Enhancing Profitability of Pond Aquaculture in Ghana through Resource Management and Environmental Best Management Practices

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ABSTRACT

The accelerating pace of growth of aquaculture in sub-Saharan Africa has received much positive appraisal because of the potential of the industry to contribute to economic development and food security by providing jobs and animal protein. Adoption of best management practices (BMPs) holds the potential to ameliorate the related environmental impacts of aquaculture, such as in the amounts of nutrients and sediment that will enter natural water bodies from earthen pond effluents. The goals of this study were to characterize adoption of aquaculture BMPs on small-scale, pond-based farms in Ghana, and to assess selected economic, social, and environmental outcomes of BMP adoption. Two BMPs: 1) water reuse, and 2) commercial floating feeds, were investigated for adoption by pond-based fish farmers in Ghana. I conducted my study in Ghana using on-farm experiments involving intensive monitoring of water quality and growth of Nile tilapia (*Oreochromis niloticus*) over two production cycles. Additionally, I administered a baseline survey to 393 (and a follow-up survey to 160) fish farmers. I determined the best model for modelling farmed Nile tilapia growth with multi-model inference based on Akaike information criterion (AIC), the profitability of adopting BMPs with stochastic enterprise budgets and, social welfare impact with the Economic-Surplus model. I used a Markov model to predict the equilibrium rate of adoption of the two BMPs and determined the impact of BMP adoption on the reduction of pollutant loading with the Minimum-Data method of the Tradeoffs Analysis (TOA-MD).

My results showed that the logistic model is a better alternative to the von Bertalanffy model for modelling the growth of *Oreochromis niloticus* under pond aquaculture conditions. There were no significant differences in fish weight between the water re-use BMP and the use of new water. Adoption of the commercial floating feed BMP resulted in a 100% increase in fish final weight and yield, and in higher profitability, compared to the sinking feed type. Probability of making a profit was highest (72%) in the scenario with commercial feed and self-financing. Net present values (NPV) of about US$ 11 million and US$ 375 million could be obtained from the adoption

of commercial floating feed and Genetically-Improved Farm Tilapia (GIFT) strain, respectively, in Ghana. Hence, any innovation that has a significant impact on fish yield also will have a significant impact on mean NPV and social welfare. However, I identified a number of potential negative ecological and genetic impacts that exist from introducing the GIFT strain into Africa from Asia. Although considered low-intensity production systems, nutrients and solids in study ponds were found to be higher than levels expected in intensive culture ponds by wide margins. Pond water quality was significantly higher with commercial floating feed. The water-reuse BMP also prevented pollutants from leaving ponds altogether for the number of cycles for which pond water was reused, especially if associated BMPs such as rainfall capture and avoidance of water exchange are observed. Significant reductions in the loading of all water quality variables (nitrogen, phosphorus, solids, and BOD_5) could be achieved with the adoption of the recommended feed type in Ghana. Adoption of the water reuse BMP has the potential to cause pollution reductions of 200% - 3,200% above that from the floating feed BMP. The strongest influence on the combined adoption of these BMPs were from : farmer's awareness of the feed BMP, perceived necessity and relative profitability of the water reuse BMP, and farmer's years of experience. A combination of central media (workshops), demonstrations, and lateral diffusion was found to be the most effective channel for disseminating these BMPs. Maximum adoption rate of the feed BMPs was estimated to be 38% - 58%. Also, US$ 6,000/year and US$12,000/year need to be paid per 0.6 ha pond surface area to push adoption of the feed BMP to 50% and 70%, respectively.

Hence, to ensure the successful adoption of aquaculture BMPs, I recommend that regular well-planned workshops be organized to create awareness and a conducive atmosphere to target farmers at multiple stages of the innovation decision process. Incentives and effective dissemination will encourage the adoption of these and other environmental BMPs. Feed costs need to be lowered in order to encourage the adoption of commercial floating feed in Ghana. Future analyses could quantify the differences in production costs between using the two water types, to reveal the possible higher relative profitability of pond water reuse over draining ponds after each production cycle. Also, African governments are advised to commission rigorous baseline and ecological risk analyses before adoption of the GIFT strain from Asia. Improvements in management practices and infrastructure could increase the yield and profitability of the local strains even if genetically-improved strains are not introduced.

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ATTRIBUTION

A number of co-authors contributed significantly to this dissertation, which is a compilation of seven publications and manuscripts. This section specifies the contributions of each co-author to this work. E.A. Frimpong is my academic advisor and primary project supervisor. He wrote the grant to fund this study, and contributed heavily to the project design, analysis and writing of each manuscript.

Stephen Amisah, Daniel Adjei-Boateng, Nelson W. Agbo and Hillary Egna co-authored Chapter 2, which published in Sustainability in February 2014. This paper was the result of two separate projects of the AquaFish Innovation Lab, and co-authors were the team members who were involved in the conception, data collection, analysis, and writing of the manuscript.

Gifty Anane-Taabeah Attu and Regassa E. Namara served as co-authors on Chapter 4. Gifty played a key role in survey administration, workshop organization, data collection, and writing of this manuscript. Regassa co-supervised the Borlaug LEAP Fellowship that contributed funding for my study. He contributed to the development of survey instruments, data analysis and writing of this chapter.

Eric M. Hallerman co-authored Chapter 8, which published in Sustainability in June 2014. He contributed the sections on Genetics, and also to the overall design and writing of the manuscript.

The following chapters are to be submitted to the following journals for publication: Chapter 3: North American Journal of Aquaculture, Chapters 4: Technological Forecasting and Social Change, Chapter 5: Aquaculture Economics and Management, Chapter 6: International Journal of Sustainable Development, and Chapter 7: Journal of Environmental Management.

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Chapter 1: General Introduction

Aquaculture and best management practices

With persistent marine fisheries stock declines, the global potential for capture fisheries has been reached (Food and Agriculture Organization 2014). Global demand for fish and fish products, however, continues to increase. Aquaculture has shown great potential towards meeting this growing deficit. Compared to 1980, when production of aquaculture represented only about 5% of global fisheries production, nearly 52.5 million tons of fish and shellfish were produced by aquaculture in 2012, representing almost 50% of global food fish production (Food and Agriculture Organization 2014). However, while the share of global aquaculture production from most regions of the world has remained the same the share from sub-Saharan Africa, though low, has quadrupled from 0.17% in 2000 to 0.68 in 2012 (Food and Agriculture Organization 2014). Considering the abundance of water and land, and the increasing population and per capita consumption of fish and fish products in this region, sub-Saharan Africa has a huge potential and need to dramatically increase its aquaculture production.

Aquaculture has known benefits especially to developing countries, such as increased availability of high-quality low-cost animal protein, poverty alleviation, increased employment, foreign exchange earnings, and profit for entrepreneurs and investors (Tucker et al. 2008a). However, most forms of aquaculture are perceived to have adverse environmental effects (Tucker et al. 2008a, Klinger and Naylor 2012). Even though there are signs that the rate of growth for global aquaculture may have peaked, high growth rates may continue for some regions and species, such as the sub-Saharan African region and tilapia (*Oreochromis niloticus*), respectively (Food and Agriculture Organization 2007). Aquaculture in sub-Saharan Africa is conducted mainly in earthen ponds and is relatively less intensive

compared to the same method of food production in Asia, Europe, and North and South America. After many years of low productivity, efforts to expand the number of enterprises and increase the intensification of existing ones appears to be producing results. The Food and Agriculture Organization (FAO) reported 'rapid progress' made by Nigeria, Uganda, Kenya, Zambia, and Ghana to become major aquaculture producers in sub-Saharan Africa (Food and Agriculture Organization 2012; Frimpong et al 2014. Practices that enhance the profitability and efficiency of these small-scale aquaculture operations while protecting the environment need to be encouraged. Enhanced profitability of these small-scale operations will stimulate intensification, which will result in the increase in fish production to, in turn, advance such development goals as food security and poverty reduction. Protection of the quality of effluent-receiving waterbodies will prevent the destruction of needed water resources for fish farming, thereby ensuring the sustainability of the industry.

Best management practices (BMPs) are increasingly regarded as meaningful goals in the overall reduction of cumulative impacts of agriculture (Clay 2009). Generally, environmental BMPs are grouped into two: nutrient management and effluent management (Louisiana State University AgCenter 2003). Effluent management include guidelines of pond operation, settling ponds and vegetation ditches, draining to wetlands, top-releases for partial drainage, and pond water-reuse. Nutrient management practices include guidelines relating to fertilization and feeding regimes that avoid wastes, which result in deteriorated pond water that threaten the health or condition of the fish.

This dissertation

This study mainly examined two BMPs, one from each broad category: **water reuse** (as opposed to pond draining after each production cycle), and **use of commercial, floating feed** (as opposed to local, sinking feed). The feed BMP is referred to as floating, commercial, or commercial floating feed throughout this document. Water use is inextricably tied to issues of

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waste discharge because increasing water input volume implies increasing water discharge volume (Tucker et al. 2008b). Also, wastes from uneaten feed and excreted nutrients are potential sources of pollution if effluents are discharged from the facility, even though nutrients function as fertilizer for primary production when left within the system (Tucker et al. 2008). Therefore, the reuse of water by a farmer effectively prevents the export of sediment and nutrients from his ponds into effluent-receiving streams for those cycles that old-production water (water from a previous production cycle being used for fish culture) is employed.

Most commercially manufactured feed meets high quality standards, but poor feeding practices can negate benefits offered by the feeds (Tucker et al. 2008b). Avoidance of feed wastes saves cost and contributes to farm profitability (Engle and Valderrama 2004). Therefore, if a farmer can observe the feeding activity of fish and adjust feeding accordingly, pond water quality is improved and feed costs are reduced. Commercial, floating feed allows the farmer to observe the feeding activity of his fish in order to make the necessary changes to his feeding regime. Also, commercial aquafeed is prepared with a good balance of macro and micronutrients needed by fish for growth (Bell and Waagbø 2008). Although proximate analysis conducted on the feed in this study indicated an equal crude protein content in both feed types (30%), commercial feed processing removes anti-nutritional factors and makes commercial feed more palatable and utilizable to fish (Drew et al. 2007, Hardy 2010).

The sinking feed type usually is prepared on site as a mixture of agricultural and food-industry wastes, such as corn meal, wheat or rice bran, and peanut husk. The mixture then is milled into powdery form, which quickly sinks to the pond bottom when administered. Fish growth is hampered not only by the unavailable feed and nutrients, but sinking feed accumulates on the pond bottom, where it decomposes to set off physico-chemical reactions

that degrade the water quality of the pond (Frimpong *et al.*, 2014). Therefore, commercial feed is expected to result in faster growth, larger yields, and greater revenues.

There have been concerns about the low rate of adoption of best management practices (BMPs) aimed at improving water quality (Valentin et al. 2004). A possible explanation for this reluctance is that farmers are uncertain of the impacts of adopting these BMPs on farm profitability (Valentin et al. 2004). Additionally, resources are scarce (Alston *et al.*, 1998), and all governments and foreign aid donors need to justify their investments. However, the economic value of public investments may not be obvious (Masters et al. 1996, Antle et al. 2010). This difficulty arises because economic impacts of projects are widely spread out, both spatially and temporally (Antle and Valdivia 2006), and these impacts need to be carefully quantified at the household, national and ecosystem levels.

The impacts of the adoption of several technologies have been studied, with varying results (e.g. Valentin et al. 2004, Qaim 2006, Antle et al. 2010, Dey et al. 2010). Impact assessment can be grouped into two types: *ex-post* studies, for technologies already being used, and *ex-ante* studies, for technologies not yet adopted (Masters et al. 1996, Antle et al. 2010). *Ex-post* impact assessments are believed to be more reliable than *ex-ante* assessments, because the former involves observation of actual outcomes, whereas the latter must rely on researchers' trials and extrapolations (Masters et al. 1996). In both cases, however, the success of impact assessments depends on the judgment of the researchers in designing the survey, and collecting and interpreting their data (Masters et al. 1996). Although desired, decision makers often do not have the option of treating impact assessments *ex-post* because *ex-ante* assessment is often necessary to justify investment in a policy decision in the first place.

An ecosystem service represents the benefits human populations derive from ecosystem functions (the habitat, biological or system properties or processes of ecosystems), such as

waste assimilation (Costanza 1997, Millennium Ecosystem Assessment 2005). The Minimum

Data Method of the Tradeoffs Analysis by Antle and Valdivia (2006) has been shown to have

several uses (e.g. Economic viability of innovations: Claessens et al. (2009); Wetland

conservation: Nalukenge et al (2009); Ecosystem service supply: Antle et al. (2010)). It

basically models the supply of ecosystem services (from an innovation, such as a BMP) from

the spatial distribution of opportunity cost of providing those services. From this model, the

rate of adoption of the BMP and the changes in social welfare and farm profitability in a

region, as a result of the adoption of the BMP, can be determined (Antle and Valdivia 2006,

Antle et al. 2010). For this study, the amount of sediment (total suspended and settleable

solids) and nutrients (nitrogen and phosphorus) that is prevented from entering effluent-

receiving streams will represent the ecosystem service being supplied from the adoption of

the BMPs under consideration.

This study has two broad goals: To characterize adoption of aquaculture BMPs on small-

scale farms in Ghana, and to assess selected economic, social, and environmental outcomes

of BMP adoption. The document is broken up into seven manuscripts/chapters, each targeting

a specific aim. Chapter 2 is an in-depth characterization of the impacts of the two BMPs

under consideration on both pond water (potential effluent) quality and fish growth. Chapter

3 is a selection of the best model to predict the growth of farmed fish (tilapia). Chapter 4 is

three-part characterization of the process of adoption of BMPs: characteristics of BMP

adopters; predicted rate of BMP adoption, and relative effectiveness of three innovation

diffusion channels. Chapter 5 is a determination of the changes in farm profits should a

farmer adopt BMPs. In Chapter 6, changes in the social welfare of Ghana from the adoption

of BMPs is investigated. Chapter 7 focuses on determining the changes in the supply of

ecosystem services with the adoption of BMPs and policies that may influence adoption rate

of a BMP. Chapter 8 is a review of the potential ecological, economic, and genetic impacts of

the introduction into Africa of the Genetically-Improved Farmed Tilapia (GIFT) technology, which constitutes the management of genetic aquaculture resources.

Ghana

Ghana is located in sub-Saharan Africa, on the western coast of the continent. According to (World Bank 2014), the country is classified in the 'lower middle income' category, with a gross domestic product of US$ 48 billion and a population of 26 million that is increasing at 2.1%. Of this population, 24% are considered to be living below the national poverty line. The country derives a majority of its dietary protein from fish, which makes up about 60% of animal protein in Ghana, with an annual per capita fish consumption of 26kg (Brashares et al. 2004; Ainoo-Ansah 2013). This is higher than the global estimate of about 18 kg (Food and Agriculture Organization, 2012). Considering the country's socioeconomic status and abundant water resources, the potential for freshwater and brackish-water aquaculture cannot be over-emphasized.

Nevertheless, demand for fish has always exceeded supply in Ghana. The national annual fish demand is about 1.1 million metric tonnes (MT), but total fish supply is about 500,000 MT, with less than one-fifth of supply coming from aquaculture (Frimpong and Anane-Taabeah Attu *in press*). Aquaculture is regarded as a means to bridge this imbalance due to the high demand for fish and the availability of streams for pond operations. Aquaculture production in Ghana occurs in two main systems – floating cages in the Volta Lake and dug-out earthen ponds. Floating cage systems are intensive operations that rely solely on commercial floating feed throughout the production cycle, and these systems account for about 90% of the country's aquaculture production – about 24,250 MT – in 2013 (Ainoo-Ansah, 2013; Awity, 2013). Analysis of data from Ainoo-Ansah (2013), Awity (2013), and Food and Agriculture Organization (2014) allowed a separation of the estimated Nile tilapia pond production from the total aquaculture production for 2013 in Ghana to be 1,500 MT.

Fish farming in Ghana

A survey of 393 pond fish farms in Ghana, as part of this study, revealed a number of characteristics of Ghanaian fish farms. Land tenure was as follows: 34% owned their lands, 30% were leasing their lands, and 20% were farming on family lands. The number of species cultured per farm ranged from one to three, with the tilapias (73% of farms) and the African catfish (Clarias *spp.*; 54%) as the commonest farmed species in the country. A majority (71%) of farms feed their fish twice daily, with the rest feeding once (8%), three times (18%), or four times (3%) daily. Approximately 86% of all farmers who reported using commercial floating fish feed were using the Raanan brand. Other brands were Coppens, tilapia grower, catfish grower, and AquaSell. About 76% of fish farmers who were not using the commercial floating feed were willing to switch to it, if feed costs were lower. However, only 36% of farmers who were practicing pond-draining were willing to re-use pond water.

Bottlenecks to fish farming in Ghana
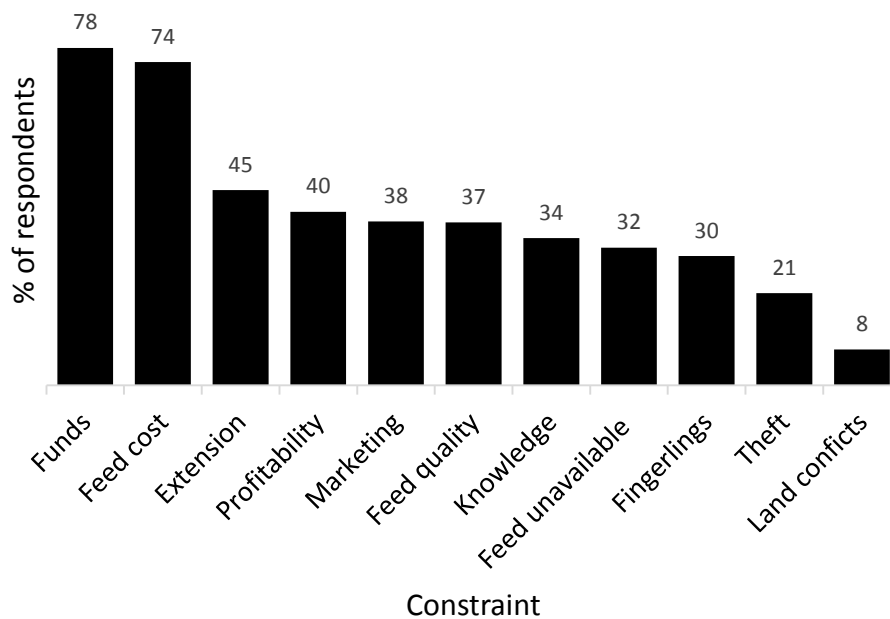
Figure 1.1. Summary of pond-based fish farmers' perceived bottlenecks to fish farming in Ghana (n = 393)

The lack of funding for fish farming activities, and the high cost of the preferred, commercial floating fish feed were the biggest reported constraints of farmers in Ghana (Figure 1.1). These were followed by the lack of extension services, unprofitability, lack of market for produced fish, lack of high quality fish feed,, and lack of fingerlings in that order.

Funding sources for fish farming in Ghana

About 70% of tilapia farmers in Ghana self-funded (0% loans) their operations, right from the start (Figures 1.2 and 1.3). Other funding sources included loans from family/relatives, banks, loan facilities through local governments, and farmer co-operatives. Bank lending rates in Ghana ranged from about 18% to about 32%.
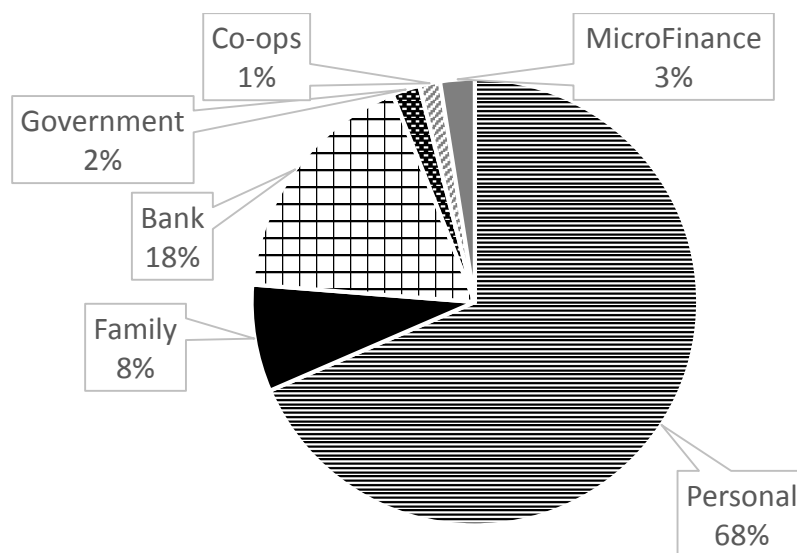
Figure 1.2. Sources of start-up capital for tilapia farms in Ghana, according to pond-based fish farmer surveys (n = 393)
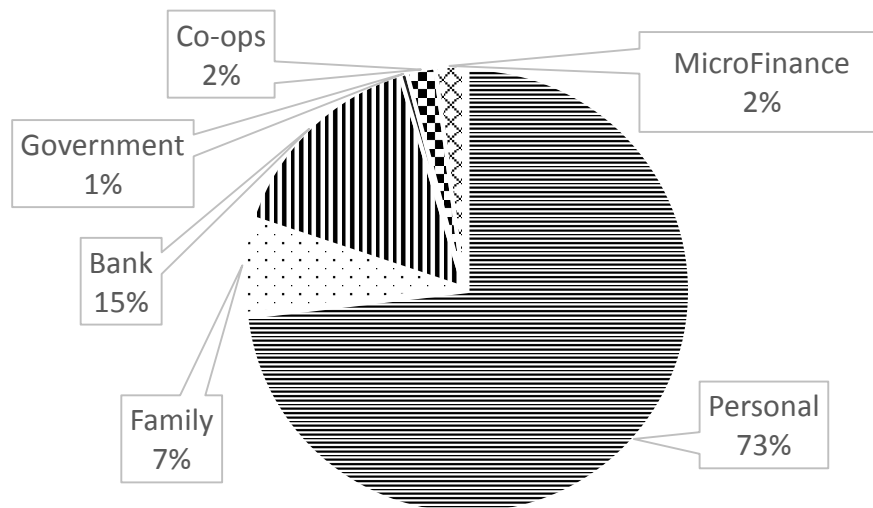
Figure 1.3. Sources of operating capital for tilapia farms in Ghana, according to pond-based fish farmer surveys (n = 393)

Chapter 2: Effects of Two Environmental Best Management Practices on Pond Water and Effluent Quality and Growth of Nile Tilapia, *Oreochromis niloticus*

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Abstract: The trajectory of aquaculture growth in sub-Saharan Africa has necessitated closer attention to the use of environmental best management practices (BMPs). Two BMPs in particular, water reuse and floating feeds, are being promoted for adoption by pond fish farmers in sub-Saharan Africa. In this study, we investigated: (1) the effect of water source and feed type on water quality; (2) the effect of water source and feed type on tilapia growth; and (3) the quality of potential effluents from ponds using different water source and feed types. The study was conducted in Ghana using on-farm experiments involving monitoring of water quality and growth of Nile tilapia *Oreochromis niloticus* for 160 days. Although considered low-intensity production systems, nutrients and solids in the study ponds exceeded levels expected in intensive culture ponds by wide margins, whereas BOD_5 was within the range for semi-intensive ponds. Floating feed was associated with higher water quality, especially dissolved oxygen, and higher growth, but water source did not significantly affect growth. Water reuse appears to be a viable BMP for sustainable aquaculture in the region, but the use of floating feed as BMP will depend on the economic profitability of floating feed use.

