, but at 22°C and the same duration the final weight would be 60 g (Santos et al., 2013). It is unknown what additional production GIFT will bring to an unfed pond, the utility in selecting a strain in this low-input environment (Charo-Charisa, 2006) and the reaction of this selected strain when facing moderate intensification.

Probably, the value of the expected gain is not able to finance any selection service or even fry distribution at these small scales. Though carp fingerlings are available at the national level, producers give up their supplies, showing how unrealistic this option is. Farmers will see access to selected fish as an additional financial cost, which does not meet their expectations. Moreover, in the current situation, some traders or projects already promote exceptional quality seed that are never verified, an inevitable scam which perhaps participates in the maturing of the fish farming sector.

First, the tilapia population used by smallholders should be described genetically. It would help to set up a management plan to preserve the potential and genetic variability taking while also considering the specific context. It should be noted that the fish farmers described have already implemented a rough genetic management plan; it is based on integral renewal of broodstock combined with exchanges of a few breeders within and between groups of fish farmers and also a small supply from the natural environment.

The position of international institutions (such as FAO, WorldFish) on genetics, since taken by the technical services of Cameroon, has to be questioned by research. Does this apparent vocation of universality of improved tilapia apply to fish farming systems that are primarily based on natural productivity and geographically scattered (Khaw et al., 2013)? Does it not exclude all forms of development based on self-sufficiency of farmers for fish stocking supply? And does it thus exclude the ability of most people in rural and poor environments to sustainably adopt a system that is self-sufficient in fish? Like the paradigm of balanced feed, access to genetically improved strains is not the limiting factor in developing smallholders' fish farming and increasing fish yields; the supply of nutrients to stimulate the pond food chain appears more efficient (Karim et al., 2011).

3.2 At the fish population level: towards improvement of existing polyculture

These fish farmers practice an elaborate fish polyculture and seem ready to make it more complex if it meets their needs. Like mixed cropping, polyculture has several advantages. It can facilitate fish management (e.g., *Hemichromis* enable tilapia to grow) or provide additional yield or increase the gross margin (*Heterotis* increases the total fish yield). It can also improve the productive environment (e.g., common carps aerate the pond bottom and remove nutrients in sediments) or generate positive interactions between fish (such as grass carp, which create trophic supply for other fish). The polyculture is generally a way to optimize use of natural foods in ponds (Milstein, 2012).

Experiments to improve the reference system should be conducted to optimize the existing combination of fish species. This means improving the marketable production based on *O. niloticus* combined with *Heterotis* and the local catfish and taking advantage of the predator *Hemichromis*.

The adoption of and passion given to *Heterotis* by the farmers is obvious. In the short term, research and development efforts should focus on improving the availability of *Heterotis* juveniles by removing constraints related to the nondetermination of the sex of adults and post-hatch larval mortality (Monentcham et al., 2009). More generally, the biology of reproduction of this species remains understudied despite its high growth potential (3-4 kg/year in ponds) and high contribution to the total yield (APDRA-F, 2002).

Regarding common carp, mastery of fingerling production would help to improve its association.

Fish farmers are in search of a fish combination that will give them higher incomes. For example, at the start of the project, a wealthy fish farmer, unconvinced by the reference system proposed, stocked his dam pond with many *C. gariepinus fingerlings* bought from a hatchery. Given the high purchase cost and disappointing harvest, he did not renew this initiative, nor did his neighbors. The project needs to be open and support such initiatives via an action-oriented research approach.

In Cameroon, as in most of Africa, the number of candidate species available to occupy complementary ecological niches is limited. Nevertheless, this polyculture could experience great changes in the future. For example, association of the macrophytophage grass carp (or an equivalent native species such as *Distichodus* spp. or *Citharinus* spp., whose suitability for this production system is unknown), occupying a vacant niche in the reference system proposed, provides a good option based on a past example in the Ivory Coast (Lazard and Lévèque, 2009; Glasser, 2003; APDRA-F, 2002; Oswald et al. 1997). However, the subject causes controversy because grass carp would be an introduced species in the country (Dabbadie, 1994). Grass carp has many advantages: it eases pond maintenance by limiting macrophyte proliferation (a constraint that increases with pond age) and can double the total yield of polyculture if large amounts of green feed are supplied. This option remains an important pathway for intensification; on the other hand, it would change the management of the rice crop because grass carp eats rice plants.

Other species feeding lower on the food chain (such as the silver carp) could increase yield (Milstein, 2012). With or without rice, stimulation of the macrophyte-periphyton compartment could intensify fish farming (van Dam et al., 2002) and be an alternative to using balanced feed, considered too expensive (Milstein, 2005).