Introduction

Aquaculture in sub-Saharan Africa is conducted mainly in earthen ponds and is relatively less intensive compared to the same method of food production in Asia, Europe, and North and South America. After many years of low production, efforts to expand the number of enterprises and increase the intensification of existing ones to increase productivity appear to be producing results. The Food and Agriculture Organization (FAO) reported 'rapid progress' made by Nigeria, Uganda, Kenya, Zambia, and Ghana to become major aquaculture producers in sub-Saharan Africa [1]. Ghana is one of the countries in sub-Saharan Africa with the potential to dramatically increase its fish production from ponds in the foreseeable future due, among other factors, to convergence of several auspicious events in the country. These include: (1) progress in the development of a better-performing strain of Nile tilapia *Oreochromis niloticus* [2], which is the major aquaculture species in the region; (2) the establishment of the first commercial fish feed mill in West Africa in the country [3]; (3) the 2012 launching of the Ghana National Aquaculture Development Plan, developed in cooperation with the FAO, with an expressed objective of increasing Ghana farmed fish output from 10,200 tons in 2010 to 100,000 tons in 2016 [4]; and (4) a stabilizing political environment encouraging better governance of fisheries resources, as exemplified by a recent reinstatement of the Ministry of Fisheries and Aquaculture Development, independent of the Ministry of Food and Agriculture [5].

Intensification of farming is invariably accompanied by environmental problems, which can threaten the sustainability of the very growth that development experts agree is needed for food security [6]. For example, almost all forms of aquaculture in the United States came

under severe scrutiny and criticism in the 1990s for alleged poor environmental stewardship [7,8] and the United States, for example, responded with increased regulatory activity that led to a frenzy of research to respond to the new rules (e.g., [9]). Much research preceding and immediately following promulgation of these regulations focused on the characterization of effluents from various types of aquaculture under a range of management conditions [10–14] and assessments of the impacts of aquaculture effluent on receiving waters [15,16]. Consensus has emerged that pond aquaculture effluents are generally too dilute for conventional treatment options and that certain management practices, if applied properly, would help aquaculture achieve an equal or better environmental performance with less economic burden on producers [17–25]. Today, best management practices (BMPs) are increasingly mainstreamed in larger aquaculture businesses, with internationally recognized bodies in place that certify farms voluntarily adopting responsible aquaculture practices, focusing comprehensively on the social, environmental, and health dimensions [26]. Guidelines and codes of conduct for responsible aquaculture with national and international foci also abound (e.g., [22,27–29]).

Due to its history of being mostly small-scale, pond aquaculture in sub-Saharan Africa has not experienced great scrutiny, but increasing scrutiny is predicted under the current rate of growth. Cage aquaculture in Africa has seen tremendous growth recently and is more conspicuous to environmentalists resulting in its being regulated in countries such as Uganda, Botswana, Mozambique, and Ghana (e.g., [30,31]). Research, especially research directed at improving environmental performance of aquaculture in Africa, is not a current focus of national governments partly because there is a sense of crisis and the perception of needing to increase production at all cost. But when aquaculture development in the region comes under increased pressure for environmental stewardship, scientific data will be required to demonstrate stewardship or identify areas where improvements can be made. There is a wide

variety of aquaculture production systems and management practices, but in the absence of data related to specific aquaculture types and management practices, there is the tendency to lump all aquaculture systems together and attribute common environmental problems to all of them [7,8].

The United States Agency for International Development (USAID)–funded Aquaculture and Fisheries (AquaFish) Innovation Laboratory (formerly AquaFish CRSP) has supported investigations over the past six years to identify the characteristics of pond aquaculture effluents and effluent receiving waterbodies in Ghana [32] and assess the impacts, if any, of aquaculture on these receiving waterbodies [33]. The results of the studies showed the presence of elevated total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), and biochemical oxygen demand (BOD_5) in ponds relative to upstream sections of receiving streams and reference streams. In addition, water downstream of aquaculture facilities trended toward similar levels of the nutrients (TP and TN), TSS, and BOD_5 [32] as in the ponds. It was concluded that while the overall impact of pond aquaculture on receiving waters in Ghana was currently low, BMPs relating to nutrient and effluent management need to be widely adopted by fish farmers in the near future, especially as the number of fish farms and intensification of existing farms continue to increase [32,33]. Subsequently, AquaFish has sought to develop and extend environmental BMPs widely to pond-based fish farmers in Ghana, Kenya, and Tanzania. One goal of the effort has been to pre-empt harsh regulations while keeping small-scale pond aquaculture profitable and environmentally benign.

The adoption of BMPs in fish production requires strategies that integrate profitability and efficiency in the fish farming enterprise [23,34]. Nutrient and effluent management practices affect the volume of water, nutrients, solids, and oxygen demand loading rates from ponds into receiving waterbodies [11,18–20,35]. Changing nutrient and effluent management

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practices has economic implications, beyond the potential environmental benefits. One way to assess environmental impact of changing practices is to empirically determine the net gain or loss in nutrients, solids, and oxygen demand in the pond water through the production cycle and the amount of water exiting the pond after production under the alternate management practices. This approach has been used to varying extents by various studies cited herein. Where there is negligible overflow or seepage from ponds, this analysis is relatively intuitive. The economic impact of changing practices on producers is assessed by determining the cost and change in production and profit associated with alternate practices (e.g., [17,23,24]).

The focus of the current study was to quantify the quality of pond water and potential effluent under selected management practices and to determine the effect of these management practices on growth of Nile tilapia, *Oreochromis niloticus*. Detailed analysis of the economic impact of these BMPs on profitability for the producer and society is the focus of another study. The two BMPs selected for assessment were: (1) water reuse (as contrasted with draining ponds and refilling with new water at the end of each production cycle) and (2) the use of commercial-grade extruded or floating fish feed (as contrasted with sinking feed of the quality made on most farms), the former accomplishing both reduction of effluent volume and nutrient, solids, and oxygen demand whereas the latter primarily serves to reduce nutrient loads. These two BMPs have clear alternative practices that are widely agreed to be the *status quo*, the BMPs are hypothesized to have significant effects on fish growth and pollution potential of ponds, and lend themselves to straightforward experimental manipulation so that their environmental effects and economic benefits can be quantified accurately. Specifically, we investigated: (1) the effect of water source and feed type on water quality; (2) the effect of water source and feed type on tilapia growth; and (3) potential effluents from ponds using different water source and feed types.

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Experimental

<u>Study Location</u>

The study was conducted in three pond aquaculture-dominated regions of Ghana on eight

farms over two six-month production cycles between June 2011 and December 2012. The

regions are Ashanti, Brong-Ahafo, and Western (Figure 2.1). Three of the farms participated

in both production cycles and the other five participated in only the first or the second cycle.

These farms, which had been selected as demonstration sites for the focal BMPs, included one

government and one university research station. Data from five farms that participated in the

second production cycle are reported in this study (Figure 2.1), although the experimental

design applies to all farms. We focus on the second production cycle because a more consistent

and intensive water quality monitoring regime was implemented during that cycle.
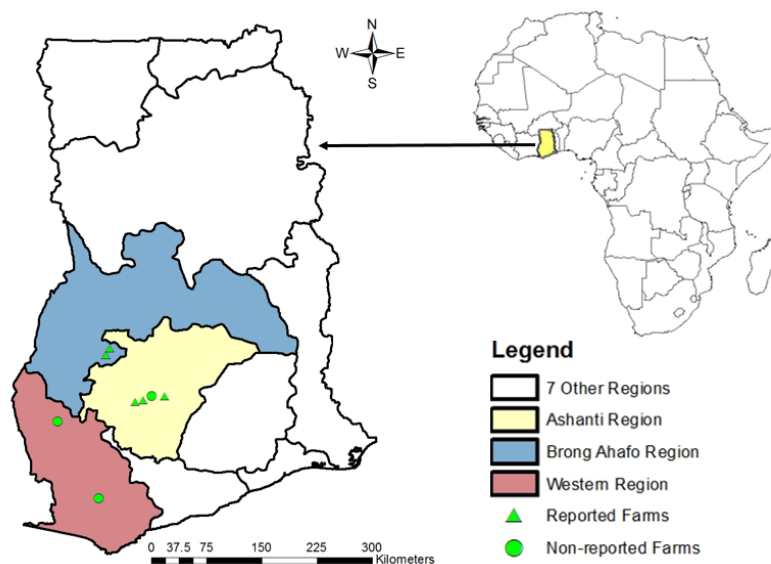
Figure 2.1. Map of Ghana showing the location of eight AquaFish Innovation Lab (formerly CRSP) best management practices (BMP) demonstration farms in three pond-aquaculture dominated regions. Water quality data from five of the farms are reported in this paper.

<u>Experiment Setup and Monitoring</u>

Five farms, each contributing four ponds, were used for the second round of on-farm

experiments. Thus, results reported in this paper cover a total of 20 ponds. The two

management practices (experimental factors) were each set at two levels which are respectively the recommended management practice and the contrasting *status quo* or common practice. For factor 1—Water source, the recommended practice is water reuse (involving reuse of "old" or "green" water) and the *status quo* is new water, where ponds are drained completely and refilled with new water from a well or diverted water from a nearby river or stream. For factor 2—Feed type, the recommended practice is floating feed, available commercially, and the *status quo* is sinking feed manufactured on-farm from food processing wastes. The two factors were combined in a 2×2 crossed factorial design, with farm serving as a blocking factor. Note that 'farm', in this paper, is a site consisting of a set of four ponds geographically isolated from other sites as shown in Figure 2.1. Farm was considered as a block in terms of experimental design because four ponds in the same geographic location experience climatic and edaphic conditions that are more similar compared to any other set of four ponds in the study. This design enabled the statistical estimation of the effect of farm, water source, feed type, and the interaction of feed and water source on fish growth, feed conversion ratio, and water quality. The four treatments were randomly assigned to the four ponds on each farm and the spatial arrangement of ponds varied across farms, and not necessarily as illustrated (Figure 2.2).
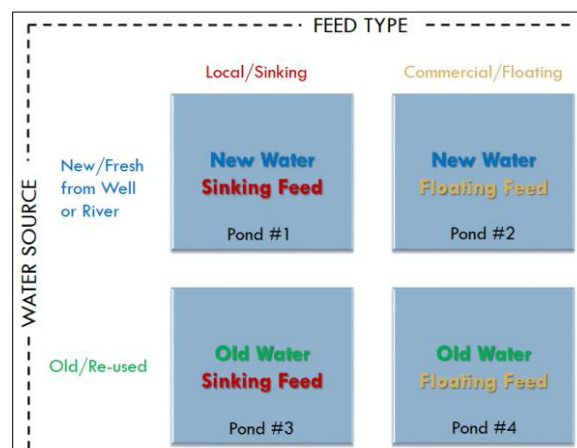
Figure 2.2. The basic experimental design replicated across all farms in this study.

All ponds underwent the same preparation prior to filling, regardless of the randomly assigned water source or feed type. After draining, the pond bottoms were dried for approximately one month, during which time each pond was limed with powdered lime, spread evenly over the pond bottom at a rate of 10 kg/100 m^2. Ponds were filled after they were completely dried out. Old-water ponds were filled by retrieving previous production water (by gravity drainage, pumping, or a combination of the two methods) from a temporary storage pond. New-water ponds were filled similarly, but from a nearby river. Water was strained through a 2 mm nylon sieve fitted to the intake to prevent transfer of unwanted eggs or larvae into experimental ponds. After filling each pond and before stocking, poultry manure, as organic fertilizer, was broadcast over the pond water in a one-time application at a rate of 5 kg/100 m^2.

Due to the fact that data reported mostly represent a second run of the same experiment on the same farms, the old water ponds on the three farms that participated in the study twice, had old water that had been treated with the same feed as the feed type assigned in the current experiment. This water, however, was pumped out of the pond for drying and bottom treatment and had to sit for one month during the changeover from the first to the second experiment. For the two farms that participated in the experiment for the first time, old water originated from previous productions
in which floating and sinking feed had both been used but not documented in detail. Again, the experimental ponds had to be emptied, dried and treated and the water pumped into these ponds. Because of the long period the water had to sit without feeding, and the assimilation of nutrients into plankton production during that period, we considered all the old water to have similar quality at the beginning of the experiment, compared to the new water.

Thorough morphometric measurements were also made for each pond after filling the pond to the normal depth as set by the farmer. Although a minimum of 1 m water depth is the recommendation made to farmers, it was discovered that most existing ponds would not reach close to 1 m water depth before they overflow their embankment. Morphometric surveys involved mapping water depths at several perpendicular transects across the entire pond by wading in the pond with a calibrated rod and using the observed depths at known locations to create a bathymetric map for each pond (Figure 2.3). The surface areas between each pair of contours were determined gravimetrically by cutting and weighing printed maps. The volume of water contained in each contour interval then was calculated using a standard formula from limnology [36]. The field bathymetric maps were used to calculate

the surface area, volume, average water depth, and maximum water depth of each pond.
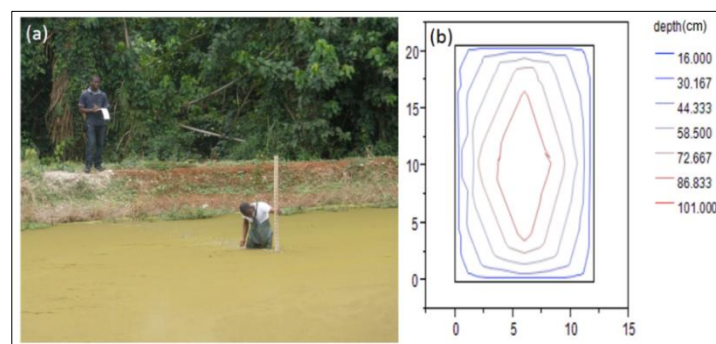
Figure 2.3. (a) Field mapping of pond depth; (b) An example of bathymetric map of a pond developed from field measurements.

Tilapia (*Oreochromis niloticus*) fingerlings were obtained from a private hatchery at 2 g average size, held in ponds and fed a high protein diet until they attained 10–20 g, and stocked in all ponds at $2/m^2$. The tilapia fingerlings were supposed to be all hormonally sex-reversed males, but previous experience had indicated that significant numbers of females or incompletely sex-reversed individuals could remain. Therefore, fingerling catfish (*Clarias gariepinus*), known to be an efficient predator on tilapia fry, were stocked at 20% of tilapia density after 10 weeks to control tilapia populations, should there be any reproduction due to

sex reversal failures. Feeding was done twice daily, by hand, and was applied to ponds

initially at 5% body weight per day and adjusted down every two weeks depending on the

weight attained in the four ponds on each farm. By using average weight attained by the four

ponds on a farm, equal quantities of feed were applied to ponds to standardize the effects of

feed on water quality. By the end of approximately 160 days, the feeding rate was 2%. All

floating feed used in the experiment was purchased from Raanan Fish Feed West Africa Ltd,

Ghana. The sinking feed was prepared as a coarse powdered mixture of groundnut husk and

rice bran (the typically used local ingredients and formulation), at the aquaculture laboratory

of Kwame Nkrumah University of Science and Technology, Ghana, and distributed to the

participating farms. The local formulation was done at one source to accurately simulate what

farmers prepare on their farms and still keep variability among farms to the minimum.

Proximate analysis performed on the two types of feed confirmed the manufacturer label of

30% crude protein content for the floating feed (exact value: 30.19%, major source of protein

was, presumably, fishmeal) and 32.81% crude protein for the sinking feed. Fish growth was

monitored every two weeks by randomly sampling 30 fish from each pond with a seine net

and measuring length and weight and returning all individuals to the pond (Figure 2.4).

Figure 2.4. (a) Monitoring fish growth by measuring length and weight of a sample every two weeks; (b) A pond that has been drained and dried, now refilling with new water. The circles in the bottom are nests of tilapia from the previous production; (c) Illustration of the ability of feed to float in water; (d) Routine pond water quality monitoring using a hand-held meter; (e) A green water pond has a high concentration of algae, measured as chlorophyll-a. Such a pond has high primary productivity, but extreme algal blooms can be detrimental to fish because of increased risk of harmful algae and critically low dissolved night-time

oxygen. Photo Credits: (a) Daniel Adjei-Boateng; (b) Emmanuel Frimpong; (c) Jacques Magnee; (d) Yaw Ansah; (e) Emmanuel Frimpong.

Ponds were monitored for a suite of water quality variables relevant for determining primary productivity and also effluent loads of nutrients, solids, and oxygen demand. Water quality monitoring began after filling each pond and ended after 160 days, deemed to be the approximate end of
the production cycle. Depending on the variable measured and availability of resources, factors that were taken into consideration were the vertical level within the pond (top, middle, and bottom), stage of production (beginning and end), subsampling to reduce variability, frequency (one-time or weekly) and the timing of measurements (e.g., mid-morning or afternoon). The two farms that were based in the university and the research station received significant additional daily water quality monitoring for a period of two to three months. It was possible to monitor these two farms extensively because they had ponds set aside for experiments with the AquaFish Innovation Laboratory and it was also the workplace of the field officers who oversaw the entire field project. Variables measured and detailed measurement protocols for water quality are summarized in Table 2.1.

Table 2.1. Water quality sampling and analysis schedule.

Variable	Stage of production	Frequency of measurements	Timing	Level in the pond	Number of subsamples	Analytical technique
Temperature	Middle	Weekly	9:00 am	Bottom/Middle/Upper	1	Hand-held meter
Dissolved oxygen	Middle	Weekly	9:00 am	Bottom/Middle/Upper	1	Hand-held meter
pH	Middle	Weekly	9:00 am	Bottom/Middle/Upper	1	Hand-held meter
Alkalinity (as HCO_3^-)	Middle	Weekly	9:00 am	Composite	1	Laboratory
Unionized Ammonia NH_3	Middle	Weekly	9:00 am	Composite	1	Laboratory
Ammonium Ion NH_4^+	Middle	Weekly	9:00 am	Composite	1	Laboratory
Nitrate NO_3^-	Middle	Weekly	9:00 am	Composite	1	Laboratory
Nitrite NO_2^-	Middle	Weekly	9:00 am	Composite	1	Laboratory
Total Kjeldal Nitrogen TKN	Middle	Weekly	9:00 am	Composite	1	Laboratory
Chlorophyll-*a*	Middle	Weekly	9:00 am	Composite	1	Laboratory
Turbidity (as Secchi disk depth)	Middle	Weekly	9:00 am	n/a	5	Field
Total Suspended Solids	Middle	Weekly	9:00 am	Composite	1	Laboratory
Total Suspended Solids	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Settleable Solids	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Orthophosphates PO_4	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Total Phosphates PO_4^{3-}	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Biochemical Oxygen Demand BOD_5	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Dissolved Inorganic Nitrogen DIN	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Dissolved Organic Nitrogen DON	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory
Total Dissolved Nitrogen TDN	Beginning/End	One time	Daylight	Bottom/Upper(surface)	1	Laboratory

Field measurements of temperature, dissolved oxygen, and pH involved the use of a Hanna HI9828 multi-parameter handheld meter. Laboratory analysis of water samples (see Table 2.1) was carried out following standard methods [37]: total nitrogen (TKN) (macro-Kjeldahl), nitrate-nitrogen (cadmium reduction), ammonia-nitrogen (salicylate), nitrite-nitrogen (diazotisation), total dissolved nitrogen (TDN), dissolved organic nitrogen (DON), dissolved inorganic nitrogen (DIN), total phosphates (PO_4^{3-}) (acid persulphate digestion method), orthophosphates (PO_4) (ascorbic acid spectrophotometric), total suspended solids (glass-fibre filtration), total settleable solids (gravimetric), 5-day biochemical oxygen demand (BOD_5) (20 °C incubation), and alkalinity (titrimetric analysis). Chlorophyll-*a* analysis followed methods described by HMSO [38]. Where applicable, formulae were used to calculate the concentration of one variable from the concentration of other variables.

Statistical Analysis
Water quality and fish growth data were analyzed using general linear models (GLM) to obtain an analysis of variance (ANOVA) table. All main effects (*i.e.*, water, feed, stage, level) were tested and estimated where applicable, in addition to testing the significance of interactions among these effects. For the water quality variables measured weekly, the variable "Day", representing the number of days since stocking, was used as a covariate. Because Secchi depth was measured at five locations in the pond (*i.e.*, subsampled or "replicated"), a nested ANOVA was performed by nesting the observations in Day. *p*-values for all estimated effects, variable and model degrees of freedom, model *R*-squared, overall mean, root mean squared error equivalent to standard deviation, and coefficient of variation was obtained for each model. Least Square Mean estimates (LSmeans) of treatment and factor effects that adjust for the effects of other factors in a model on the response variable were estimated, along with the 95% confidence intervals on estimates.

In addition to quantitative estimates, descriptive plots and correlation among variables were calculated. All general linear models and related plots were created with the SAS® statistical software version 9.3. Descriptive histograms, box and whisker plots, and correlation estimates and associated scatterplot matrices were obtained using SAS JMP® version 10 (SAS Institute Inc., Cary, North Carolina, USA).

Results and Discussion

Ponds in the study areas were small, as reflected in various morphometric data. Pond area ranged from 147 to 1066 m^2, with the average of 407 m^2 skewed toward the small end of the distribution. Ponds were mostly shallow, with average water depths ranging from 18 cm to 74 cm with a mean of

50 cm which is only half of the recommended water depth. Even the maximum depth observed in any pond did not exceed 1m, ranging from 42 cm to 98 cm with an average of 74.8 cm. The filled pond volume ranged from 51 m^3 to 353 m^3 and averaged 194 m^3 (Figure 2.5). In general, the larger ponds also tended to be deeper.

Water quality variables exhibited approximately unimodal distributions and were mostly uncorrelated or weakly correlated with each other. With the exception of the expected correlations such as PO_4 and PO_4^{3-} ($r = 0.91$), TSS and Settleable solids ($r = 0.76$), NH_3 and NH_4^+ ($r = 0.99$), NO_3^- and NO_2^- ($r = 0.96$), DO at levels in the pond ($r = 0.99$), temperature at levels in the pond ($r = 0.99$), and pH at levels in the pond ($r = 0.87$–0.98), only six pairs of variables had correlations that exceeded 0.50: These correlations included DON and TDN ($r = 0.61$), DON and DIN ($r = -0.57$), Chl-a and NO_2^- ($r = 0.59$), Chl-a and NO_3^- ($r = 0.55$), Secchi depth and TSS ($r = 0.55$), and Secchi depth and Chl-a ($r = 0.54$) (Figures 2.6 and 2.7). All water quality variables measured before and after the production cycle showed significant changes between the two stages, and every variable differed between at least two of the five farms. BOD_5, DIN, and TIN showed significant differences by water source, whereas DON

was significantly different between feed types. Settleable solids and TSS varied by the level within the pond water column. In addition to the significant main effects, there were various significant two-way and three-way interactions. Model R-squares ranged from 0.52 for settleable solids to 0.89 for DON, reflecting differences in noise associated with the different variables measured. Settleable solids had the highest coefficient of variation of that group of variables (71.6%) and DON had the lowest (23.8%) (Table 2.2). The variables PO_4, PO_4^{3-}, TSS, settleable solids, and DIN increased significantly from the beginning to the end of production, whereas BOD_5, DIN, and TDN decreased. Significantly higher BOD_5, DIN, and TDN were associated with old (reused) water compared to new water, whereas significantly higher DON was associated with sinking feed compared to floating feed. Settleable solids and TSS were higher at the bottom level of pond compared to the surface (Table 2.3).
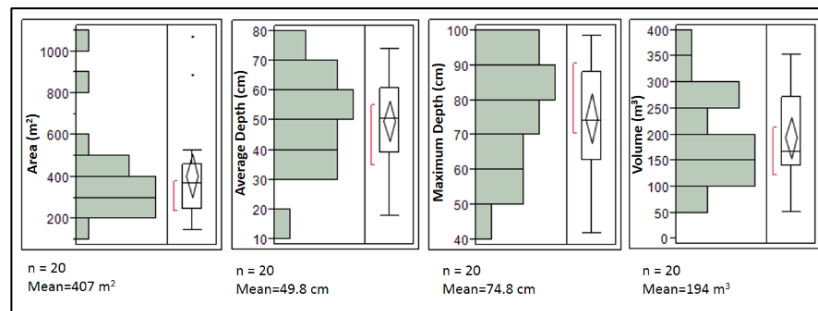
Figure 2.5. Morphometric characteristics of the 20 ponds sampled for this study.
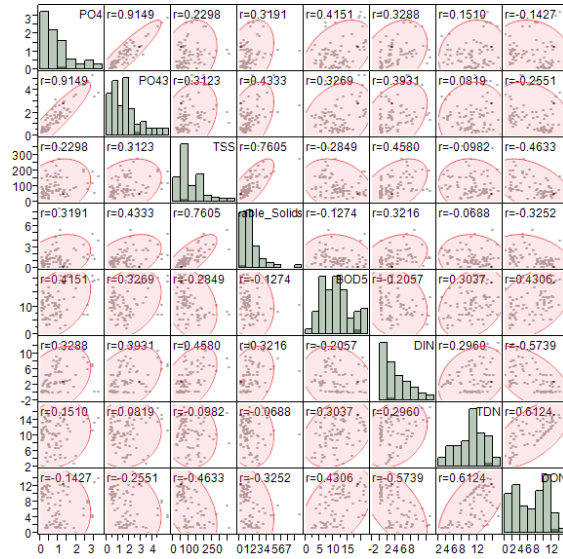
Figure 2.6. Distribution and correlation matrix of water quality variables measured at the beginning and end of the production cycle. Shaded areas are 95% confidence ellipses around the bivariate distribution
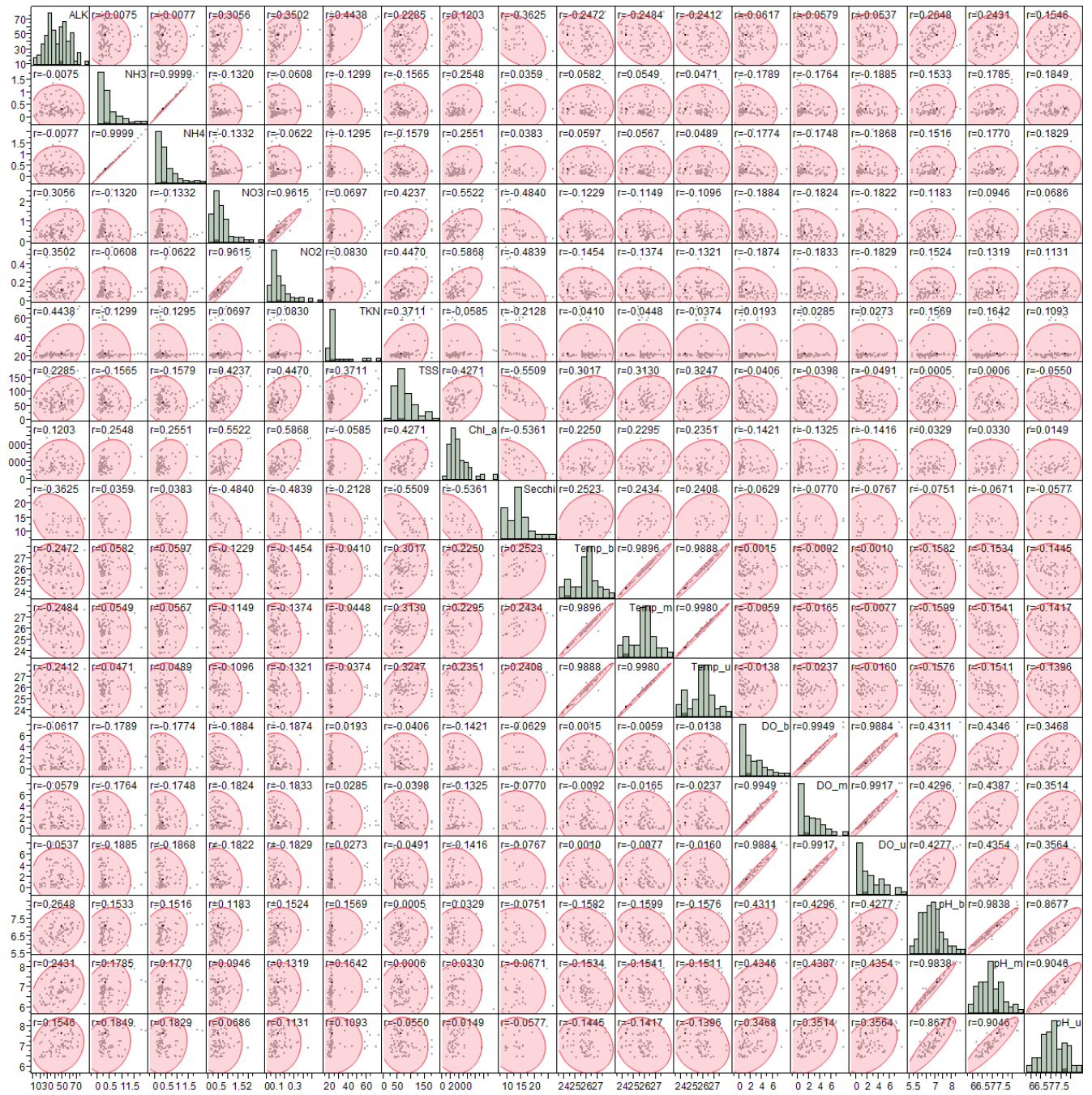
Figure 2.7. Distribution and correlation matrix of water quality variables measured weekly during the production cycle. Shaded areas are 95% confidence ellipses around the bivariate distribution.

Table 2.2. p-values, model evaluation criteria and descriptive parameters for water quality variables measured at the beginning and end of production cycle. Boldface p-values indicate significant effects at $\alpha = 0.05$.

Source\Variable	DF	PO$_4$ (mg/L)	PO$_4^{3-}$ (mg/L)	TSS (mg/L)	Settleable Solids (mL)	BOD$_5$ (mg/L)	DIN (mg/L)	DON (mg/L)	TDN (mg/L)
Farm	4	<0.0001	<0.0001	0.0202	0.0334	<0.0001	0.0074	<0.0001	<0.0001
Water	1	0.5384	0.0617	0.0793	0.2829	0.0122	0.0305	0.1256	0.0073
Feed	1	0.1596	0.1389	0.2472	0.0621	0.8690	0.6017	0.0066	0.2043
Water × Feed	1	0.2214	0.3930	0.3908	0.1519	0.6923	0.0536	0.0953	0.0101
Stage	1	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Water × Stage	1	0.6873	0.8927	0.5368	0.7602	0.2644	0.5947	0.5093	0.4008
Feed × Stage	1	0.2875	0.9717	0.1532	0.0359	0.5101	0.6417	0.3507	0.8520
Water × Feed × Stage	1	0.1356	0.5327	0.1532	0.8867	0.2644	0.0468	0.8905	0.0835
Level	1	0.6738	0.3904	0.0064	0.0112	0.5531	0.5722	0.7510	0.7850
Water × Level	1	0.9223	0.7710	0.3608	0.5420	0.5314	0.0329	0.0837	0.0056
Feed × Level	1	0.9253	0.8927	0.8491	0.3940	0.8690	0.2281	0.7697	0.2408
Water × Feed × Level	1	0.9545	0.8983	0.5397	0.8387	0.9737	0.7392	0.1055	0.2063
Stage × Level	1	0.9721	0.8240	0.4897	0.597	0.9474	0.7679	0.6492	0.6023
Water × Stage × Level	1	0.8325	0.8964	0.8694	0.8387	0.7919	0.0045	0.3470	0.0038
Feed × Stage × Level	1	0.9077	0.7422	0.6972	0.2248	0.7168	0.1703	0.5214	0.4545
Water × Feed × Stage × Level	1	0.8526	0.7873	0.2353	0.9675	0.9474	0.6998	0.7042	0.9309
Model degrees of freedom		19	19	19	19	19	19	19	19
Error degrees of freedom		60	60	60	60	60	60	60	60
Model R-Square		0.54	0.58	0.60	0.52	0.53	0.72	0.89	0.61
Mean value		0.90	1.68	105.88	1.53	11.25	3.72	6.85	10.57
Root MSE (StDev)		0.61	0.94	51.48	1.09	4.05	2.08	1.54	2.52
Coefficient of Variation (%)		67.2	55.9	48.6	71.6	36.0	56.0	22.4	23.8

Table 2.3. Least square means estimates and upper and lower 95% confidence limits for main factor effects for variables measured at the beginning and end of the production cycle. Boldface entries indicate the confidence intervals do not overlap, i.e., the confidence interval for the difference between the corresponding means is does not include 0.

	Water		Feed		Stage		Level	
	New	**Old**	**Floating**	**Sinking**	**Begin**	**End**	**Bottom**	**Surface**
PO_4 (mg/L)	0.86 (0.67, 1.05)	0.94 (0.75, 1.13)	0.81 (0.61, 1.00)	1.00 (0.81, 1.20)	0.64 (0.44, 0.83)	1.17 (0.98, 1.36)	0.93 (0.74, 1.12)	0.87 (0.68, 1.06)
PO_4^{3-} (mg/L)	1.52 (1.23, 1.82)	1.84 (1.54, 2.14)	1.48 (1.18, 1.78)	1.88 (1.58, 2.18)	1.10 (0.80, 1.40)	2.26 (1.97, 2.56)	1.77 (1.47, 2.07)	1.59 (1.29, 1.89)
TSS (mg/L)	99.15 (82.87, 115.43)	112.6 (96.32, 128.88)	95.60 (79.32, 111.88)	116.15 (99.87, 132.43)	63.20 (46.92, 79.48)	148.55 (132.27, 164.83)	122.13 (105.84, 138.41)	89.63 (73.34, 105.91)
Settleable Solids (mL)	1.30 (0.95, 1.64)	1.76 (1.41, 2.11)	1.40 (1.05, 1.74)	1.66 (1.31, 2.01)	0.82 (0.47, 1.17)	2.24 (1.89, 2.58)	1.85 (1.50, 2.19)	1.21 (0.86, 1.55)
BOD_5 (mg/L)	10.08 (8.80, 11.36)	12.42 (11.14, 13.70)	11.18 (9.89, 12.46)	11.33 (10.04, 12.61)	13.61 (12.32, 14.89)	8.90 (7.61, 10.18)	11.52 (10.24, 12.80)	10.98 (9.70, 12.26)
DIN (mg/L)	3.20 (2.54, 3.86)	4.23 (3.57, 4.89)	3.84 (3.18, 4.50)	3.60 (2.94, 4.25)	1.34 (0.68, 2.00)	6.10 (5.44, 6.76)	3.58 (2.93, 4.24)	3.85 (3.19, 4.51)
DON (mg/L)	6.58 (6.10, 7.07)	7.12 (6.63, 7.60)	6.37 (5.88, 6.85)	7.33 (6.85, 7.82)	10.47 (9.98, 10.96)	3.23 (2.74, 3.72)	6.90 (6.42, 7.39)	6.80 (6.31, 7.28)
TDN (mg/L)	9.78 (8.99, 10.58)	11.35 (10.55, 12.15)	10.21 (9.41, 11.00)	10.93 (10.13, 11.73)	11.81 (11.00, 12.60)	9.33 (8.53, 10.13)	10.49 (9.69, 11.29)	10.64 (9.85, 11.44)

Table 2.4. p-values, model evaluation criteria and descriptive parameters for water quality variables measured weekly for up to 12 weeks during the production cycle. Boldface p-values indicate significant effects at α = 0.05.

Source\Variable	DF	Dissol. Oxygen (mg/L)	Temperature (°C)	pH	Alkalinity (mg/L HCO_3^-)	NH_4^+ (mg/L)	NH_3 (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	TKN (mg/L)	TSS (mg/L)	Chl-*a* (µg/L)	Turbidity (Secchi depth, cm)
Farm	1	<0.0001	<0.0001	<0.0001	<0.0001	0.4623	0.4672	0.0256	0.0023	0.0004	0.0138	0.2548	<0.0001
Water	1	0.0062	0.1403	0.2550	0.0023	0.1438	0.1438	0.3527	0.3558	0.4899	0.9624	0.0095	<0.0001
Feed	1	<0.0001	0.0023	0.0075	0.5047	0.3479	0.3428	0.6211	0.4025	0.4493	0.9774	0.2060	0.0005
Water × Feed	1	0.0049	0.4991	0.3261	<0.0001	0.1490	0.1497	0.5784	0.2811	0.6878	0.4163	0.2917	0.0671
Level	2	0.1859	0.8652	0.0002									
Water × Level	2	0.9959	0.9969	0.9899									
Feed × Level	2	0.9546	0.9896	0.9343									
Water × Feed × Level	2	0.9953	0.9953	0.9974									
Day	1	<0.0001	<0.0001	0.0116	0.1313	0.0228	0.0239	<0.0001	<0.0001	0.0155	<0.0001	<0.0001	0.0355
Day (Replicate)	4												0.9953
Model degrees of freedom		13	13	13	5	5	5	5	5	5	5	5	9
Error degrees of freedom		250	250	250	106	105	105	106	106	106	106	74	190
Model *R*-Square		0.56	0.39	0.31	0.51	0.10	0.10	0.30	0.32	0.19	0.31	0.30	0.32
Mean value		2.15	25.85	6.91	43.44	0.42	0.40	0.58	0.13	25.21	73.31	1843.06	13.73
Root MSE (StDev)		1.35	0.82	0.49	10.33	0.39	0.37	0.38	0.08	11.13	29.99	993.72	3.34
Coefficient of Variation (%)		62.6	3.2	7.2	23.8	92.9	93.1	64.8	64.4	44.2	40.9	53.9	24.3

Table 2.5. Least square means estimates and upper and lower 95% confidence limits for main factor effects for variables measured weekly for up to 12 weeks during the production cycle. Boldface entries indicate the confidence intervals do not overlap, i.e., the confidence interval for the difference between the corresponding means is does not include 0.

	Water		Feed		Level		
	New	Old	Floating	Sinking	Bottom	Middle	Upper
Dissolved Oxygen (mg/L)	1.92 (1.69, 2.15)	2.38 (2.15, 2.61)	3.33 (3.10, 3.56)	0.97 (0.74, 1.20)	1.98 (1.70, 2.27)	2.11 (1.83, 2.40)	2.35 (2.07, 2.64)
Temp (°C)	25.93 (25.79, 26.07)	25.78 (25.64, 25.92)	26.01 (25.87, 26.15)	25.70 (25.55, 25.84)	25.88 (25.71, 26.05)	25.86 (25.69, 26.03)	25.81 (25.64, 25.99)
pH	6.87 (6.79, 6.96)	6.94 (6.86, 7.03)	6.99 (6.90, 7.07)	6.82 (6.74, 6.91)	6.78 (6.67, 6.88)	6.86 (6.76, 6.96)	7.08 (6.98, 7.18)
Alkalinity (mg/L HCO_3^-)	46.50 (43.75, 49.23)	40.39 (37.65, 43.13)	42.79 (40.05, 45.52)	44.09 (41.36, 46.83)			
NH_4^+ (mg/L)	0.37 (0.26, 0.47)	0.48 (0.37, 0.58)	0.39 (0.28, 0.49)	0.46 (0.35, 0.56)			
NH_3 (mg/L)	0.35 (0.25, 0.44)	0.45 (0.35, 0.55)	0.36 (0.26, 0.46)	0.43 (0.33, 0.53)			
NO_3^- (mg/L)	0.55 (0.45, 0.65)	0.62 (0.52, 0.72)	0.56 (0.46, 0.66)	0.60 (0.50, 0.70)			
NO_2^- (mg/L)	0.12 (0.10, 0.14)	0.14 (0.11, 0.16)	0.12 (0.10, 0.14)	0.13 (0.11, 0.16)			
TKN (mg/L)	25.94 (23.00, 28.89)	24.49 (21.54, 27.43)	24.42 (21.47, 27.37)	26.01 (23.06, 28.96)			
TSS (mg/L)	73.45 (65.50, 81.39)	73.18 (65.23, 81.12)	73.39 (65.45, 81.34)	73.23 (65.29, 81.18)			
Chl-*a* (µg/L)	1547.12 (1234.05, 1860.19)	2139.00 (1825.93, 2452.07)	1984.81 (1671.74, 2297.87)	1701.31 (1388.24, 2014.38)			
Turbidity (Secchi depth, cm)	15.15 (14.48, 15.82)	12.94 (12.27, 13.61)	13.21 (12.54, 13.88)	14.88 (14.21, 15.55)			

All water quality variables monitored weekly during the first half of production cycle, except Alkalinity, exhibited a directional change (*i.e.*, significant effect of Day). Significant farm-to-farm variation was also observed, except for Chlorophyll-*a* (Chl-*a*) and NH_3/NH_4^+. Dissolved oxygen (DO), alkalinity, Chl-*a*, and turbidity differed significantly by water source, whereas feed type affected DO, temperature, pH, and turbidity. Thus, DO and turbidity were the only variables significantly affected by both water source and feed type. Dissolved oxygen, turbidity, and alkalinity also showed interaction effects of water and feed, with the effect on turbidity being only marginal (*p* = 0671) (Table 2.4). Also, only pH differed significantly by water level. Model R-squares were much lower for variables measured weekly, ranging from 0.10 for NH_3 and NH_4^+ to 0.56 for DO. Temperature (3.2%) and pH (7.2%) had the lowest coefficients of variation, reflecting minimal change over time and across ponds on the same farm, whereas NH_3 and NH_4^+ had the highest (93%) (Table 2.4). Dissolved oxygen was higher in ponds with reused water and floating feed than in ponds with new water and sinking feed (Table 2.5). Temperature was slightly but significantly higher in treatments with floating feed compared to sinking feed. Although overall average pH (6.90; Table 2.4) and average pond surface pH (7.08; Table 2.3) were close to neutral, there was a significant trend toward increased acidity from the surface to the bottom of the pond. The pH also differed by feed type, with ponds with sinking feed being more acidic (Table 2.5). Alkalinity and Secchi depth (a proxy for water clarity and inverse of turbidity) were higher and Chl-*a* was lower in ponds with new water compared to reused water. Secchi depth was higher for ponds with sinking feed than floating feed.

The GLM for fish growth indicated significant differences in growth between at least two treatments. There was a significant difference in growth between the two feed types (*p* = 0.0005; $F_{1,12}$ = 22.03). Neither the water source effect (*p* = 0.7145; $F_{1,12}$ = 0.14) nor water x feed interaction (*p* = 0.7501; $F_{1,12}$ = 0.11) was significant. The highest average growth of 300

g in 160 days was observed in the new water-floating feed treatment (Figure 2.8). Least square means estimate of growth associated with the four factor levels are floating feed (279.5 g), sinking feed (164.0 g), new water (226.4 g), and old water (217.2 g) with a common standard error of 26.3 g. The FCR averaged 2.13 in the ponds fed floating feed and 5.36 in the ponds fed sinking feed (Figure 2.8).

Aquaculture is the fastest growing sector of food production globally, and this trend is also occurring in Africa, leading to an increased expectation to use better environmental practices. In this study, experiments were designed to evaluate the effect of two BMPs on pond water, effluent quality, and tilapia growth rates. Most chemical constituents of the water had increased concentration from the beginning to the end of production, conforming to the generally known pattern that the inputs to ponds in the form of fertilizer and feed produces a surplus of nutrients. Surprisingly, biochemical oxygen demand and dissolved organic nitrogen decreased from the beginning to the end of production.

Since DON and BOD_5 were positively correlated ($r = 0.43$), and were the two independent variables that decreased from the beginning to the end of the production cycle, it is conceivable that the source of water (mostly streams) used to fill ponds were enriched with organic material, making the pond a net user of nutrients and organic material from the water source. High nitrogen levels in the ponds in Ghana was also observed in TKN, which includes organically bound nitrogen. TKN levels averaged 25.2 mg/L, more than 2.5 times the level typically observed in intensive aquaculture ponds [39].

Also, although DIN (consisting of NO_3^--N, NO_2^--N, and NH_3/NH_4^+-N) was higher at the end of the production cycle (Table 2.3), the initial value of 1.34 mg/L was quite high. Thus, not only organic but also inorganic nitrogen was high in the water source. Previous studies using the Hilsenhoff Biotic Index in Ghana [28] had concluded that aquaculture effluent-receiving

streams, which are also the water source for ponds downstream, were being enriched with organic materials, possibly from non-point agricultural sources and animal feeding operations. A concurrent analysis with chemical measurements detected similarities in nutrient concentrations between ponds and streams downstream of ponds, although BOD_5 was significantly lower in streams [32].
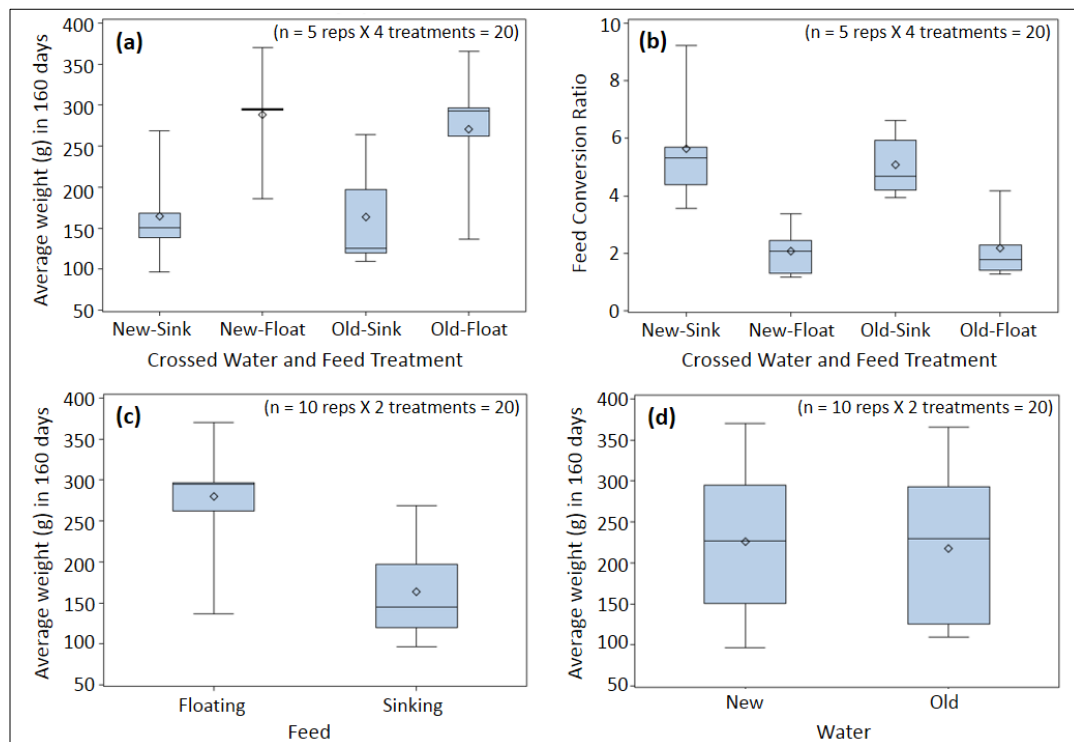
Figure 2.8. Comparison of growth and Feed Conversion Ratio (FCR) of tilapia *Oreochromis niloticus* among four treatments (a) the crossed water source x feed type combination (b) FCRs for the four treatments (c) Floating and Sinking Feed averaged over water source (d) Contrasting New and Reused Water averaged over feed type.