The choice and success of a complementary species will remain dependent on fingerling availability. For species in which reproduction cannot be mastered by farmers or by the existing local group, this constraint could be removed by setting up a socio-technical network such as in Asian countries (e.g., nurseries, fingerling brokers) (Sabur et al., 2010; Silva et al. 2009).

3.3 At the level of the service pond: an opportunity to intensify the fish farming unit by improving input management

The fish farmers and local groups want to intensify production by feeding or fertilizing. Adapting a response to this desire has to consider the extensive fish farming system. In some farms, use of plantation by-products such as palm oil residues offer one way to intensify at the pond and the fish rearing unit levels. However, availability of vegetable or animal by-products remains limited in the rural forest environment of the Centre Region. Without excluding specific situations, successful intensification should focus on using one input (fertilizer and/or feed) in a particular location and at a particular time of the breeding cycle. The service pond seems the place to initiate this process. This research and development work should be conducted with the fish farmers in order to have it validated by groups and the surrounding network and to strengthen sharing of technical references. The input should be abundant, widely available and have the highest ratio:cost efficiency in the local context and meet fish farmer expectations. It can be mineral (Oswald et al., 1997) or organic (Table 3; Brummett et al., 2005) and should stimulate fish growth directly or through the food chain (i.e., have a high C:N ratio). Other practices such as the addition of probiotics (Welker and Lim, 2011) in simple feed could be explored. It will not be a balanced-diet fish feed, which is already marketed at a high price. Many projects subsidize feed purchases, but to date, this approach has never allowed use of feed year after year, especially in rural areas. The production of rural fish farmers has returned to the situation before the project (Brummett et al., 2011).

Fertilization efficiency depends on a high level of water management. Even though it is well-controlled in service ponds, it remains variable in dam ponds, depending of their characteristics.

Some fish farmers build a bypass canal (whether and how to do so discussed on a case-by-case basis), which can require more labor than dam construction. In doing so, the smallholder shows an interest in intensifying. Changes in fertilization and feeding practices will modify the standards for planning ponds.

3.4 At the level of the “dam pond” plot : the role of floating rice (and macrophytes) in building up rice and fish yields

Since planting rice in their dam ponds, the first fish farmers have conducted several cycles of rice production despite difficulties with the crop. The impact of bird predation should decrease with the increase in planted area due to improved water management that considers both rice and fish requirements. When planting rice in ponds, the smallholders benefit from two types of production: although rice initially decreases fish growth at the start by reducing water area, the loss is greatly compensated by the weeding required in the shallows, where macrophytes multiply.

Rice farming is therefore also a means of getting rid of aquatic plants that are a nuisance for fish farmers. If not put to economic use, macrophytes probably constitute a trophic dead-lock (Avery, 2012; Dabbadie, 1996) , a disturbance for fish harvesting and a refuge for fish predators.

In the present situation, where most ponds are managed extensively, this co-culture can conserve land and water resources, which is particularly interesting in a livelihood agriculture relying on slash-and-burn cultivation. Rice and fish production generate positive interactions for each other (Holwarth et al., 2004; Frei and Becker, 2005). These positive effects justify the support of these smallholders by the project and technical agricultural services. Co-culture in dam ponds raises several questions about its contribution to intensification at the pond level: How does it interact with the current polyculture? Specifically, does it affect the contribution of *Heterotis* to the overall yield? Does rice increase feed resources available to fish? What changes occur in the soil-sediment compartment (stocking and exportation of nutrients, carbon storage)? The ultimate utility of introducing floating rice in dam ponds (confirmed by fish farmers in Guinea and Ivory Coast) should be evaluated in this particular rural context in Cameroon, which has a scarcity of inputs and low flows of organic matter at the farm level.

In the long term, evolution of this rice-fish co-culture is difficult to predict. Considering smallholder attempts to fertilize and the hydrologic functioning of the pond, too much fertilization can lead to excessive development of vegetative rice parts (stems and leaves). This could cause pond anoxia, which renders good fertilization of the pond difficult and could greatly decrease fish production. In such a system, understanding input efficiency remains complex. Studying the consequences of these alternatives (rice or fish intensification) should help fish farmers make good decisions when they face these situations, which are frequent in West Africa.

The relation between rice cropping and fish farming also calls into question pond ecosystem stability. Several fish farmers realized that pond fertility increased during the first few years, which could increase rice yield. These fish-rice farmers have to withstand an evolution in the pond environment. Few studies have examined this evolution, which emphasizes the system's complexity. Such analysis, however, could be useful during the first few years to advise fish farmers better about factors that limit pond productivity (and perhaps that of their investment). On the other hand, environmental change should be included in all environmental evaluations. We also addressed control of macrophytes, which can become invasive in older ponds. In Ivory Coast, fish farmers have started using herbicides to manage these constraints.