The excess nitrogen in the water source, with the additional fertilization and feeding, could explain the extremely high levels of Chlorophyll-*a* observed in the study ponds which averaged about four times the levels typically observed in intensive aquaculture ponds ([39], Table 2.6). This is more remarkable considering that pond aquaculture production systems in sub-Saharan Africa are generally classified as low-intensity to semi-intensive due to low stocking densities and feeding levels. Even at its lowest levels before reaching the full

plankton bloom, Chlorophyll-*a* exceeded 1000 µg/L in most ponds (Figure 2.9). With the high levels of nitrogen recorded in ponds, ammonia toxicity could be expected. Contrary to expectation, total ammonia nitrogen in the ponds in Ghana averaged at the low end of the semi-intensive range (Table 2.6). Although the sampling was not designed specifically to detect episodic high levels of ammonia, the results suggest that ammonia toxicity was not a major problem in the ponds studied.

Table 2.6. Comparison of Ghana Nile tilapia *Oreochromis niloticus* pond water and potential effluent quality with values from other studies and reviews pond of aquaculture effluents.

Variable	Typical Pond Effluent [a]			Baitfish Pond Effluent, AR, USA [b]	Channel Catfish Pond Effluent, AL, USA [c]	Ghana Overall Average	Pond Surface Average for End of Production in Current Study			
	Low Intensity	Semi-intensive	Intensive				Old Water	New Water	Floating feed	Sinking feed
NH_3 & NH_4^+-N (mg/L)	0.1–0.5	0.5–2.0	2.0–5.0	-	1.13	0.82	-	-	-	-
NO_3-N (mg/L)	0.01–0.1	0.1–0.2	0.2–0.3	-	0.69	0.58	-	-	-	-
TKN (mg/L)	0.5–2.0	2.0–4.0	4.0–10.0	-	4.42	25.21	-	-	-	-
Total P (PO_4^{3-}) (mg/L)	0.05–0.1	0.1–0.3	0.3–0.7	0.50	0.25	1.68	2.36	1.94	2.01	2.29
Chl-*a* (μ/L)	10–50	50–150	150–500	-	-	1843.1	-	-	-	-
BOD_5 (mg/L)	2.0–5.0	5.0–20.0	20.0–40.0	9.0	9.43	11.25	10.11	7.08	8.91	8.28
TSS (mg/L)	-	-	-	36.0	69.4	105.9	140.0	116.6	118.8	137.8
Settleable Solids (ml/L)	0.0–0.05	0.05–0.1	0.1–0.5	-	0.08	1.09	2.09	1.61	1.73	1.97

[a] [39]; [b] [13], Numbers are average of samples from 10 ponds during draining of the first 10% of pond volume; [c] [10], Numbers are the recalculated averages of reported surface average values ($n = 8$) for 25 ponds observed four seasons per year for two years.
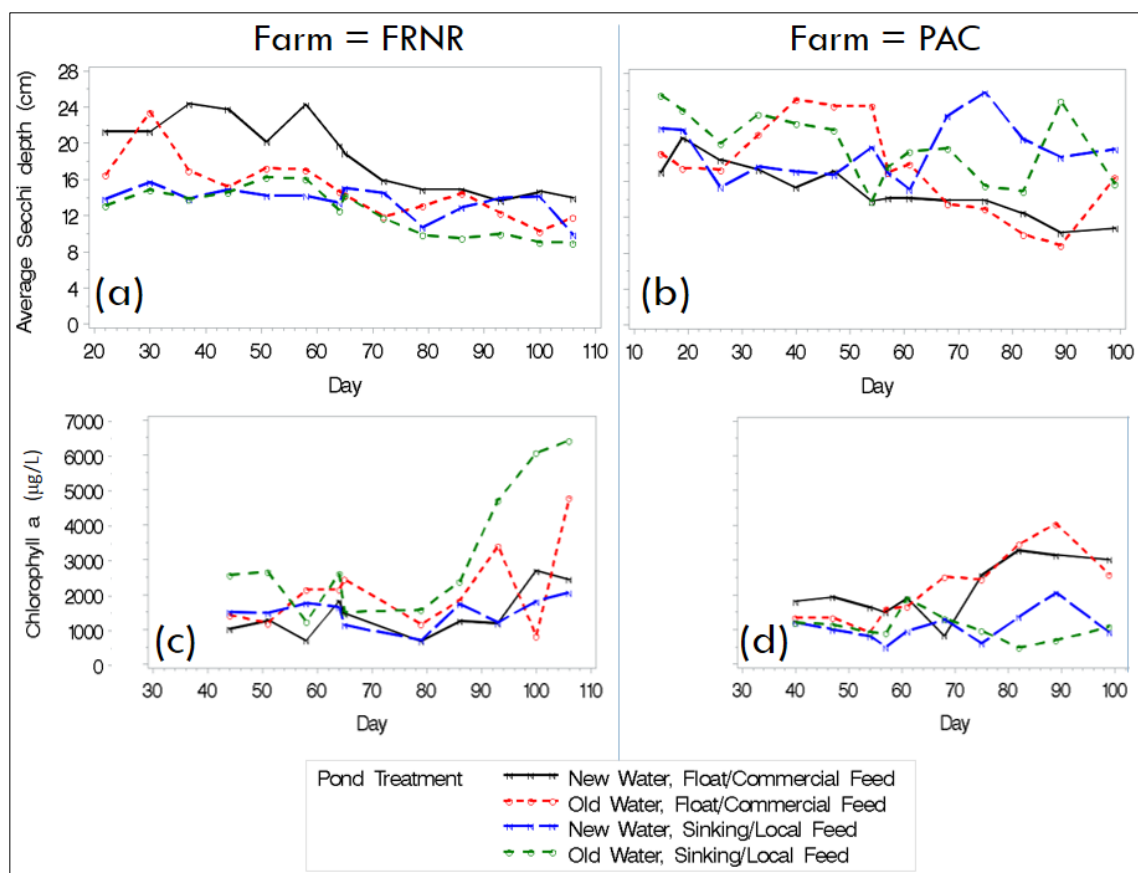
Figure 2.9. Fluctuation in pond water quality superimposed on a trend of increasing Chlorophyll-a and decreasing water transparency during the first part of the production cycle. (a) Secchi depth on FRNR farm; each line represents one pond; (b) Secchi depth on PAC farm; (c) Chlorophyll-a on FRNR farm; (d) Chlorophyll-a on PAC farm.

It is instructive to compare water quality variables at the end of production with the typical effluents observed in aquaculture ponds (Table 2.6). Values from surface of the pond in the current study are used in Table 2.6 for two reasons. Firstly, surface water tends to be of better quality than the bottom (Table 2.3) and there are BMP prescriptions for improving bottom water before discharging into receiving waters. A specific recommendation made for managing channel catfish (*Ictalurus punctatus*) pond effluents that might apply to annually drained tilapia ponds is to drain pond from the surface and hold the last 10%–20% of the pond water for two to

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three days after harvesting to reduce the discharge of solids, nutrients, and organic matter [40].

Secondly, the typical effluent values reported for comparison in Table 6 [10,13,39] are also from

surface measurements, making the comparison more appropriate. Although there are a limited

number of variables for comparison from Table 2.6, a clear pattern begins to emerge: three of the

four variables measured at the end of production (Total-P, TSS, and Settleable solids) exceeded

the range of typical values by wide margins of two to five times the high values for intensive

systems [39]. Only BOD_5 was within range but for semi-intensive, not low-intensity systems. In

addition, these values were uniformly high and not significantly different between the treatments

of this study, except BOD_5 which was significantly higher in reused water than in other

treatments. This observation suggests that in terms of environmental benefits, both of the feed

types at the current stocking, feeding, and fertilization levels resulted in high loads of nutrients

and solids compared to effluents from aquaculture ponds of similar levels of management

intensity. A significant component of biochemical oxygen demand in ponds is due to respiration

by live plankton [12]. Thus, given the higher level of plankton activity in ponds with reused

water (Figure 2.9) a higher BOD_5 would be expected.

The water reuse BMP has the potential to significantly reduce the number of times a pond is

drained, although every pond will eventually be drained fully or partially after several production

cycles, for example, for pond maintenance. Even if a pond is used for only two production cycles

before draining, effluent output is effectively reduced by 50%, and the increased hydrologic

retention time increases the pond's natural waste processing efficiency as well [40]. Although the

ponds in the study area were small, the cumulative impact of many small ponds draining after

every production cycle with high concentrations of nutrients, solids, and organic materials can be

large [35]. This is like the root of many environmental problems, where independent actors make

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a multitude of defuse and seemingly insignificant decisions across the landscape, which aggregate into a major public natural resource conservation problem [41]. Conversely, in the case of tilapia farming with water reuse, it seems that a significant amount of nutrients can be retained on a farm and recycled through multiple production cycles to result in a large cumulative positive effect in the form of better environmental performance, agronomic efficiency, and increased private farm profit. The results of this experiment showed that although there are slight positive effects of new water on fish growth, water source did not significantly affect the growth of Nile tilapia. Additional analysis of results from this experiment indicates that efficiency of conversion of feed to fish biomass was atypically low across treatments, and twice as inefficient in the ponds fed sinking feed, suggesting that feed may have been wasted and not efficiently utilized. Since nutrient levels and indicators of primary productivity were extremely high, it is arguable that feeding rates could have been reduced without affecting growth rates, and the benefits of using reused water over new water would have been more apparent if supplementary feed and nutrients were limiting. This apparently excessive input of the rather expensive feed and fertilization has undesirable effect on farm profit. It is also worth noting that DO levels in ponds with reused water were higher than ponds with new water. However, the DO measurements were taken mid-morning and not indicative of early morning DO which, in the absence of aeration, tends to be lower for ponds with higher plankton productivity because the oxygen consumption load of plankton during night time can be extremely high.

Compared to water source, feed type had a large effect on growth of tilapia, with the floating feed treatment resulting in higher growth rates. Although the two feed types had similar levels of the crude protein content, an economic analysis of the experimental results is needed to shed

more light on whether the current cost of the floating feeds can be sustained by the amount of

additional growth observed over the sinking feeds. The protein source of the two feed types

(vegetable versus fishmeal) may not offer a sufficient explanation for the observed differences in

growth. Significant water quality differences were observed between feed types for variables

measured during the production cycle (Table 2.5). Dissolved oxygen was more than 3.5 times

higher in the floating feed ponds, temperature was a fraction of a degree higher in floating-feed

ponds, and floating-feed ponds were almost perfectly neutral compared to a relatively acidic

condition for the sinking feed ponds. The average DO of 0.97 mg/L in sinking-feed ponds is

stressful even for the hardiest of non-air-breathing fishes. Apart from the physiological stress of

low DO that can directly inhibit growth, fish also feed less under low DO conditions because of

decreased appetite. Clearly, a high amount of feed remained at the pond bottom of the sinking-

feed ponds throughout the production cycle, increasing suspended and settleable solids,

decomposition and oxygen consumption. Surprisingly, pond surface BOD_5 at the end of

production was not different between ponds with floating or sinking feeds, supporting the

inference that the biochemical oxygen demand in the surface effluent consisted mostly of oxygen

for plankton respiration rather than decomposition of organic material. The pond temperature

difference between the two feed types is most perplexing. Since the floating-feed ponds

maintained higher Chlorophyll-*a* levels and therefore would be less transparent, it is possible that

the floating feed ponds absorbed more heat, leading to a small but consistent difference in

temperature between neighboring ponds. Within the range of temperatures observed in this study

warmer ponds favored faster growth of tilapia, however small the difference.

An important observation of this study is the pervasive effect of farm or site on the observed

water quality levels in the general linear models. This result emphasizes the importance of the

climatic and edaphic context in understanding the effect of management practices on water quality. Statistically, without controlling for the effect of farm, many significant differences in treatment effects may not have been detected because of large variability introduced by farm as a factor contributing variance. For practical management purposes, these farm-to-farm variations suggest that natural background variations in water quality exist among farms, even in small geographic areas, and these will lead to differences in productivity of ponds even under the same management regimen. It also raises the possibility that even under controlled experimental conditions, small systematic differences in management practices between farms may lead to different outcomes of applications of BMPs.

Conclusions

This study describes the effect of water source and feed type on pond water, effluent quality, and growth of Nile tilapia in earthen ponds in Ghana. The ponds in the experiment were found to maintain an extremely high phytoplankton standing crop, reflecting high primary productivity, and fueled by high levels of nitrogen and phosphorus in ponds. Source streams for filling ponds appear to be enriched with organic material, contributing to high levels of dissolved organic nitrogen and biochemical oxygen demand at the beginning of the production cycle rather than at the end. Source water could be treated before use to reduce enrichment before use. Total phosphorus, total suspended solids, and settleable solids in ponds exceeded the range expected for intensive aquaculture ponds, even though these production systems would be classified as low-intensity or semi-intensive, based on stocking densities. Nutrient addition to ponds through fertilizer and feed may have been excessive and savings may have been realized by reducing both fertilizing and feeding rates, with emphasis on reducing feeding rates because it is the major driver of the total variable cost of production. Reused water had higher biochemical oxygen demand and higher Chlorophyll-*a* compared to new water, but also had higher dissolved oxygen.

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There was no statistical difference between tilapia growth in reused water and new water. Tilapia fed floating feed had significantly higher growth compared to those fed sinking feed, which may be explained by the sources of crude protein content of the feed types in addition to sinking feed being associated with extremely low dissolved oxygen, slightly lower temperature, and pH in the acidic range. Water reuse appears to be a viable BMP to achieve a more sustainable intensification of pond aquaculture in sub-Saharan Africa, but the viability of nutrient management through feed as a BMP in pond-based tilapia farming will depend heavily on the economic profitability of floating feed use, which we encourage in subsequent studies.

Acknowledgments

Conflicts of Interest

The authors have no conflict of interest.

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Chapter 3: Using Model-Based Inference to Select a Predictive Growth Curve for Farmed Tilapia

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Abstract

Aquaculture presents a unique challenge to the modeling of fish growth, because the main objective is to accelerate fish growth for profit. Growth pattern in captive and well-fed conditions will diverge from that found in wild fish. For a fish-farming enterprise, over-estimating growth will lead to expectations for revenue and profit that will not be realized. Underestimating growth will lead to planning for later harvest than optimal and unnecessary additional cost of feeding. We evaluated the performance of four candidate models – Gompertz, logistic, quadratic, and von Bertalanffy – in predicting the growth of Nile tilapia *Oreochromis niloticus*. Each model was fitted to 20 weight-at-age datasets collected from five demonstration farms in Ghana over a five-month period. We used the small sample-adjusted Akaike Information Criterion (AICc) and model weights to assess model fit. We also assessed predictive performance by comparing predicted to actual growth observed over the last month of the experiment. The logistic growth model performed best for both model fitting and prediction. For a one-month period approximately between day-121 and day-152, all but the Logistic model over-predicted growth, with corresponding standard errors as follows: Gompertz (14.9 ± 3.8g), von Bertalanffy (21.0 ± 3.9g), and quadratic (34.0 ± 3.6g). The logistic model is recommended

for predicting future growth of tilapia under pond culture conditions in applications such as the construction of enterprise budgets to assess profitability of tilapia farms. The default fitting of von Bertalanffy growth model to farmed tilapia data is not supported by this study.

Introduction

The von Bertalanffy growth model is usually the default choice for modeling fish size-at-age data (e.g. De Graaf and Prein 2005), even though a number of alternate models exist for describing the somatic growth of animals (e.g. Chen et al. 1992; Rosa et al. 1997; Gamito 1998; Katsanevakis 2006). The model has been found useful over the years, and it has been shown to closely follow the growth of most fish species in different environments. Until recently, the model has not been widely tested to establish whether it is the best fit for all size-at-age datasets (Roff 1980; Katsanevakis 2006; Rabaoui et al. 2007).

There is a growing number of studies that have compared the performance of other models to that of the von Bertalanffy growth model in predicting fish size with age, in attempts to select the best model for particular growth scenarios (e.g. Chen et al. 1992; Katsanevakis 2006; Katsanevakis and Maravelias 2008). However, the number of studies on this topic is skewed toward modelling the growth of fish species in natural (wild) environments.

A few studies also have applied model selection methods to determine the most appropriate model for a given fish growth dataset (e.g. Chen et al. 1992; Rosa et al. 1997; Gamito 1998; Katsanevakis 2006). The situation is different for fish under aquaculture conditions. In fact, it is still common for aquaculture studies to depict growth over time without fitting a model to growth data at all, but instead with average size-at-age joined. We are aware, at this time, of two peer-reviewed studies (Rosa et al. 1997; Gamito 1998) on the selection of a growth model for predicting the size-at-age of a fish species under aquaculture conditions. Both studies pre-date

the era during which information theoretic statistics has revolutionized how we compare and select growth models.

Aquaculture presents a unique challenge in the modeling of fish growth (Prein et al. 1993). The primary objective of farming fish is to achieve the largest practical size in as short a time as possible, ultimately to maximize profit. This objective is achieved through: 1) selecting faster-growing strains 2) providing supplementary or complete feed to meet at least minimum daily nutrient and energy requirements, and 3) making improvements to the environment of cultured fish, such as disinfecting and managing water quality in various ways. The accelerated growth of cultured fish is expected to result in a temporal pattern divergent from the usual growth for the same species in the wild (Pauly et al. 1988), but growth still must be predicted accurately in order to assess business viability, project profit for current crop before harvest, and plan for timing of harvest. Over-estimating fish growth has the potential to result in unexpected losses of business revenue, whereas under-estimating growth, while conservative with respect to projected profits, could result in poor business planning regarding allocation of labor, optimal feeding, and timing of harvest.

Multi-model inference (Burnham and Anderson 2002; Anderson 2008) is an improved statistical technique for comparing and selecting models. The application of multi-model inference to select a model for a specific dataset reduces model selection uncertainty. This uncertainty could result in significant over-estimation of precision and under-estimation of confidence intervals of parameters (Burnham and Anderson 2002; Katsanevakis 2006). Model selection using the information-theoretic approach (Akaike 1973) is relatively new to the biological sciences.

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This approach is considered superior to traditional null hypothesis significance testing when alternate models are being considered (Burnham and Anderson 2002; Anderson 2008; Katsanevakis and Maravelias 2008). The information-theoretic approach involves the selection of the best candidate model on the basis of parsimony as measured by the Akaike information criterion (AIC) (Akaike 1973; Anderson 2008). This approach recognizes that model parameters must be estimated from data, instead of the traditional approach where these parameters are assumed to be known (Anderson 2008).

Plant and animal growth in controlled laboratory conditions (such as pond or cage aquaculture), where the environment and supply of nutrients can be maintained, approximates sigmoidal growth (Gamito 1998). Numerous growth models have been applied in the study of fish size-at-age data, each model with some desirable qualities. These models include: Brody, Chapman-Richards, Gompertz, exponential, Johnson, logistic, monomolecular, parabolic, Putter, restricted, and the von Bertalanffy growth models. Some of these models, though named differently, are just re-parameterization of other models or special cases of a common general form (e.g. Pienaar and Turnbull 1973). In this study we compared the performance of four growth models – Gompertz, logistic, quadratic, and von Bertalanffy – in the prediction of the growth of farmed Nile tilapia *Oreochromis niloticus*. The choice of these four candidate models is based mainly on the fact that they can all approximate sigmoid forms, growth rate increases and then decreases with size within the data range, and they share the feature of a relatively steep approach to the mature stage (i.e., the asymptotic size is achieved at a relatively early age), which is the expected growth pattern in most farmed fishes. The model choices also follow the recommendation of Katsanevakis and Maravelias (2008) that fish growth model comparisons include von

Bertalanffy, Logistic or Gompertz, and a 'non-asymptotic' model such as the quadratic ('power'

sensu Katsanevakis and Maravelias (2008)).

The Gompertz growth model (Gompertz 1825) is a sigmoidal growth curve that derives from

models of self-limited growth where rate of growth decreases exponentially with size (Karkach

2006). It has been applied successfully to wild, juvenile fishes (Andrade 1992; Gamito 1997). At

the early stage of the life cycle, fish growth is very fast compared to later stages. The objective of

farming a fish species is to achieve the asymptote in as short a time as possible, making the

Gompertz model a promising candidate. The form of the model we used in this study is

according to Jørgensen (1994):

$$W_t = W_0 e^{m_0(1 - e^{-kt})} \tag{1}$$

where W_t is the weight at time t, W_o is the theoretical weight that corresponds to age zero, m_0 is

the initial instantaneous growth rate, and k is the rate of decrease of m_o.

In the logistic model, growth is limited or regulated by the maximum weight. It is sigmoid with a

lower limit at 0 and an upper limit at the maximum (or asymptotic) weight. This model is

considered to be an apt description of the growth of organisms with a simple life cycle in the

laboratory (Krebs and Krebs 1994). As argued above, aquaculture basically involves the

maintenance of a constant environment conducive for accelerated fish growth. Hence, a simple

life cycle that is 'rushed' to completion in a controlled environment is the end result. The form of

the logistic curve we used is according to Sit and Poulin-Costell (1994):

$$W_t = \frac{W_{max}}{1 + e^{(a - kt)}} \tag{2}$$

where W_t is weight at time t, W_{max} is the maximum weight, a is the initial rate of growth, and k is the rate of decrease of growth with time.

The quadratic (parabolic) growth model, along with its cubic form, has been advocated for by a number of studies in fisheries (e.g., Rafail 1972; Roff 1980; Chen et al. 1992). It is characterized by decreasing growth with time due to decrease in the metabolic rate, even though weight continues to increase without limit (Gamito 1998). This model choice could be a good fit in some situations because it is flexible in shape, it can reduce to a linear function, and can be fitted fairly easily to data, using standard techniques (Roff 1980). The quadratic growth is specified as:

$$W_t = a + bt + ct^2 \tag{3}$$

where W_t is weight at time t, and a, b, and c are latent variables representing intercept, linear slope, and quadratic slope, respectively.

The von Bertalanffy (1938) growth model is a sigmoid curve that is ubiquitous in the fisheries literature. We specified the von Bertalanffy growth model as:

$$W_t = W_{inf}(1 - e^{-k(t-t_0)^3}) \tag{4}$$

where W_t is weight at time t, W_{inf} is the asymptotic weight, and t_0 the theoretical age-at-zero weight. Because model complexity is explicitly penalized by the Akaike Information Criterion, we sought to fit all models with the minimum number of parameters needed to specify the model type. It was a welcome coincidence that all the models compared involved three parameters.

Methods

Data

We recorded weight-at-age data of all-male *Oreochromis niloticus* individuals cultured in earthen ponds every two weeks for 156 days (approximately 5 months). The ponds were part of a demonstration study in which fish growth was compared under two water-quality conditions (fresh water and reused [green] water) and two feed types (commercial, floating feed and sinking feed prepared locally from domestic and industrial food wastes). Five farms in Central Ghana were included in the study, each with four ponds. On each farm, the treatments were assigned randomly to four ponds in a crossed, two-factor factorial design, i.e.: floating feed + fresh water, floating feed + reused water, sinking feed + fresh water, and sinking feed + reused water (Frimpong et al. 2014). Each of these 20 ponds were stocked with male Nile tilapia fingerlings of the Akosombo strain with an average initial weight of 20g at the start of the experiment, and at a stocking density of 2 m^{-2}. Feeding was standardized across all treatments at an average of 2.8% of body weight per day (reduced from 5% to 1% from beginning to end of study). In the seventh week after stocking tilapia fingerlings, juvenile catfish *Clarias gariepinus* of 5g mean weight also were stocked in all ponds at 0.4 m^{-2} as a predator to check overcrowding from potential reproduction. At two-week intervals from June to November, 2012, a random sample of 30 tilapia individuals was seined from each pond, their weights were measured, and all individuals returned to the pond. This resulted in 20 weight-at-age datasets, one for each pond.

Model selection procedure

The best model was determined for each dataset using the model weights calculated from the Akaike Information Criterion (AIC) (Anderson 2008). The four candidate models were fitted to the weight-at-age data separately for each of the study ponds using the non-linear (NLIN)

procedure with the Gauss-Newton optimization method (which had the highest convergence rate) in SAS® version 9.3 (SAS Institute Inc., Cary, North Carolina, USA). We obtained the residual sum-of-squares (SSE) for each model and calculated the small sample-corrected AIC (AICc) and model weight (w_i). For each of the 20 models, we calculated the AICc as:

$$AIC = nLOG\left(\frac{SSE}{n}\right) + 2K + \left(\frac{2K(K+1)}{n-K-1}\right) \tag{5}$$

where n is the number of observations in a dataset, and K the number of estimated parameters in the model. For each dataset, the best model was determined as the one with the smallest AICc value (AICc$_{min}$). The differences in model AICc values were calculated among the four candidate models for each pond dataset as: Δ_i = AICc$_i$ - AICc$_{min}$, where i = 1,2,3,4. The relative plausibility of each of the four models, given a dataset and given the set of candidate models, then was computed for all 20 datasets as the model weight, w_i. The model weight is considered the weight of evidence in favor of model i as being the best among the set of candidate models (Akaike 1983, Anderson 2008). Model weights were calculated as:

$$w_i = \frac{\exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{r=1}^{4} exp\left(-\frac{1}{2}\Delta_r\right)} \tag{6}$$

Growth prediction and model validation

To obtain the data actually used to compare with model predictions, we truncated our recorded growth data for all 20 ponds at 120 days, and used those data to fit new models and predict the average weight for the last observation (day 152). We performed statistical comparison of model predictive performance with an analysis of variance (ANOVA). The ANOVA was conducted with the difference between the weight predicted by each growth model and observed fish weight (i.e., predicted minus observed) as the response, and growth model as the explanatory factor with

four levels (von Bertalanffy, Gompertz, Logistic, and Quadratic). By subtracting observed

weight from predicted weight, we interpreted positive values of the response variable as over-

prediction or positive bias and the negative values as under-prediction or negative bias. Because

the observed and predicted final weight varied among ponds and incorporates pond-specific

observational error that introduces significant between-pond variation, we included 'pond' as a

blocking factor. Ponds could serve conveniently as a blocking factor because for a given pond,

all models are subject to the same observational error and the degree of over- or under-prediction

by different models can therefore be accurately estimated after accounting for the pond effect.

The Tukey multiple comparison test was used for post-hoc analysis of which factor levels (i.e.,

growth models) differed in their prediction of growth.

Results

We tested the fit of four commonly-used growth models to data on growth of all-male tilapia in

four farms in Ghana, subjected to two feeding and two water quality treatments.

Model selection

The logistic growth model was selected the most times (45%) as the best model for tilapia

growth in earthen ponds in Ghana, according to the Akaike model weights (Fig. 3.1). The

Gompertz model was selected the most times (60%) as the second-best model. This was

followed by the von Bertalanffy growth model (55%) and quadratic (60%) as the third- and

fourth-best models, respectively.
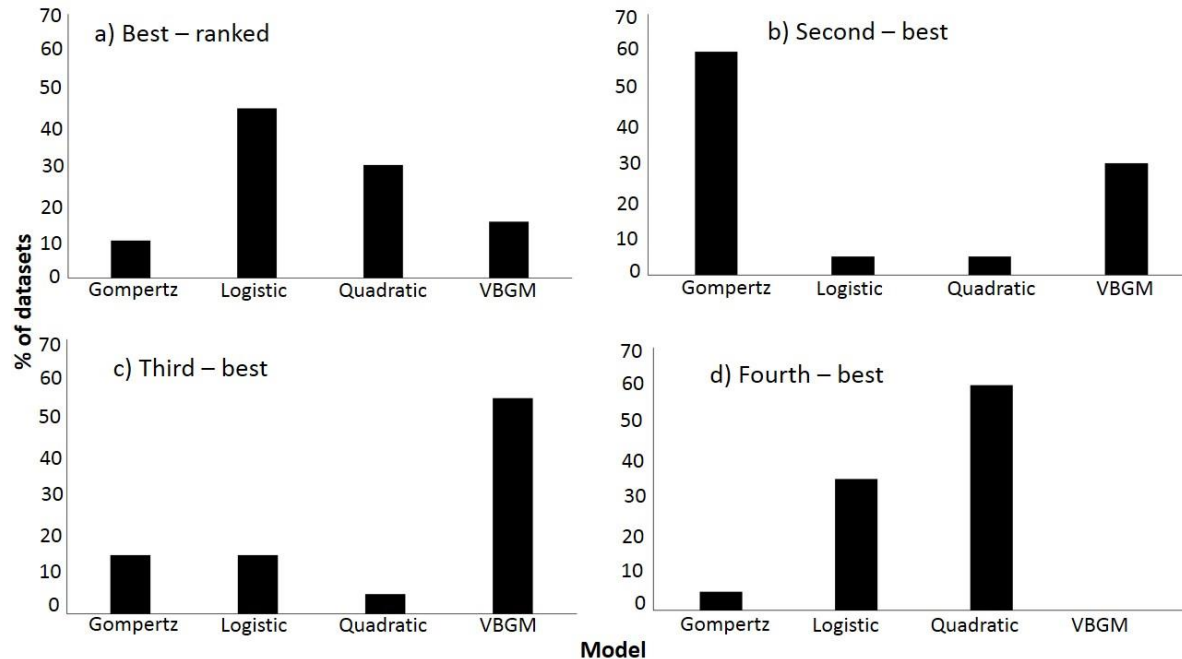
Figure 3.1. Rankings of the performance of candidate models by percentage of the number of datasets in which each model ranked highest, second-, third-, and fourth, according to Akaike model weights.

The distribution of model weights was asymmetrical with the highest frequencies generally found in the lower values of model weights (Fig. 3.2). The logistic growth model had the highest frequency of weights above 0.50 and the highest average weight ($\pm$SE) of 0.401 ($\pm$0.403) on a scale of 0 - 1 (Fig. 3.2).

Prediction and validation
The logistic model was identified as the best model for prediction of growth of tilapia in earthen ponds in Ghana (Table 3.1). The logistic model predicted the observed final weight at Day 152 with nearly a zero mean bias (-0.5 $\pm$ 3.8g), unlike the other candidate models, which all over-predicted the final weight by 14.9 to 34.0g, significantly according to the Tukey post-hoc test (Table 3.1). On average, the models ranked in the order of over-prediction as follows: quadratic > von Bertalanffy > Gompertz (Fig 3.4).

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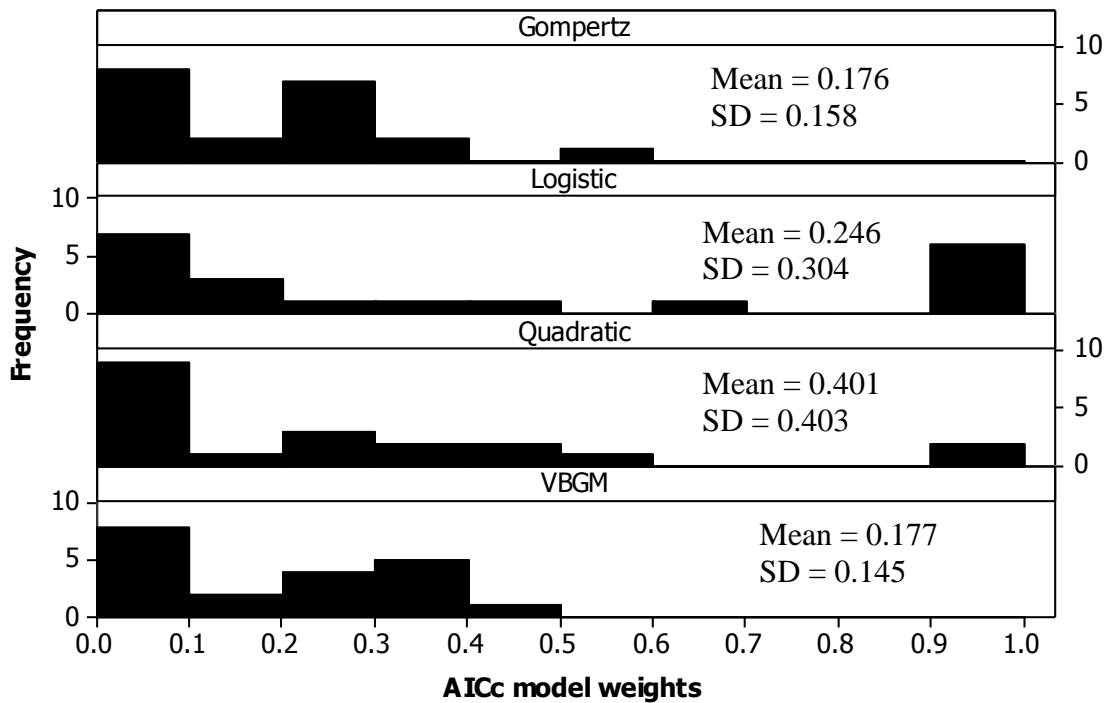
Figure 3.2. Distribution of AICc model weights for Gompertz, Logistic, Quadratic and von Bertalanffy growth models using growth data from *O. niloticus* grown in earthen ponds.

Table 3.1. Results of Tukey's Multiple Comparison Test, showing the mean difference (standard errors in parentheses) between observed and predicted weights, and the grouping of similar candidate models.

Growth Model	Observations[a]	Mean Predicted minus Observed (g)	Grouping[b]
Quadratic	20	34.0 (3.6)	A
von Bertalanffy	18	21.1 (3.9)	A B
Gompertz	19	15.0 (3.8)	B
Logistic	19	-0.50 (3.8)	C

[a]Four data points where some models did not converge were excluded from analysis.

[b]Means that do not share a letter are significantly different.

Discussion

Average growth curve vs fitted growth curve

Although it is convenient to show fish growth by joining average size over time (e.g., Ofori et al. 2010; Fig. 3.3B), there are other, more informative ways to analyze and present fish growth pattern (Fig. 3.3C and D). As seen in Fig. 3.1B on day-150, it not unusual to observe a lower average fish weight from a pond at a later time-step, due to random sampling or observational error, although a fitted growth curve, regardless of model choice, is a monotonically increasing function (Fig. 3.1C). A fitted model allows for statistically defensible interpolation of weight-at-age for any time in the observation range and not only the times when fish are observed. Moreover, extrapolation beyond the last observation (Fig. 3.3D) is often desired, for reasons previously stated. Interpolations and extrapolations are not possible without fitting a model and, when interpolations and extrapolations are done anyway, error is likely high and proper standard error or confidence intervals cannot be estimated to characterize such error. However, as can be seen in Fig. 3.3C and Fig. 3.3D each candidate model fits differently to the same data, which has implications for the predicted final weight, especially beyond the data range. The model selection and comparison of predicted growth to actual observed growth enabled us to not only fit a model to the data but also determine the best model to use.

Model selection and validation

Based on the fit to the data alone (Katsanevakis and Maravelias, 2008), we could conclude that the logistic growth model is the best for modeling the growth of *O. niloticus* under aquaculture conditions, followed by the Gompertz, and then the von Bertalanffy models. Also, Katsanevakis and Maravelias (2008) interpreted the mean Akaike weight for each candidate model calculated over all datasets as the expected weight of evidence in favor of that candidate model being the
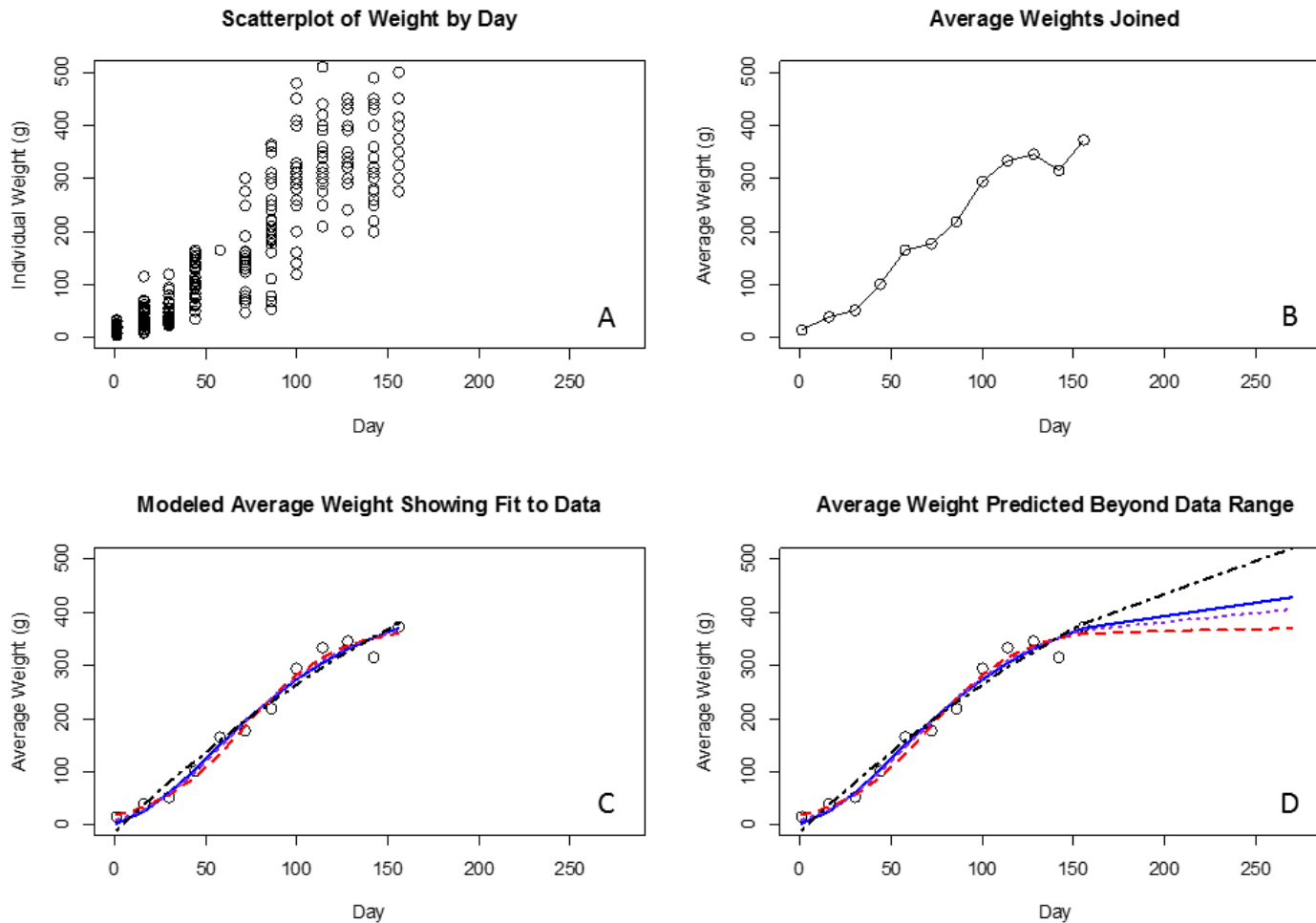
Figure 3.3. Comparison of alternative ways for reporting the pattern of fish growth over time, using data from a single study pond. A) plot of the raw data of all observations from each sampling event; B) the common reporting of the average size for each event to represent a 'growth curve'; C) fitting of candidate growth models to the raw data; and D) prediction of fish growth beyond final event with different candidate models.

actual best growth model, among the set of candidate models, of an arbitrary growth-at-age data set. Based on that approach, the weight of evidence in favor of the logistic growth model was 40.1%, leaving 59.9% as the combined evidence for all the other candidate models. Notably, the von Bertalanffy growth model (VBGM) is the only model that had all model weight values below 0.50, meaning that even when it was selected as the best model, VBGM never really had clear, strong support from the data.

Nevertheless, the majority of studies on fish growth modeling assumes the von Bertalanffy model by default under nearly all growth prediction scenarios. For example, De Graaf et al. (2005) created a simulation model for commercial aquaculture production of Nile tilapia, which is based on an exponential decay model used in population dynamics, and which incorporates an individual-based growth model. The von Bertalanffy growth function is incorporated to simulate growth, without the option to base simulation on other models. The model by De Graaf et al. (2005) has been employed in a number of studies in various parts of the world to simulate the production, and to determine the economic viability, of a number of aquaculture enterprises. Two such studies (Kaliba et al. 2006; Kaliba et al. 2007) employed this simulation model to estimate the economic profitability of producing Nile tilapia in Tanzania and Ghana, respectively, and concluded economic viability of the pond-based tilapia culture in these countries. Sensitivity of these economic analyses to the selected growth model for tilapia were not considered. However, the results of the current study indicate that the logistic growth model is the best out of the candidate set for modeling *O*. *niloticus* growth under aquaculture conditions. The Gompertz growth model could be employed as the second-best.

In spite of appearing to be the worst performer in our set of candidate models, we observed that the quadratic growth model far outperformed the others in the few datasets in which it was

selected as the best. Roff (1980) lists a number of good characteristics of the quadratic (parabolic) model, concluding that this model type might be a "reasonable" choice in particular circumstances. Upon closer examination of our data, the quadratic model was best in situations where the growth did not approach a clear asymptote during the period of observation – an observation that was also made by Katsanevakis and Maravelias (2008) regarding the power model.

Two other studies have employed other model selection methods to determine the best option to model fish size-at-age data under aquaculture conditions. Rosa et al. (1997) studied weight-at-age data for farmed *O. niloticus* and Common carp (*Cyprinus carpio*) in Brazil, and selected the Chapman-Richards growth model (a form that is very similar to the von Bertalanffy model) as the best candidate model for modelling *O. niloticus* growth, out of a set that also included the Gompertz, von Bertalanffy, Silva, Brody, monomolecular, logistic, and Johnson growth models. However, the referenced study employed the index of fit, which resembles the coefficient of determination (R^2) as the criterion for their ranking. Anderson (2008) illustrated a situation where multiple non-linear models were compared on the basis of R^2 and showed that R^2 is an unreliable indicator of model performance for non-linear models, compared to AIC and model weights. Furthermore, the use of the various forms of the R^2 for model selection has been criticized. It is known that R^2 increases whenever new parameters (even completely unrelated ones) are added to a model, which implies that model complexity is always supported. The adjusted R^2 (R^2_{adj}) attempts to correct this. In linear regression analysis, the adjusted R^2_{adj} is arguably the first model selection criterion to be widely used (McQuarrie and Tsai 1998), and it indicates the proportion of the response variable's variance that can be explained by independent or predictor variables. The R^2_{adj} is a measure of the overall accuracy of the model in terms of

within-sample prediction (Anderson, 2008). However, McQuarrie and Tsai (1998) proved, on the basis of the signal-to-noise ratio, that the R^2_{adj}-based model selection had the tendency to overfit and was not expected to reliably choose the 'true' model. Therefore, while R^2_{adj} values are useful as a measure of the proportion of the variance in common, they are not useful in model selection, and should be restricted to description (Anderson 2008).

Based on Rosa et al. (1997), we initially included the Chapman-Richards model in our set of candidate models. However, due to a large number of failed convergence events in our runs from this model, we had to eliminate it because the resultant SSEs obtained could not be relied upon to be entered into subsequent steps of the AICc calculations. In effect, the Chapman-Richards model would have been the worst performer had we left it as a candidate model.

Gamito (1998) compared the performance of six growth models in modelling the growth of gilthead sea brean (*Sparus aurata*), a species commonly cultured in the Mediterranean Sea. The author concluded that the Gompertz or parabolic growth models were the most appropriate for modelling the growth of young fish, whereas the von Bertalanffy growth model was the best for older fish. Other models in Gamito's candidate model set were the logistic, exponential, and restricted ("a simple mathematical model that considers a decreasing growth rate with an increase in body weight, until an upper limit is reached") growth models. Gamito (1998) employed simulations based on a compilation of growth and environmental parameters from the literature.

The results of the current study contrast with that of Katsanevakis and Maravelias (2008) in a significant way. In the referenced study, the von Bertalanffy and power (similar to quadratic) model outperformed logistic and Gompertz, based on the Akaike model weight criteria. The main difference between the data sets used in the two studies is the species used, mostly long-

lived wild marine species in the Katsanevakis and Maravelias (2008) study, whereas the current study was based on a relatively short-lived species under accelerated-growth culture conditions. The general observation that the von Bertalanffy model is best suited for long-lived species is thus supported by the results of the two studies taken together.

Implication for profitability assessment of tilapia farming

Table 3.2. Size range and farm gate price of tilapia on the Ghanaian market in 2011 (Cocker 2014)

Size category	Weight range (g)	Price (USD$) kg^{-1}
Size 3	800+	6.0
Size 2	500 – 800	4.5
Size 1	400 – 500	3.5
Regular	300 – 400	2.2[a]
Economy	200 – 300	2.2[a]
Small	150 – 200	1.5

[a] We suspect this might be an erroneous repetition of the price/kg for the two categories

Much effort currently is being invested in promotion of tilapia farming in developing countries, and construction of enterprise budgets for tilapia farms (e.g. Engle and Neira 2005), especially in the sub-Saharan Africa region. An enterprise budget is an important input to determine the profitability and economic sustainability of such enterprises. These and other methods of determining the profitability of aquaculture enterprises that rely on the prediction of fish weights after a period of time would benefit from careful choice of growth models. Most of the existing studies either predict final weights with the von Bertalanffy model, without any model selection procedure, or assume parameters of a von Bertalanffy model based on observed growth averages from previous production cycles. Predicted growth translating into harvest weight then is combined with a price function to estimate revenue.