Finally, this questioning should be seen from the fish farmers' viewpoint: what criteria will they use to decide whether to give priority to one of the two types of production? Solving these questions in the field comes up against socio-economic constraints which can only be removed with smallholder participation (Oswald et al., 1997b).

Conclusion

Through this technical review, the contribution of fish farming innovation in this context to agricultural intensification is obvious. Similar conclusions were obtained with a socio-economic approach by analyzing the rationale behind diversification of fish farming in Ivory Coast and Guinea (Oswald, 2013).

Today, potential answers to improve intensification in this context belong to the agro-ecology field. In contrast, we have shown that options proposed by the private sector (e.g., selected fish strains, feed) do not seem appropriate to accompany this intensification (except perhaps for herbicides, though they could be replaced by Chinese carp). That this result agrees with many previous observations is surprisingly not the main concern for developing fish farming; promoting public-private partnership as the only way to reinforce fish farming cannot resolve the questions raised here.

However, many technical changes take place and can be identified at multiple levels of analysis. Other changes are expected, such as in fertilization, polyculture, and rice association. At the farm and territory levels, potential intensification of this fish farming has not yet been sufficiently investigated. Its impacts on changes in water resources and cropping method (from slash-and-burn to irrigated cropping) at the watershed level and its contributions to major environmental (climate change, greenhouse gas emissions, water resources) and social issues (nutritional balance, rural incomes, employment) are to be investigated.

Consequently, what resources are available to support these developments, which help provide sustainable intensification and have shown their pertinence for alleviating poverty and increasing food security? Smallholder fish farming is able to evolve by itself, but it would greatly benefit from national and international recognition, particularly in countries where it occurs. This means setting up differentiated policies adapted to each type of fish farm, smallholder, small- and medium-sized enterprise or industrial (Sarnissa, 2010).

And what about the need of research to accompany this development? The assessment levels reviewed generate questions about lowland intensification, not only about fish production. Other ways to intensify have been identified, but they need study by researcher and validation by producers. This research will use one of three research models depending on the question asked: laboratory research, field research (in which the researcher is the only one who decides) or action-oriented research. It seems essential to us to link smallholder social dynamics and fish farm development to research to reduce dissymmetry between smallholders, development agents, researchers and other actors in the sector. Putting research in this place favors the emergence of subjects on rural fish farming intensification and takes its complexity into account.

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Fig. 1. Location of the Centre Region in Cameroon

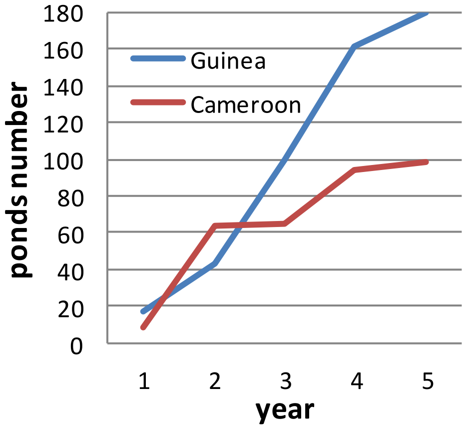

Fig. 2. Changes in pond numbers during the first five years of the fish farming projects in Guinea (2001-2005) and Cameroon (2006-2011)