An overly optimistic estimate of growth, combined with a price function where there is a premium on fish size can lead to a significantly upward-biased estimate of profit that will not materialize. For example in Ghana, the price per kg of tilapia increases as a step function as size increases, which makes larger fish more profitable (Table 3.2). Thus, small increases in average weight increases profit non-linearly. Farmers therefore routinely keep their fish in ponds longer when they expect weight to move into a more profitable size bracket. Therefore, for projection purposes, small differences in predicted average weight can significantly impact profit and make profit very sensitive to the growth model applied. The vital point here is that even when fish weight differences in the predictions from different models are not significantly different from each other, these differences could translate into significant differences in profitability assessments.

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Chapter 4: Characterization of the Adoption of Environmental Best Management Practices in Pond Aquaculture

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Abstract:

Environmental best management practices (BMPs) are widely accepted as the most realistic means of abating the negative impacts of agriculture on the environment. This is especially true in the sub-Saharan Africa region, where aquaculture is being encouraged to provide much needed low-cost, high-protein fish. We administered a baseline survey to 393 (and a follow-up survey to 160) pond fish farmers in Ghana. Using the ordered logit model, we then determined factors that influenced the combined adoption of two environmental BMPs – water reuse and commercial fish feed – on earthen pond farms. These two BMPs are recommended for

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simultaneous use for the full economic and environmental benefits to be realized. We also

determined both rate of adoption and effectiveness of three techniques for diffusing these BMPs

to additional users. The factors that had the strongest influence on the combined adoption of

these BMPs were: farmer's awareness of the feed BMP, perceived necessity/relative

profitability of the water reuse BMP, and farmer's years of experience. Maximum adoption

rates for the commercial feed and the water-reuse BMPs were 58.2% and 27.4%, respectively.

Also, a combination of central media (workshops), demonstrations, and lateral diffusion was

found to be the most effective channel for disseminating these BMPs, although workshops had

the highest average ranking. Therefore to ensure successful adoption of aquaculture BMPs,

regular well-planned workshops incorporating effective demonstrations and opportunities for

lateral-diffusion are a favored mechanism to both create awareness and to create an atmosphere

conducive to encouraging target farmers at multiple stages of the innovation decision process.

Research also is needed within the sub-Saharan Africa region on ways to reduce feed costs to

encourage farmers to adopt the commercial feed BMP.

Keywords: Econometric ordered logit model; Markov model; Adoption rate; Innovation

diffusion channels; Ghana

Introduction

Aquaculture currently is actively being promoted in sub-Saharan Africa by both governmental

and non-governmental organizations because of its several benefits. Farming of fish is widely

regarded both as a supplement and a relief to dwindling stocks of wild fish. Aquaculture also is

expected to play a major role in poverty-reduction and food security efforts in the sub-region,

from provision of much-needed high-quality low-cost protein (Dey et al. 2011) and socio-

economic benefits such as increased employment and income (Ansah et al. 2014). Ghana, like a

number of other countries in the sub-region, derives a large proportion of its dietary protein from fish, with an annual per capita fish consumption of more than 20 kg in 2009 (Brashares et al. 2004, Food and Agriculture Organization 2012), slightly higher than the global per capita fish consumption of 18 kg (Food and Agriculture Organization 2012).

However, most forms of fish farming are perceived to have adverse environmental effects, including sedimentation and eutrophication of effluent-receiving waterbodies (Burridge et al. 2010, Klinger and Naylor 2012, Frimpong et al. 2014). Because of the relatively dilute nature of effluents from fish farms (Boyd and Queiroz 2001, Tucker et al. 2002, Engle and Valderrama 2004, Ansah et al. 2013), aquaculture environmental best management practices (BMPs) are considered as the most practicable solutions to minimize negative impacts of fish farming on the environment. Therefore, as the fish farming industry in sub-Saharan Africa continues to develop, voluntary adoption of innovations such as environmental BMPs by fish farmers could minimize the negative environmental impacts of the industry to ensure sustainability of the industry.

Although several aquaculture BMPs exist, each BMP can be placed in one of two groups: nutrient management and effluent management (Louisiana State University AgCenter 2003). Effluent management practices include technologies such as settling ponds and vegetation ditches, draining to wetlands, top-release for partial drainage, and water reuse. Nutrient management practices typically include technologies and guidelines relating to fertilizing and feeding regimes that avoid waste and prevent deterioration of pond water quality (Tucker et al. 1996). For this study, we characterized the adoption of two BMPs – one from each broad category: water reuse, and the use of commercial aquafeed (as opposed to sinking feed mixtures made from agro-industrial by-products). Additionally, it is possible to directly quantify the environmental (e.g. annual kilograms of nitrogen prevented from entering streams) and

economic benefits (e.g. change in profits of the farm) from the adoption of these two BMPs, which are the subjects of separate publications.

Water reuse provides the most environmental benefit because intentional pond drainage, which accounts for most effluent output, can be avoided altogether for several years. Wastes from uneaten feed and excreted nutrients also are potential sources of pollution if effluents are discharged from the facility. A new crop is stocked in the old, "green" water in subsequent production cycles. Nutrients in the green water function as fertilizer for primary production when left within the system, and primary production could serve as a sigificant supplement to fish feed (Frimpong et al. 2014).

Avoidance of feed waste saves cost, which contributes directly to farm profitability (Engle and Valderrama 2004). Feeding is best regulated by observing how much the fish are eating and then adjusting the amount of feed accordingly. This is possible only when pelleted, floating fish feed is used as opposed to the local alternative, which sinks as soon as it is administered. Feed that is not eaten functions very much like fertilizer and results in highly eutrophic water conditions that both reduce yields and potentially pollute receiving waterbodies when drained. Commercial fish feed also is known to be produced with a good mix of macro and micro nutrients, which accelerate growth of cultured fish (Bell and Waagbø 2008), implying bigger fish in a shorter time or multiple cycles in a year. Frimpong et al. (2014) showed that using commercial feed resulted in fish twice the size of fish fed the sinking feed alternative. Enterprise budget analysis (Chapter 5) also indicated that although the commercial feed type was more expensive, a fish farm that used the commercial feed recorded net returns about seven times that of a farm that used sinking feed. However, as with many new technologies, the higher cost of the commercial feed could be a barrier to its adoption.

Adoption is the choice of a new technology (an innovation) over an existing one (Rogers 2003), and occurs the moment the individual makes the decision to adopt or reject the innovation, which results in the spread (diffusion) of a new technology (Scandizzo and Savastano 2010). Because the future of a new technology is uncertain, different people are expected to exhibit varied behavior with regards to adoption because of their different levels of risk aversion. According to Rogers (2003), a farmer may discontinue adoption or adopt later, after initially adopting or rejecting a new technology, respectively. A literature search revealed a paucity of innovation adoption studies in aquaculture, unlike in terrestrial agriculture, where such studies abound. A number of factors have been cited by various studies as essential in influencing farmers in Africa to adopt agricultural innovations: education, age, wealth, farming experience, geographical location of farm, membership of farmers' associations, availability of labor, visits by extension agents, and participation in on-farm trials (Weir and Knight 2000, Ntsama et al. 2008, Aïtchédji et al. 2010, Nchinda 2010, Tura et al. 2010).

Diffusion is the process by which an innovation is communicated through various channels (innovation diffusion channels) over time among members of a social system (Rogers 2003). Two important factors that characterize adoption of a new technology are *rate of adoption* and *innovation diffusion channels*. Rate of adoption of an innovation is influenced by its attributes, such as relative advantage, 'trialability', compatibility, complexity, observability, whether the decision is made by an independent individual or a group, the nature of the social system, farmer perception of the attributes of the innovation, promotion efforts by the change agent, and the nature of the diffusion channels at each stage of the innovation decision process (Batz et al. 1999, Negatu 1999, Rogers 2003).

Effectiveness of a chosen innovation diffusion channel is influenced by the nature of the target audience (Martin and Taylor 1995), and the stage of the adoption decision process pertaining to the audience (Rogers 2003). There always is a compromise between the number of people a selected technique can reach at a time, and the amount of trust achieved. Reaching a lot of people implies a fast rate of awareness creating, but trust and conviction are generally required to cause adoption. Transfer of ideas is easier if it occurs between individuals who have similar attributes, such as beliefs, education, and socioeconomic status (Rogers 2003). However, this process can be slow in terms of the number of people reached. Therefore, impersonal techniques, such as mass and central media, can be used to create awareness, whereas more personal techniques, such as farmer-to-farmer dissemination, can be used to convince a farmer to make or confirm a decision. The high degree of uncertainty related to new technologies can be reduced if the promised characteristics of these innovations can be proven to potential adopters via a trial or demonstration (Rogers 2003).

For this study, we determined the relative effectiveness of three major diffusion channels: central media (workshops), lateral (farmer-to-farmer) diffusion, and demonstrations. These three diffusion channels represent both the full range of personal versus impersonal techniques, and the most appropriate channel needed at each of the five stages of Rogers' (2008) Innovation Diffusion Model: knowledge, persuasion, decision, implementation, and confirmation. These innovation diffusion channels were employed as part of a bigger effort by the Aquaculture and Fisheries (AquaFish) Innovation Laboratory to disseminate environmental BMPs to fish farmers in Ghana, Kenya, and Tanzania.

Experimental section

The ordered logistic model

We employed the econometric ordered logistic framework to determine the characteristics of an adopter. The ordered choice (e.g., 0, 1, or 2 technologies) allows the determination of the factors that influence the adoption of a higher or lower number of innovations using relatively few options. This approach is particularly useful in the study of bundled innovations that have to be adopted together in order to realize the full benefits – more is better (recommended). One major aim of this study was identifying the factors that significantly influenced the number of innovations (environmental BMPs) adopted simultaneously by small-scale fish farmers in Ghana.

Probability of adoption and utility maximization

The adoption or rejection of an aquaculture BMP is an individual decision made by a fish farmer to maximize utility. The probability that a producer will choose a technology over other alternatives is given by the probability that the utility gained from the chosen technology is greater than the utility the farmer will gain from a given alternative. A fish farmer's decision to adopt a BMP can be modeled in the random utility framework (Judge 1980, Johnson et al. 2010). The utility of the ith fish farmer, who has j management practices to choose from, is

$$U_{ij} = x_{ij}\beta_i + \mu_{ij}, \tag{1}$$

where i = 1, 2, ..., I, and j = 1, 2, ..., J; $\beta_i = \bar{\beta} + v_i$ is a vector of preference variables for the ith farmer, $\bar{\beta}$ is the mean preference parameter, and v_i is a vector of random factors that represent the ith farmer's deviation from the mean. Because v_i cannot be observed in practice, (1) becomes

$$U_{ij} = x_{ij}\bar{\beta} + (x_{ij}v_i + \mu_{ij}). \tag{2}$$

It is assumed that β_i and random error, μ_{ij}, are multivariate normal and independent of one another with Weibull distributions (a bell-curve with restricted tails). Therefore, when the ith farmer adopts the jth technology, the utility of the farmer is maximized.

Jung (1993) describes the ordered logit model as follows: The underlying response model is given as

$$Y_i = X_i'\beta + \mu_i \qquad i = 1, 2, \ldots, N \qquad (3)$$

If the ordered response, b, has m categories, the ordered response model can be defined as

$$\Pr(Y = b|X', \alpha, \beta) = F_b(\alpha_b - X'\beta) - F_{b-1}(\alpha_{b-1} - X'\beta) \qquad (4)$$

where b = 1, 2, . . ., m, and $\alpha_0 = -\infty, \alpha_{b-1} \leq \alpha_b, \alpha_m = \infty$, F is the cumulative distribution function of logistic distribution, $F_b = 1/(1 + \exp(-(\alpha_b - X'\beta)))$.

A set of ordinal variables, Z_{ib}, can be defined as:

Z_{ib} = 1 if Y_i belongs to the bth category,

Z_{ib} = 0 otherwise.

Data collection and modeling

Data Collection

We developed a baseline questionnaire, which we administered in person to 393 pond fish farmers in south-western Ghana from June 2011 to August 2013. A majority of fish farmers in Ghana culture Nile tilapia (*Oreochromis niloticus*), sometimes as a polyculture with African Catfish (*Clarias spp*). A random sample of already-interviewed respondents were re-interviewed in a shorter follow-up survey every 6 months (the usual length of a production cycle) to identify changes of previous adoption decisions. This schedule resulted in 5 survey events over the course of the study. In all, 160 follow-up surveys were administered, with certain respondents interviewed up to three times throughout the study period. The study area comprised four

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political regions of Ghana – Ashanti, Brong-Ahafo, Eastern and Western regions, which

contained about 2,400 such farmers in total. We obtained a list of active fish farmers in the study

area from the Ghana Fisheries Commission, and we surveyed all farmers that we were able to

locate in the study area. Respondents were asked which of the two recommended BMPs (use of

commercial fish feed, and water reuse) they had adopted. The ordered response is therefore

categorized as:

BMP = 1   if no BMP was adopted,

BMP = 2   if one BMP was adopted, and

BMP = 3   if both BMPs were adopted.

Therefore, our logit model was:

$$\Pr(BMP = b|X', \alpha, \beta) = F_b(\alpha_b - X'\beta) - F_{b-1}(\alpha_{b-1} - X'\beta), b = 1, 2, 3 \tag{5}$$

Independent variables targeted by the survey, and used in the model, included socioeconomic

and technical characteristics of respondents and farm operations. A summary of all independent

variables used in this study is indicated on Table 4.1. All information came directly from

respondents through the interviews. Respondents also were asked in the follow-up surveys to

rank each of the three innovation diffusion channels to reflect how influential that channel was in

their decision to adopt either BMP over a scale of 1 to 4 (Ranking: 1 = Highly influential, 4 =

Not influential).

Nile tilapia was cultured in ponds on eight demonstration farms in Central Ghana over the study

period. These were already-existing fish farms, from which ponds were selected and set aside for

this study. Stocking, feeding, and other management practices employed for production of tilapia

on these demonstrations were consistent with those used on typical tilapia farms in Ghana, but

experimentally controlled. A major aim of these demonstrations was to disseminate the two BMPs to farmers in an area by proving their effectiveness on a nearby farm, without the farmers having to bear the risk themselves.

We also organized a 3-day workshop on aquaculture environmental BMPs for fish farmers in the study area once every year for the three years of the study. The material at these workshops was not limited to just these two BMPs. Apart from presentations to farmers, participants were allowed to interact with each other and share ideas. Government extension agents also were invited to interact with farmers and answer questions. As part of each workshop, participants were taken to the demonstration farm nearest the venue to see the BMPs at work. The workshops were attended by a total of about 300 participants.

Data summaries indicated that fish farming in Ghana is male-dominated, with almost 90% of farmers being men (Table 4.1). The average age of fish farmers was 47 years, with almost 50% of respondents having finished middle school. Approximately 30% of respondents had a bachelor's degree or higher. Size of farmland ranged from 0.02 to over 182 hectares. More than 50% of surveyed farms sourced water from a nearby river, and almost all farms had a year-round supply of water of good quality. Whereas 85% of respondents were aware of the extruded fish feed BMP, fewer (40%) were aware of the water reuse BMP. Also, only 16% of respondents were full-time fish farmers.

Table 4.1. Summary of independent variables used in the study. All entries were from farmers' direct responses and perceptions.

Variable	Description	Mean or frequency	Std. Dev.	Min	Max
Location of farm					
REGA	Ashanti region	0.42	0.49	0	1
REGB	Brong-Ahafo region	0.33	0.47	0	1

REGW	Western region	0.24	0.43	0	1
Land ownership and tenure					
LSYZ	Size of farmland (ha)	8.70	20.20	0.02	182.12
OWNL	Farmland owned	0.39	0.49	0	1
LEAS	Farmland leased	0.34	0.47	0	1
FAML	Extended family owns farmland	0.26	0.44	0	1
OWNF	Respondent owns farm	0.90	0.30	0	1
Water source and availability					
RIVW[a]	Water sourced from nearby river only	0.53	0.50	0	1
WQTY	Water is available year-round	0.92	0.27	0	1
WQLT	Water is of good quality	0.94	0.24	0	1
Farm management practices					
SPNO	Number of species cultured	1.80	0.62	0	3
LABO	Labor readily available	0.79	0.41	0	1
KNOL	Farmer is aware of water reuse	0.40	0.49	0	1
KNOF	Farmer is aware of extruded feed	0.85	0.35	0	1
FPRO	Extruded feed is relatively profitable	0.74	0.44	0	1
WPRO	Water reuse necessary/relatively profitable	0.64	0.48	0	1
Socioeconomic characteristics					
MALE	Farmer is male	0.89	0.31	0	1
AGE	Age of farmer	46.37	12.15	17	79
EDUO	Farmer has no formal education	0.04	0.19	0	1
EDUM	Farmer has up to middle school	0.46	0.50	0	1
EDUH	Farmer has up to high school	0.24	0.43	0	1
EDUT	Farmer has bachelors or higher	0.26	0.44	0	1
FULT	Fish farming is full-time job	0.16	0.37	0	1
EXPE	Number of years fish farming	4.73	5.99	0.08	32
Extension opportunities					
EXTE	Farm visited three or more times in the last year by gov't extension agents	0.60	0.49	0	1
TRIAL	Farmer participates in hands-on aquaculture trials	0.48	0.50	0	1

ASSO	Famer association membership	0.64	0.48	0	1
TRAIN	Farmer has had some aquaculture training in the last year	0.40	0.49	0	1
COOP	Farmer cooperative membership	0.14	0.35	0	1

Note: [a] Other water sources were combined as 'others' and modeled as the base group. Total

number of observations, $n = 393$

Two criteria were used to eliminate some variables. Firstly, some categorical binary variables

were omitted in order to prevent perfect linear dependency (Wooldridge 2006), and these

omitted variables were designated as base groups for those categorical sets of variables. An

example of such an omitted variable is EDUO (no formal education) for the education

variables. Secondly, variables that were strongly correlated to others (≥ 0.50) were omitted in

order to prevent multicolinearity (Wooldridge 2006). Therefore the final model we evaluated,

using the STATA 12 (StataCorp, College Station, Texas) statistical software, was:

$$BMP = \beta_0 + \beta_1 REGA + \beta_2 REGW + \beta_3 LSYZ + \beta_4 OWNL + \beta_5 OWNF + \beta_6 RIVW \qquad (6)$$
$$+ \beta_7 WQTY + \beta_8 SPNO + \beta_9 LABO + \beta_{10} KNOL + \beta_{11} KNOF + \beta_{12} FPRO$$
$$+ \beta_{13} WPRO + \beta_{14} MALE + \beta_{15} AGE + \beta_{16} EDUH + \beta_{17} EDUT$$
$$+ \beta_{18} FULT + \beta_{19} EXPE + \beta_{20} EXTE + \beta_{21} TRIAL + \beta_{22} ASSO$$
$$+ \beta_{23} TRAIN + \beta_{24} COOP + \mu_i$$

Characterizing the rate of adoption

The observed adoption-decision behavior of farmers deviated significantly from our initial

prediction in that there was not a clear directional change over time in the percentage of

randomly sampled farmers who were using either floating feed or water reuse. While some

farmers who were not using a technology at one event reported using it during a subsequent

event (implying 'adoption'), others who were using it also had a tendency to discontinue

(implying 'abandonment'). It was also clear from survey responses that neither trial of a technology nor discontinuation of its use was a permanent decision and that persuasive factors (e.g., good result in the initial trial, perceived additional improvements in the technology) or changing market conditions (e.g., changing cost of feed and availability of water) influenced farmers' short term decisions to retry a technology or put it on hold. Adoption and abandonment, then, applied only loosely to this system we observed, which we believe illustrates a fine temporal-grain stochastic dynamism of adoption decision in the very early stages of the introduction of a technology. This phenomenon may not be widely investigated or reported.

We modelled this process as a Markov process (Urban and Wallin 2002). There were a total of five survey events. This implies a maximum of 10 opportunities (separately for each of the two BMPs) for a respondent to switch from 'not adopted' to 'adopted', or vice-versa, or to remain with their previous choice. Next, the sum of the responses for each 'opportunity' was summarized into a 2x2 matrix corresponding to the four possible responses for each respondent in that event, and row sums calculated. Each diagonal term in the matrix was normalized by being divided by its corresponding row sum, and by the event number to incorporate the element of time. Non-diagonal terms then were obtained by subtracting the corresponding normalized diagonal term from 1.

An average 2x2 transition matrix was created for each of the two BMPs, with each diagonal cell calculated as the average of the 10 corresponding cell values from the 10 matrices. Non-diagonal values were calculated by subtracting the corresponding diagonal value from 1. A vector (1x2) then was calculated from the responses of the final event. The average transition matrix and the final event vector were input into a Markov model to determine final or asymptotic adoption rate, and the number of time steps needed to achieve this asymptote.

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Relative effectiveness of innovation diffusion channels

The mean ranking of each innovation diffusion channel was determined separately for the

commercial feed BMP and the no-drain BMP. Average ranking and the standard error of each

channel was also plotted to reveal the trend of importance of each channel throughout the period

of the study.

Results and Discussion

<u>Characteristics of BMP adopters</u>

We looked to identify factors associated with adoption and what these factors meant. The

estimated coefficients and *p*-values from the ordinal logit regression are indicated in Table 4.2.

Also indicated for each factor in Table 4.2 is the percentage change in the probability of a

respondent moving to the next ordinal category of the response variable. For example, a negative

"% change in probability" indicates the percentage change in the probability of a respondent

adopting the next lower number of BMPs. The McFadden R-squared for the regression suggested

a strong relationship between dependent and independent variables (Hensher and Johnson 1981).

Statistical significance is shown at 1%, 5%, and 10%.

Table 4.2. Results of logit model for the factors that influence the ordinal adoption of two best management practices

Independent variable	Coefficient	*p*-value	% Change in Probability[b]
Geographical Location			
REGA	-0.95[**]	0.02	-61.30
REGW	-0.34	0.47	-28.80
Land Ownership and Tenure			
LSYZ	0.00	0.32	0.00
OWNL	-0.32	0.33	-27.60
OWNF	0.41	0.45	50.50

Water Source and Availability

RIVW	-0.75**	0.02	-52.80
WQTY	0.05	0.94	4.90

Farm Management Practices

SPNO	-0.30	0.28	-26.00
LABO	0.67*	0.11	96.10
KNOF	1.33***	0.01	279.20
KNOL	-0.03	0.93	-3.00
FPRO	-0.14	0.69	-13.40
WPRO	1.39***	0.00	302.70

Socioeconomic Characteristics

MALE	-0.17	0.73	-15.60
AGE	0.01	0.32	1.40
EDUH	0.23	0.56	26.40
EDUT	0.11	0.79	11.70
FULT	0.85**	0.05	134.30
EXPE	-0.18***	0.00	-16.20

Extension Opportunities

EXTE	0.57*	0.11	76.90
TRIAL	0.17	0.64	18.50
ASSO	0.05	0.90	4.60
TRAIN	0.84**	0.02	130.90
COOP	-0.34	0.45	-29.00

Note: McFadden $R^2 = 0.20$; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Total number of observations, $n = 393$

[b] The percentage change in the probability of a respondent moving to the next higher or lower ordinal category of the response variable, depending on the sign.

The variables with the strongest influence on the number of recommended technologies that a farmer adopted were farmer's awareness of the feed BMP, perceived necessity (relative profitability) of the water reuse BMP, and the number of years a farmer had been engaged in fish

farming. Awareness of a technology is the essential first step in the innovation adoption process (Rogers 2003). A farmer cannot adopt a technology if he or she is not aware of it. Awareness can be easily achieved through mass and central media diffusion methods, and also through farmer-to-farmer diffusion. The perceived relevance/relative profitability of an innovation to a farmer is known to positively influence adoption of that technology (Weir and Knight 2000). This perception comes after the persuasion stage, which is the second step of Rogers' Innovation Diffusion model (Rogers 2003). For a farmer to be persuaded to adopt a new technology, more personal approaches are often required, such as actually trying the technology or observing another farmer use it. To realize the necessity of an innovation, farmers will have to convince themselves of the relative advantage, compatibility, and acceptable flexibility of the new technology over existing technologies (Rogers 2003).

A number of pond fish farmers in sub-Saharan Africa believe that pond water from a previous cycle is 'dirty' water, which must be drained out, and ponds must be refilled with fresh water to enhance fish growth. It will be very difficult to diffuse the water-reuse BMP to such a farmer who has been draining and refilling his ponds for many years, as the result for number of years of experience confirms. However, our results indicated that farmers who perceived the reuse of pond water as necessary as or relatively more profitable than pond draining had a very high probability of adopting not just the water reuse BMP, but both recommended BMPs.

Additionally, Ghanaian fish farmers have expressed concern about the lack of a ready market for produced fish, which results in lost revenue. As such, experienced farmers can be expected to lower any investments to a minimum in order to reduce losses, based on their negative experiences. Previous studies (Rosenberg 1976, Batz et al. 1999) have showed that the risk associated with a new technology could serve as a barrier to its continued adoption. Therefore,

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number of years of experience may be related to the level of aversion of a farmer to capital-intensive innovations in pond fish farming, especially if previous adoption led to revenue losses.

A farmer located in the Ashanti Region was 61.3% less likely to adopt a higher number of the recommended BMPs, compared to another who was located in the Brong-Ahafo region (the base group). We also found that a farm that sources water from a nearby river was about 53% less likely to adopt both recommended BMPs, when compared to those using other water sources. Geographical location has been found to have a strong influence on transfer and adoption of new technologies (Feder et al. 1985, Martin and Taylor 1995). Location determines climatic factors that could either facilitate or impede innovation adoption. Also, it was shown decades ago that a farmer is expected to be less inclined to adopt an 'efficiency' (input-saving) agricultural innovation when he/she perceives a primary resource to be in abundance (Boserup 1966). The Ashanti region is located in the moist semi-deciduous forest ecozone, which is characterized by high rainfall and an abundance of rivers and streams. The Brong-Ahafo region, in contrast, is partially located in the savanna zone, and is significantly drier. Therefore, pond fish farmers in the Ashanti Region might not see the need to reuse pond water. However, with the number of fish farms in Ghana estimated to be increasing at a rate of 16% per annum (Asmah 2008), quality and quantity of water for fish farming is likely to deteriorate with the current practice of draining fish ponds into receiving waterbodies. Thus, fish farmers must be convinced of the need to adopt BMPs in general, and water reuse in particular in order to prevent potential conflicts over water use in the near future.

When labor was readily available, a fish farmer was almost 100% more likely to adopt a higher number of recommended BMPs. Pond aquaculture farms in Ghana (and in most developing countries) are semi-intensive operations, which rely heavily on labor for the various management

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practices. Examples of these labor-intensive practices are: clearing of both aquatic and terrestrial nuisance plants, pond construction, pond maintenance and preparation between production cycles, daily feeding, water quality, and stock monitoring, brood care and various hatchery activities, and harvesting of fish. It is expected that if a limiting input, such as labor, cannot be guaranteed when needed, a farmer will be wary of making any investments into the enterprise or making any expansions that will potentially require additional labor. The limiting nature of labor availability to adoption of agricultural innovations has been found in other studies. Examples are adoption of yam minisett technology in Cameroun (Nchinda 2010) and adoption and continued use of improved maize seeds in Ethiopia (Tura et al. 2010). A possible solution to the issue of labor unavailability is dissemination of labor-saving technologies on fish farms in Ghana, which could facilitate the adoption of BMPs and other innovations whose adoption would be contingent on labor availability.

A fish farmer who practices fish farming as a full-time occupation was over 130% more likely to adopt a higher number of the recommended BMPs than a part-time farmer. It is expected that a farmer whose sole income is fish farming will be amenable to innovations that improve efficiency and increase revenue. Aquaculture BMPs have been proposed to be both cost-saving and revenue-enhancing. However, because awareness of a technology precedes its adoption (Rogers 2003), it is more likely that a full-time farmer would have the willingness and time to actively search for new technologies to increase his only livelihood.

A farm that was visited three or more times in a year by government extension officers was about 80% more likely to adopt a higher number of the recommended BMPs than a farm with fewer visits in a year. It is widely accepted that personal contact is essential in promoting new technologies, especially at the persuasion stage of the Innovation Diffusion Model (Martin and

Taylor 1995, Rogers 2003). Government extension agents are invaluable to the diffusion of agricultural innovations in developing countries, and these agents form trusted relationships that facilitate the diffusion process (Rogers 2003). In our experience, farmers who are visited frequently by extension officers are those who seek advice from and work closely with the agents, thus suggesting a reinforcement interaction among several factors that facilitate adoption. Also, farmers who had received training in fish farming over the last year were over 130% more likely to adopt a higher number of the recommended BMPs, compared to farmers who had not. Such training offers extension agents a platform to introduce new technologies, such as BMPs. These training programs also serve as an opportunity to interact with other farmers, allowing farmer-to-farmer diffusion of innovations.

Characterizing the rate of BMP adoption

According to the Markov model, the maximum adoption rate for the commercial feed BMP was 58.2%, and this asymptote is expected to be reached by June, 2016 (Figure 4.1). However, the results for the water-reuse BMP showed that the maximum adoption rate of 27.4% had already been reached by June, 2014 (Figure 4.2). A stochastic model with the Markov property is characterized by a conditional probability distribution that predicts future states of a process as conditional on both past and present states, but depending only on the present state.

The low predicted rate of pond water reuse confirms the amount of dissemination effort that will need to be invested to change the minds of Ghanaian fish farmers towards the water reuse BMP. Most farmers are not convinced of any direct benefits of reusing pond water because water for fish farming is currently in plentiful supply. Farmers also are convinced that green pond water is not a conducive environment to start a new production cycle.
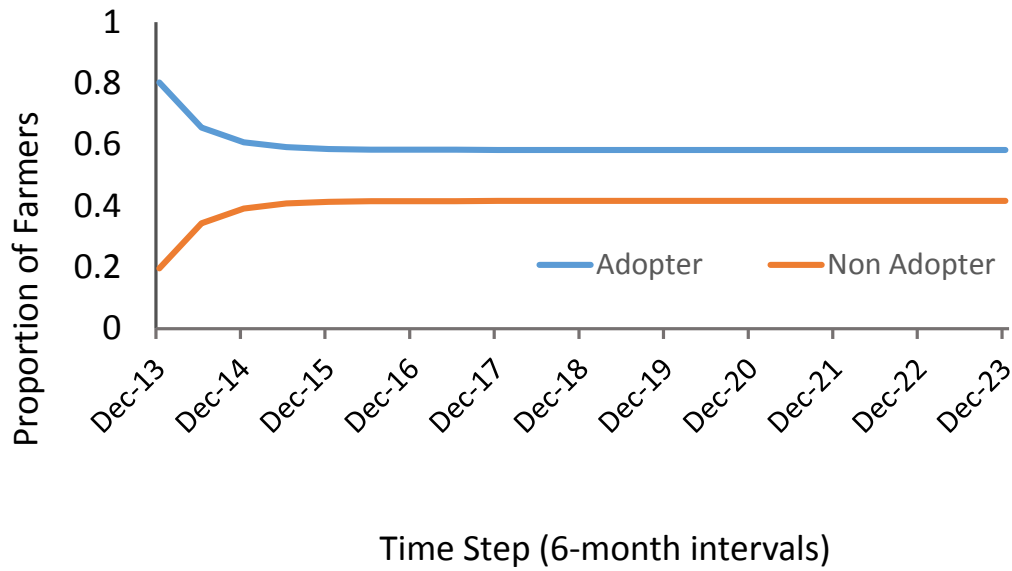
Figure 4.1. Predicted adoption of commercial aquafeed for ponds in central Ghana over time
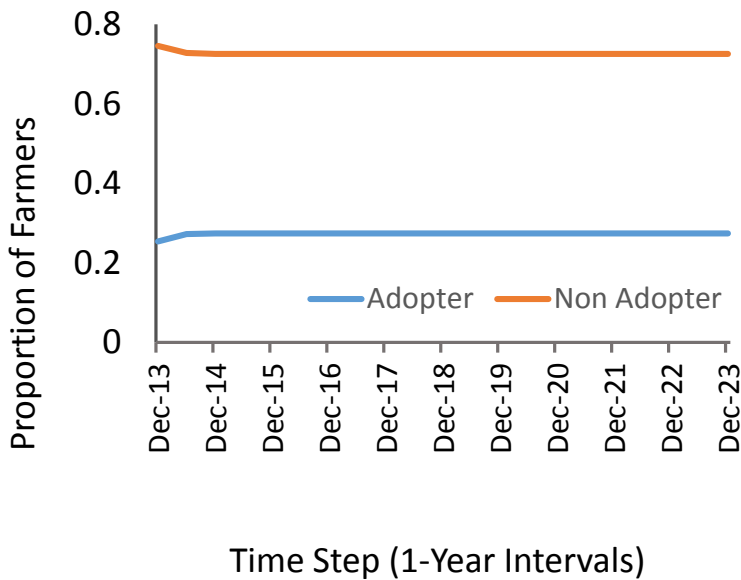
Figure 4.2. Predicted adoption of pond water reuse over in central Ghana over time

Commercial feed usage has a relatively positive reception among fish farmers in Ghana. It is common knowledge that flexibility associated with fish feed usage allows farmers to switch between feed types even during a production cycle, allowing a majority of respondents to

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actually try the commercial feed BMP and become convinced of its performance. However, the biggest barrier to complete commercial feed usage throughout the production cycle is the high cost of this feed type. Budget analysis has shown that commercial feed usage results in a significantly higher profit margin, compared to using the local alternative, but the high commercial feed cost is sure to put off a number of farmers (Chapter 5). We also found feed costs to be over 70% of total costs on farms that used commercial feeds exclusively. We recommend that studies on ways to cut down on the total amount of feed needed per production cycle be replicated in the sub-Saharan Africa region. A possible solution is alternative-day feeding, which could effectively cut the amount and cost of feed by 50%, without compromising growth rate (Bolivar et al. 2006, Borski et al. 2011). Investigation of the use of less costly substitutes for fish meal, which is the most expensive ingredient in commercial fish feeds, also is suggested.

Relative effectiveness of innovation diffusion channels

Throughout the two-year study period, the random samples of farmers interviewed consistently reported higher awareness of floating feed compared to water reuse (Table 4.3). No farmers reported trying water reuse whereas 48.8% reported using floating feed. Although, the goal was to capture farmers' awareness of the technologies before attending the BMP workshop and questions were specifically designed to make that distinction, a pattern of higher awareness was associated with water reuse for surveys taken during the workshop (Events 1, 3, & 5), suggesting that farmers did not always separate their prior awareness from the information received at the workshop. Awareness of floating feed remained high throughout the survey period, which was surprising given that floating feeds were just beginning to increase in availability at the inception of this project. Raanan® feed, which is the locally manufactured commercial feed brand more

than 80% of floating feed users reported using, was just starting to be marketed to farmers in the country in 2011. Less than 10% of farmers also report using Coppens® feed (imported from the Netherlands) and another 10% used a combination of these feed brands or other.

Table 4.3. Awareness and usage of water reuse and floating feed technologies by survey event.

| | | | Technology/Management Practice | | | |
| | | | Water Reuse | | Commercial Floating Feed | |
Survey Event	Approximate date	Sample size	Awareness (%)	Usage (%)	Awareness (%)	Usage (%)
1	June 2011	127	41.6	0.0	88.9	48.8
2	December 2011	56	36.7	7.7	96.7	61.1
3	June 2012	78	48.0	33.3	80.0	54.5
4	December 2012	105	28.0	17.2	95.9	65.7
5	June 2013	151	67.7	25.4	97.0	80.3

Unlike awareness, which had minimum change during the two-year survey period, reported usage of both water reuse and floating feed showed overall increase from the beginning to the end of the study. Water reuse increased from none in 2011 to 25.4% in 2013, whereas floating feed use increased from 48.8% in 2011 to 80.3% in 2013. This trend shows that sustained awareness creation through various technology dissemination channels, especially demonstrations, precedes the trial and subsequent adoption of a technology. Fluctuations in numbers of users of both technologies recorded over time (Table 4.3) was not just from random sampling error, but an indication of farmers trying and not always continuing to use either technology for various reasons. The observed behavior of pond-based tilapia farmers in Ghana toward adoption of water reuse and floating feed could best be characterized as a stochastic process involving transitions between decisions and reversal of decisions (as shown in the preceding section).

In terms of the influence of the dissemination channels in the adoption decision, the ranks assigned by farmers using floating feed averaged 1.5 for workshops (central media), 1.9 for demonstrations, and 2.1 for farmer-to-farmer (lateral diffusion). In a similar order, farmers reusing water ranked workshops at the top (1.6), followed by demonstrations (2.0) and farmer-to-farmer (2.6). We noted temporal patterns behind these averages that suggest all dissemination channels played important roles and worked in concert to influence farmers' decisions (Figure 4.3). As illustrated with the rankings of floating feed users for Event 2 to Event 4, lateral diffusion, which was ranked lowest near the beginning of the project increased in importance throughout the project to rank highest at the end. Because the project could not last forever, and one of our main objectives was to establish nodes of farmers who would then become the agents of diffusion of innovation to other farmers beyond the life of the project, this pattern is indicative of the concept working well. As more farmers became exposed to a technology and tried it, the proportion of farmers who were influenced primarily by other farmers to also try the technology increased through time. Another subtle pattern in Figure 3 is decreasing influence of the demonstrations through time and the significant dip in the ranking of demonstrations during Event 3. The demonstrations ran for parts of 2011 through early 2012. The majority of new farmers who were surveyed at the last workshop and shortly afterward received no benefit of visiting one of the demonstrations where the two BMPs were being implemented side-by-side.
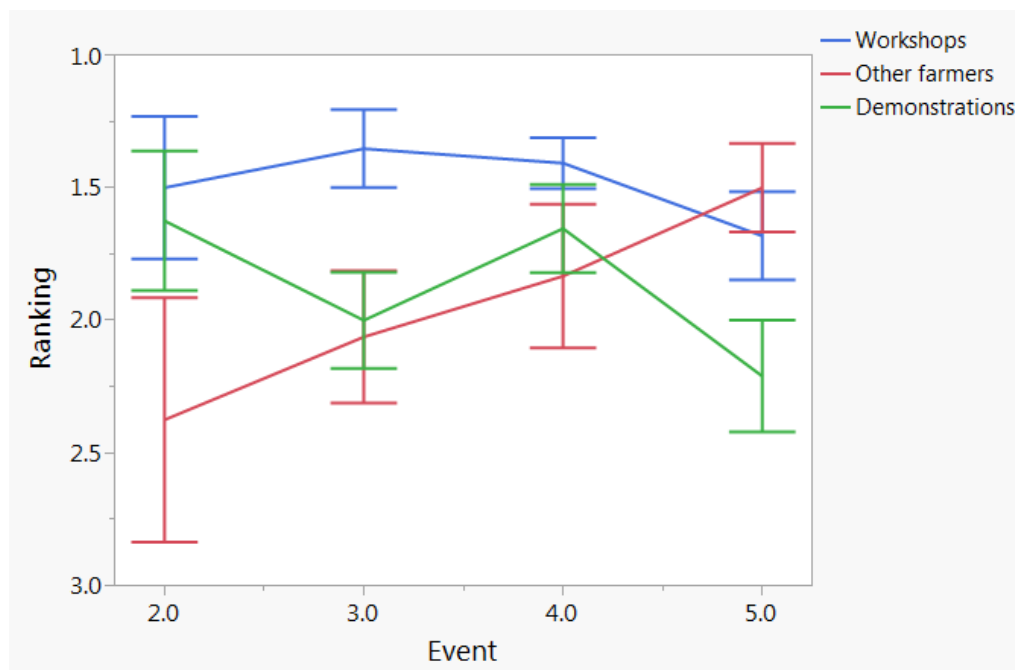
Figure 4.3. Mean (±standard deviation) of the ranking by floating feed adopters of the three BMP dissemination channels in terms of which most influenced their decision to adopt. Events were approximately 6 months apart from December 2011 to June 2013. Ranks were 1 – 3 with 1 being the strongest.

Unlike the first BMP workshop (Event 1), the demonstration farm at the second BMP workshop (Event 3) was not particularly successful in convincing farmers for two reasons: 1) the farmer did not maintain his ponds and farm in an exemplary way and many of the farmers who visited during the workshop expressed their lack of satisfaction with that farm as an example of BMPs in action, and 2) the fingerlings were just stocked within three weeks of the visit to the farm so farmers who attended the workshop and visited the farm could not see the effects of the BMP treatments on the growth of fish, which was the goal of the demonstrations. Clearly, for a farm to function well as a demonstration site, there should be an intersection of a well maintained farm and farmer understanding of and commitment to the concept of demonstration. Finding farms and farmers who fit these criteria proved to be much more difficult than we envisaged.
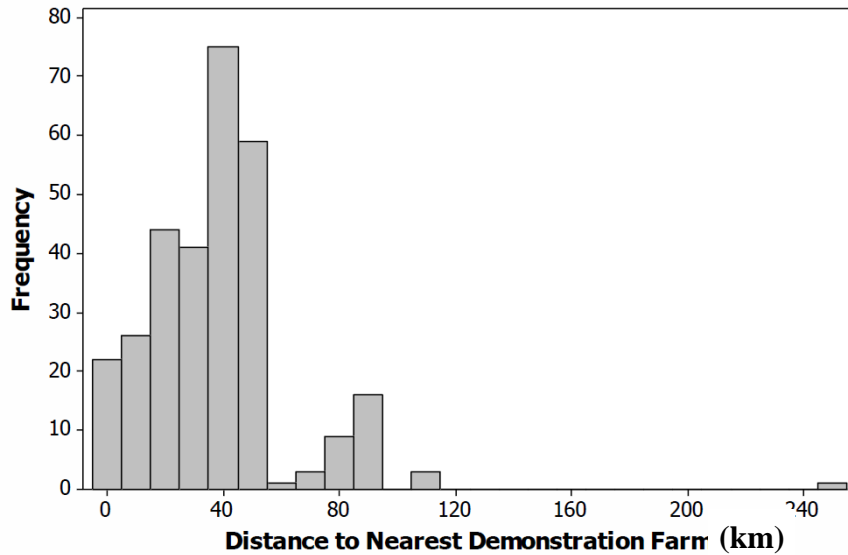
Figure 4.4. Distribution of the surveyed farms around the nearest demonstration farm

Another constraint to the effectiveness of demonstrations was that they were spatially sparse (Figure 4.4). The median distance to the nearest demonstration farm for the farmers surveyed was 38km, which is much farther than most farmers will travel from home to seek knowledge on a routine basis. We suggest that to use demonstrations effectively in the dissemination of pond aquaculture BMPs in Ghana and other sub-Saharan African countries in the future, greater consideration be given to accessibility of these demonstrations to the target farmers. For farms that are not spatially clustered such as pond farms in Ghana, this means a higher density of demonstration farms and a longer period of operation of each demonstration. Because of the high costs involved in setting up one demonstration (even on an already-existing farm), and the large number of demonstration farms required to be in relatively close proximity to most farmers, demonstrations might not be a practicable BMP diffusion mechanism if the target farms are dispersed over a wide area.

Central media, such as workshops, offer several opportunities for pushing farmers along the innovation decision process. A relatively large number of farmers can be targeted in one event, compared to lateral diffusion. At the workshop, farmers interact with each other to set off lateral diffusion. A well-planned workshop also may include demonstrations to participants on location or at a nearby farm. Rogers (2003) describes homophily as the degree to which two or more interacting individuals are similar in attributes, such as beliefs, education, and socioeconomic status. Transfer of ideas is facilitated if it occurs between individuals who are similar, or homophilous, as opposed to individuals who are heterophilous. Rogers (2003), however maintains that some degree of heterophily must exist for diffusion to be successful. A workshop offers a farmer both homophilous participants in the form of fellow farmers who already have adopted an innovation, and heterophilous participants (mostly the conveners and trainers at the workshop). Therefore, well-planned workshops could be the diffusion channel to disseminate an innovation to different people at various stages of the innovation decision process.

Conclusions

This study showed that the factors with the most influence on adoption of aquaculture BMPs are 1) farmers' awareness of BMPs, 2) perceived necessity or relative profitability of BMPs, and 3) years of experience of a farmer. We also have shown that the pond water-reuse BMP requires more extension effort to disseminate than the commercial-feed BMP, although the high cost of this feed type could be a barrier for its widespread adoption. Additionally, central media, such as well-planned workshops is likely the most effective innovation diffusion channel for disseminating BMPs and other innovations in fish farming.

Therefore, to ensure successful adoption of aquaculture BMPs, it is recommended that regular well-planned workshops (incorporating effective demonstrations and opportunities for lateral-

diffusion) be organized to both create awareness and to create a conducive atmosphere to target farmers at multiple stages of the innovation decision process. At these workshops, the relative profitability of BMPs can be demonstrated to participants in order to convince them to adopt. We also suggest that research also must be conducted within the sub-Saharan Africa region on ways to cut down feed cost to encourage farmers to adopt the commercial feed BMP. Results of these studies could be included on the agenda of the regularly-held workshops for fish farmers to enable them to both adopt this BMP, and improve profitability of their operations. Adequately equipping government extension agencies also will allow for frequent farm visits.

With the paucity of studies on innovation adoption in aquaculture as a whole and on pond aquaculture BMPs in particular, the results of this study could prove useful in the design of extension projects aimed at disseminating aquaculture innovations, especially in the developing world. We expect adoption of other BMPs in the sub-Saharan Africa region to mirror what we found in this study, because these two BMPs were selected to be representative of the full suite of existing aquaculture BMPs.