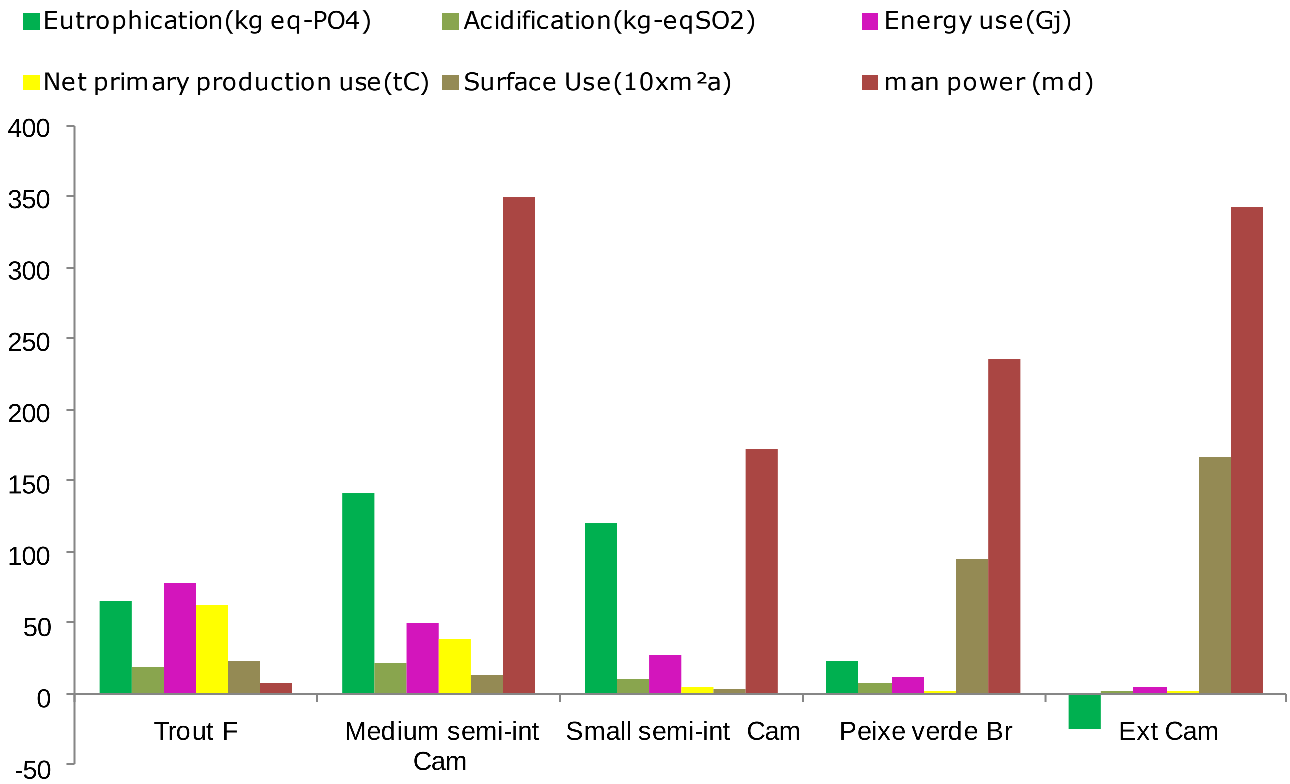

Fig. 3. Potential impact categories per tonne of fish produced in an extensive system in Cameroon, semi-intensive (medium and small) systems in Cameroon (Efolé, 2011), a "Peixe Verde" semi-intensive system in Brazil (Casaca, 2008) and an intensive trout system in France (Aubin et al., 2009)

Table 1. Dam pond fish cycles of 2 farmers (Centre Region in Cameroon)

	Sp	Initial Number	Total Weight	Initial Weight	Density	Total Weight	Final Weight	Survival	Growth	Yield	
			kg	g	N/m^2	kg	g	%	g/d	kg. ha/yr	%
Farm 1	*O.n*	140	4.2	30	0.11	58	422	99	2.2	830	50
Pond area: 1300 m²	*H.f*	20	0.2	10	0.02	6				90	5
	H.n	22	15.3	695	0.02	28	1251	100	3.1	188	11
	fry *H.n*					17	60		0.3	266	16
	C.c	18	2.5	139	0.01	21	1500	78	7.5	284	17
										1658	100
Farm 2	*O.n*	130	2.6	20	0.13	38	313	92	1.6	700	52
Pond area 1000 m²	*H.f*	25	1.3	50	0.03	6		0		100	7
	H.n	14	7.5	536	0.01	28	2536	79	11.0	404	30
	H.n	7	0.5	70	0.01	8	1598	71	8.4	150	11
										1354	100

O.n: Oreochromis niloticus; H.f: Hemichromis fasciatus; H.n: Heterotis niloticus; C.c: Cyprinus carpio

Table 2. Rice cycles in fish dam ponds of 4 farmers (Centre Region in Cameroon)

Farm	Seed kg	Area are	Harvest kg	Yield Kg/are	Duration day
1	1.3	3.3	60	18	193
2	1.3	3.0	30	10	214
3	5	7.9	217	27	191
4	1.7	4.7	127	27	197

Table 3. Estimated individual growth from "wild" population (Sanaga River) and from "domestic" population (small farms) of *Oreochromis niloticus* on-station and on-farm (Centre Region) in Cameroon from Brummett et al., 2004.

Population	Location	Initial Weight g	Density Number/m^2	Duration Day	Final Weight g
Wild	station	10	2.3	183	284
	farm	10	2.0	168	121
Domestic	station	10	2.3	183	178
	farm	10	2.0	168	87

Table 4. Some general characteristics of by-products used in fish ponds and fish performance (West and Centre Regions, Cameroon) from Brummett et al., 2005.

Material	Price per kg (€1.00 = Fcfa 656)	Food Conversion Ratio	Specific Growth Rate	Feed cost /kg fish
Cacao Husks	284	1.28	2.16	364
Brewery Waste	282	0.77	2.31	217
Chicken Manure	308	0.48	2.52	148
Coffee Hulls	297	1.08	2.28	321