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Chapter 5: Comparison of the Profitability of Alternative Management Practices for Pond Tilapia Farms

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Abstract

The perceived relative profitability of a new technology is a significant determinant of its adoption or rejection, and the adoption of efficiency-enhancing technologies is seen as a means to enhance production from fish farms in the sub-Saharan African region. This study sought to compare profitability of use of commercial fish feed to that of local fish feed, which is an inexpensive, powdery mixture of by-products of the food processing industry for production of Nile tilapia in Ghana. Profitability of self-financing fish farming operations versus that of taking a loan also was investigated. Data were collected from demonstration farms producing tilapia in ponds, and through a comprehensive survey of 363 tilapia farmers in Ghana. Both a traditional and a stochastic enterprise budget were used to compare feed and loan scenarios. Results indicated that the most profitable scenario is self-financing and use of commercial feeds. Sensitivity analysis with Monte Carlo simulations revealed that profitability of using commercial feed can be enhanced by improving factors that increase harvest weight (such as water quality and fingerling genetic quality), making fish ponds deeper, and reducing the feeding rate without reducing growth rate. Hence, it is recommended for fish farmers in Ghana to make efforts to deepen fish ponds, use better-performing fingerlings, and ensure good pond water quality. Also

studies on ways to cut down the amount of fish feed used will reduce feed costs and encourage farmers to use this profitability-enhancing feed type.

Keywords

Monte Carlo simulation, Tilapia production, Feed conversion ratio, Enterprise budgets, Financing

Introduction

Study background and rationale

Fish farming is regarded not only as a means of easing the pressure on overfished fish stocks, but also as a relatively cheap source of much-needed protein for human consumption. As such, significant effort currently is being invested in promoting aquaculture in sub-Sahara Africa by both governmental and non-governmental agencies. Nevertheless, several studies have correlated aquaculture production with negative impacts on effluent-receiving streams (e.g. Klinger and Naylor 2012, Ansah et al. 2013). There is the need to encourage adoption of environmental best management practices (BMPs) along with promotion of aquaculture to mitigate any undesirable environmental impacts. However, in order to achieve rapid diffusion of these environmental BMPs, their profitability should be established relative to existing management practices (Rogers 2003).

The perceived relative profitability of a new technology is a significant determinant of its adoption or rejection (Rogers 2003). Change in production from the adoption of BMPs will be of interest to the risk-averse fish farmer, and making this information available to such a farmer from demonstrations will reduce that level of uncertainty surrounding adoption of the new technology (Rogers 2003; Engle and Valderrama 2004). Additionally, beyond the usual

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deterministic calculation of enterprise profits, the knowledge of the level of risk or uncertainty associated with reported results will further facilitate the comparison of alternate technologies (Valentin et al. 2004).

<u>Modifications to traditional enterprise budgets</u>

Enterprise or farm budgets are a useful way to compare profitability of two or more technologies. Such documents provide a summary of costs and revenues associated with an enterprise over a fixed time period for a defined production unit (Riepe 1997, Engle 2012). Profits or net returns can be calculated as the difference between gross receipts or revenue and summation of the various costs. Profitability of different management scenarios then can be compared on the basis of net returns.

A typical enterprise budget has sections for revenues (gross receipts), variable costs and fixed costs (e.g. Riepe 1997, Engle and Neira 2005). Entries from these sections then are combined to obtain total costs, net returns above variable costs and net returns above total costs. All these variables involve calculations based on a specified size of farm unit and time frame. Variable or running costs indicate those costs that are incurred within the specified production cycle or budgeting time frame. Variable costs include feed, labor, and fertilizer costs.

Fixed costs indicate long-term costs that usually require multiple production cycles or specified time frames to defray. Fixed costs include payments for land, pond construction, and machinery costs, which are incorporated into the budget as depreciation and/or interest rates for the specified time frame. An important component of fixed costs is repayment of loans borrowed to supplement fixed and operating capital. A loan could facilitate expansion of operations, but the terms of repayment could have a significant bearing on profits.

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The only source of direct revenue on a tilapia farm is the sale of harvested fish, which is determined by the sale or market price of tilapia. Therefore, calculation of price per unit weight of produced fish in an enterprise budget must be approached thoughtfully. It generally is acknowledged that larger-sized tilapia sell for a higher price per unit weight than smaller-sized ones (Kaliba et al. 2006, Kaliba et al. 2007, Ponzoni et al. 2007, Ofori et al. 2010).Therefore, calculating total revenue simply as the product of total yield and price per unit weight is imprecise. It is more informative to state fish price as a function of harvest weight instead of using an average price per unit weight across board, thereby allowing price to change with different harvest weight-classes. One possibility for achieving this is by incorporating a price function into an enterprise budget.

The final or harvest weight of fish usually is entered on enterprise budgets as a static or calculated mean value (e.g. Engle and Neira 2005). However, because fish price (and therefore total farm revenue) depends on harvest weight, it follows that weight of harvested tilapia be stated as a function of important production variables. Variables that are known to have direct bearing on the final size of pond-cultured fish include feed quality or type (Borski et al. 2011, Frimpong et al. 2014), and stocking density (El-Sayed 2002, Yakubu et al. 2013).

Stocking density is stated in fish farm manuals as the number of fish per unit surface area, with the assumption that the average pond depth is 1 m (e.g. Diana et al. 2004). A stocking density of 3 m^{-2} translates to 3 m^{-3}, implying that reducing average pond depth to 0.5 m effectively doubles the stocking density to 6 m^{-3}. Most of the ponds in Ghana are shallower than 1m at construction because they are constructed manually (Frimpong et al. 2014). Also, when pond desilting is not done regularly, pond depth reduces with time. In effect, lower pond volume and overcrowding

are common in the country, as well as relatively small individual harvest sizes (Frimpong et al. 2014).

Therefore, it is useful to allow the individual harvest weight of fish in an enterprise budget to be determined directly by feed type, and effective stocking density. Incorporating these considerations into an enterprise budget better informs the investment decisions of farmers, such as adopting or rejecting new technologies for fish production. This study sought to develop stochastic enterprise budgets to compare profitability of commercial fish feed to that of local fish feed, and the profitability of self-financing fish farming operations to that of taking a loan.

Methods

Data

Nile tilapia (*Oreochromis niloticus*) was cultured in ponds on five demonstration farms in central Ghana. These were already-existing fish farms, from which ponds were selected and set aside for use in this study. Stocking, feeding, and other management practices employed for the production of tilapia in these demonstrations were consistent with those used on typical tilapia farms in Ghana, but experimentally controlled. A main goal of these demonstrations was to obtain data on the effects of two best management practices (BMPs) – use of commercial, floating feed (as opposed to locally-made feed prepared on site from food wastes), and reused or 'green' water (as opposed to freshwater) – on the growth of Nile tilapia. Frimpong et al. (2014) present details on the experimental design and methods. The demonstrations also provided us with data on other production variables such as input costs.

Frimpong et al. (2014) concluded that of the two factors (feed type and water source) tested, only feed type significantly influenced growth, and so only budgets based on feed typed were

compared in this study. Without resulting in differences in growth, the only potential source of

economic benefits of water reuse is saving input cost. The vast majority of pond farmers in

Ghana obtain water at no direct cost from diverted streams or ground water seepage. Hence, cost

savings to the farmer therefore are not readily apparent.

Additionally, a comprehensive survey was administered over three years (2011 – 2013) to 363

fish farmers whose farms are located in the central and southwestern parts of Ghana, specifically

in the Ashanti, Brong-Ahafo, Central, Eastern, and Western regions. A number of questions

included in the survey addressed production variables, such as feed cost, labor cost, and fish

prices. We also drew on the experience of notable and experienced farmers for additional,

specific information on variables such as land cost. We converted nominal interest rates to real

interest rates using the Fisher equation (Crowder and Hoffman 1996). Data on the various

production and economic/financial variables were recorded and/or calculated and are

summarized in Appendix 4.1.

Price function

Analysis of tilapia price data from the administered survey, and a review of the literature on the

price of tilapia in Ghana, revealed a positive non-linear relationship between price and fish size

(weight). Different prices are quoted for different ranges of fish weights or weight classes, with

higher classes attracting higher prices in a step-wise manner (e.g., Cocker 2014). Growth and

price data from Cocker (2014) indicated a strong ($R^2 = 0.98$) logarithmic relationship between

wholesale price and size class. Therefore, the logarithmic price function used in the calculation

of price in the present study was:

$$price = 2.621 \ \ln(fish \ weight) - 11.798 \qquad\qquad (1)$$
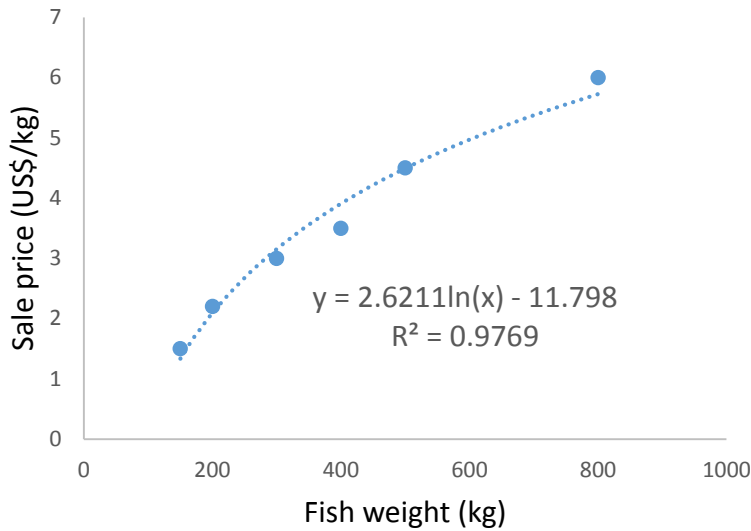
Figure 5.1. Relationship between tilapia weight and price in Ghana, plotted from Cocker (2014)

Harvest weight function

The greatest determinants of fish harvest weight are: feed type and pond depth (or volume). Feed type determines the amount and form of proteins and other nutrients needed for fish growth, while pond depth determines stocking density and freedom of vertical movement to escape hot surface temperatures or birds of prey. Hence, we applied a regression with harvest weight as the response variable, and with feed type (binary), and average pond depth as predictors. The resulting intercept and coefficients, along with their standard errors, were included as inputs in the stochastic enterprise budget and also in subsequent risk/sensitivity analysis (Table 5.1).

Table 5.1: Results of regression for Nile tilapia harvest weight (n=44, p-value=0.001)

Parameter	Coefficient	Standard Error	t-ratio	Prob>$|t|$
Intercept	205.25	31.56	1.96	0.06
Feed type (binary)	71.12	16.54	4.30	0.00
Average pond depth (m)	48.74	58.23	0.84	0.41

<u>Key definitions and computations</u>

An enterprise budget contains a number of key entries. The feed conversion ratio (FCR) indicates how efficiently feed is converted to body tissue or mass in farmed animals. A lower FCR value indicates a higher efficiency (Boyd et al. 2007). It is calculated as:

$$FCR = \frac{total\ feed\ used}{total\ weight\ gain} \qquad (2)$$

Total weight gain is the difference between total yield and total stocking weight. The total weight gain takes into account the survival rate of the tilapia. Gross receipts represent the total revenue accrued by a farm within a specified period. It is calculated as follows:

$$gross\ receipts = number\ of\ specified\ cycles * total\ yield\ per\ production\ cycle \qquad (3)$$
$$* unit\ sale\ price$$

Total costs are computed as:

$$total\ costs = total\ variable\ costs + fixed\ costs \qquad (4)$$

Net returns (NR) indicate profits, and it is calculated both over total variable costs (TVC) and over total fixed costs (TFC). It is economically feasible for a firm to continue production so long as net returns above total variable costs (NRtcv) are determined to be positive (Engle 2012). Net returns over TVC and TFC are calculated as follows:

$$NR\ over\ i_{1,2} = Gross\ receipts - i_{1,2} \qquad (5)$$

where i_1 = TVC and i_2= TFC.

Breakeven analysis allows the determination of both the minimum levels of price and yield to achieve profitability above either TVC or TC. Values of breakeven price and yield allow comparison of technologies, in which case a lower breakeven price or lower breakeven yield is more profitable (Engle and Neira 2005). While the breakeven price is computed for a specified

weight of produce, breakeven yield is computed for an existing price per unit weight of yield.

Breakeven price (BP) and yield (BY) over either TVC or TC is calculated as:

$$BP = \frac{TVC\ or\ TC}{total\ yield} \tag{6}$$

$$BY = \frac{TVC\ or\ TC}{price} \tag{7}$$

Risk / Sensitivity Analysis

We then developed enterprise budgets within a stochastic framework, using a risk/sensitivity analysis to determine influence of the full range of input variables on output variables in the enterprise budget. Static (or the average) values of these ranges resulted in the traditional, deterministic version. Four scenarios were investigated with the deterministic budgets: 1) Commercial feed + No loan, 2) commercial feed + loan, 3) sinking feed + no loan, and 4) sinking feed + loan.

A probability distribution was defined for each input variable in the risk/sensitivity analysis. We selected a triangular distribution for each input variable. A triangular distribution basically entails the specification of three values: the most likely value, the maximum possible value, and the minimum possible value (Wing Chau 1995). This approach allows assignment of probable values based on field trials, the literature, expert opinion and experience. For this analysis, we used calculated average values from results of the survey and demonstration data as the most likely values. Maximum and minimum values also were determined from the compiled data in Appendix 4.1 (Table 5.2).

We then ran Monte Carlo simulations in @Risk® 6 (Palisade Corporation, Ithaca, New York, USA). Each simulation was run for 5,000 iterations. Output variables were gross receipts, net

returns above both variable and total costs, breakeven price and yield (over both TVC and TC),

fish sale price, and FCR.

Table 5.2: Distributions of input variables used for Monte Carlo simulations

Variable	Minimum	Most likely	Maximum
Stocking density (#/sqm)	1	3	5
Average pond depth (m)	0.1	0.5	0.9
Fingerling weight (g)	2	5	10
Feeding rate (% body weight)	1	2	3
Real interest on operating capital (%)	1.5	8.5	15.5

Results

Deterministic enterprise budget analyses

Table 5.3. Summary of four enterprise budget scenarios (commercial feed, sinking feed, with loan, and without loan) for the production of Nile tilapia on a 0.6-ha farm in four 0.12-ha earthen ponds in Ghana for two production cycles (1 year). All items are in US$ unless otherwise noted.

| Item | No loan | | With loan[*] | |
	Floating feed	Sinking feed	Floating feed	Sinking feed
Harvest weight (g)	300	150	300	150
Price per kg	3.16	1.35	3.16	1.35
Yield (kg)	6,787	3,399	6,787	3,399
FCR (ratio)	1.65	3.34	1.65	3.34
Gross revenue	21,434	4,574	21,434	4,574
Total variable costs (VC)	17,591	5,831	18,565	6,078
Total fixed costs (FC)	129	129	226	226
Total costs (TC)	17,720	5,959	24,067	6,304
Total net returns				
above VC	3,843	-1,257	3,095	-1,504
above TC	3,714	-1,385	2,870	-1,730
Breakeven price/kg				
above VC	2.59	1.72	2.70	1.79
above TC	2.61	1.75	2.74	1.85
Breakeven yield (kg)				
above VC	5,570	4,333	5,807	4,517
above TC	5,611	4,428	5,879	4,685

[*] 50% of both fixed and variable costs borrowed, at a real interest rate of 8.5%.

Sale price for a kilogram of 300 g fish (average harvest weight with commercial feed over 5

months) was estimated at US$ 3.16, whereas price for a kilogram of 150g fish (average harvest

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weight with sinking feed over the same period) was estimated at US$ 1.35 (Table 5.3). Higher harvest weight resulted in the commercially-fed farm having an annual yield twice that of farms using sinking feed. Because of both superior productivity and sale price, the commercial feed farm ended the year with a gross revenue of US$ 21,400, compared to the sinking feed scenario, which grossed almost five times less. Additionally, the significantly more expensive commercial feed resulted in total costs which were over three times that of sinking feed farms.

Net returns over total costs showed that using commercial feed led to profits approximately four times that from using sinking feed. Financing 50% of variable and fixed costs at an average real interest rate of 8.5% reduced profitability for both feed types. Although taking a loan increased total costs on commercial feed farms by greater than US$ 6,000, using sinking feed with a loan increased costs by < US$ 500. An investigation into the impact of loans on farm profitability showed that taking a higher proportion of variable and fixed capital as a loan reduced profitability, whereas taking a lower proportion increased total costs by less.

Breakeven analysis showed profitability for only the floating feed scenarios, but not for the sinking feed scenarios (Table 5.3). A self-financed fish farm that used floating feed could still break even if current fish sale price or yield dropped by 17%, while taking a loan with floating feed will break even if the estimated sale price or yield dropped by 13%. On the contrary, both of the sinking feed scenarios required a significant increase in either fish sale price or yield to break even.

The four detailed enterprise budget scenarios (processed feed, sinking feed, both with loan, and without loan) are included in Appendices 4.2 – 4.5. Although commercial floating feed was the largest component of costs on commercial feed farms, feed and fingerling costs were equally

significant components on the sinking feed farms. Floating feed constituted between 74% and

77% of total costs on farms that used it, whereas sinking feed cost comprised between 31% and

33% of total costs on sinking feed farms. Also on sinking feed farms, fingerling cost constituted

between 42% and 44% of total costs, but just 14% - 15% on floating feed farms.

Stochastic enterprise budget analysis / uncertainty analysis

Table 5.4. Summary of the mean (and standard deviation) of four Monte Carlo simulation scenarios (commercial feed, sinking feed, with loan, and without loan) for the production of Nile tilapia on a 0.6-ha farm in four 0.12-ha earthen ponds in Ghana for two production cycles (1 year). All numbers are in US$ unless otherwise noted. N = 5,000 iterations.

Item	No loan		With loan[*]	
	Floating feed	Sinking feed	Floating feed	Sinking feed
Harvest weight (g)	301 (51)	151 (48)	301 (51)	151 (48)
Price per kg	3.1 (0.5)	1.2 (1.0)	3.1 (0.5)	1.2 (1.0)
Yield (kg)	6,934 (2,298)	3,465 (1,489)	6,938 (2,282)	3,465 (1,489)
FCR (ratio)	1.7 (0.3)	4.3 (4.7)	1.7 (0.3)	3.9 (30)
Total gross receipts	22,174 (9,457)	5,128 (4,716)	22,168 (9,272)	5,141 (4,716)
Total variable costs (VC)	17,965 (4,654)	5,941 (1,331)	18,731 (4,873)	6,215 (1,628.3)
Total costs (TC)	18,048 (4,654)	6,088 (1,331)	18,957 (4,875)	6,440 (1,398)
Total net returns				
above VC	4,209 (7,256)	-831 (4,502)	3,437 (7,086)	-1,073 (4,440)
above TC	4,080 (7,256)	-960 (4,502)	2,870 (7,088)	-1,299 (4,440)
Breakeven price				
above VC	2.7 (0.5)	2.0 (4.2)	2.8 (0.5)	2.2 (5.6)
above TC	2.7 (0.5)	2.1 (4.3)	2.8 (0.5)	2.2 (5.8)
Breakeven yield (kg)				
above VC	5,909 (1,889)	4,099 (114,282)	6,151 (1,946)	5,329 (95,277)
above TC	5,951 (1,893)	4,196 (117,088)	6,225 (1,954)	5,540 (97.930)

[*] 50% of both fixed and variable costs borrowed, at a real interest rate range of 1.5 – 15.5

Allowing the full range of possible values of key input variables resulted in standard deviation

about the mean for all output variables (Table 5.4). Stochastic analysis revealed generally more

profitable results relative to the results of the deterministic analysis in Table 5.3. However, the

trend in the profitability of scenarios from floating to sinking feed, and from self-financing to

taking a loan, was identical to the corresponding deterministic values: floating feed + no loan,

floating feed + loan, sinking feed + no loan, and sinking feed + loan.

Net return and breakeven analysis indicated that feeding with floating feed, both with and without a loan resulted in profitability. Breakeven analysis further showed that choosing sinking feed or a loan resulted in extremely high variability in the farm's profitability. For example, although the standard deviations of the mean of net revenue over total costs for both floating feed scenarios were less than a third of their respective means, the standard deviations for the sinking feed scenarios were >200 times that of their respective means.

Table 5.5. Probabilities of variable values exceeding deterministic values in Table 5.4. Net returns values in brackets indicate the probability of a positive value. N = 5,000 iterations.

Probability (%)	No loan facility		With loan facility[*]	
	Floating feed	Sinking feed	Floating feed	Sinking feed
Yield	49.8	48.4	49.4	47.8
Price per kg	49.1	49.3	49.3	49.1
Gross receipts	47.6	47.7	47.6	47.0
Total variable costs (TVC)	36.1	43.6	36.3	43.3
Total costs (TC)	35.9	43.3	36.2	43.4
Total net returns				
above TVC (NRtvc)[a]	61.5 [72.8]	52.6 [37.3]	63.4 [67.1]	53.5 [34.7]
above TC (NRtc)[b]	61.5 [72.0]	52.6 [36.1]	63.6 [65.6]	53.4 [33.1]
Breakeven price				
above TVC (BPtvc)	32.1	46.8	33.3	46.7
above TC (BPtc)	32.2	46.8	33.7	46.9
Breakeven yield				
above TVC (BYtvc)	38.7	36.4	38.8	39.1
above TC (BYtc)	38.7	18.1	38.9	35.1

[*] 50% of both fixed and variable costs borrowed, at a real interest rate range of 1.5 – 15.5
[a, b] Net returns values in brackets indicate the probability of obtaining a positive value (profit)

Analysis of the probability of real budget values exceeding their corresponding values on the deterministic budget showed almost a 50% probability across the board that values on the ground could be higher (Table 5.5). Probability of making a profit (net revenue over total costs greater than zero) was highest in the scenario with commercial feed and self-financing (72%). This scenario was followed by the commercial feed + loan (66%), sinking feed + no loan (36%), and sinking feed + loan (33%) scenarios (Table 5.5).

The Monte Carlo simulations allowed analysis of which input variables had the greatest impacts on key output variables. The largest determinants of FCR and mean profitability (net revenue above total cost) were feeding rate, average pond depth, and feed type.

Discussion

Yield, all costs, and breakeven yields in the stochastic analysis all had probabilities close to 50% of being higher than their corresponding deterministic values. A deterministic enterprise budget is just one scenario or iteration of many possible combinations of inputs and outputs on the ground, with numerous interacting effects. Using a stochastic framework allows determination of the probability of obtaining a particular benchmark, which is more useful for decision-making than results of calculations based on static 'average' conditions. Probability of obtaining that benchmark then may be obtained for any output variable of interest, based on the full range of data.

For example, we were interested in the likelihood of a farm making a profit. Hence, we set the benchmark for net returns over total costs (NRtc) at zero for each scenario. Generally, each scenario involving use of commercial feed had a probability of obtaining a profit, which was twice that of its corresponding sinking feed pairing. Also, chances of recording a profit was seen to drop slightly when a loan was acquired in any scenario. Using floating feed resulted in higher probabilities for profits, whereas using loans reduced the chances of making a profit.

Besides profitability of a new technology, another weight of evidence to forecast whether a farmer will adopt or reject that innovation is the level of uncertainty associated with its expected revenues. The standard deviation of the mean shows how accurately the mean can be predicted,

and so is an indicator of uncertainty. Standard deviation values from the commercial feed

scenarios generally equaled a smaller proportion of the mean compared to the sinking feed

scenarios, which were several times that of the mean in certain situations. The smallest standard

deviation in breakeven yield values were observed in the scenario with commercial feed with

self-financing. Thus, the outcome of this feed and loan combination was easier to predict with

more certainty compared to other scenarios. The wide margins of uncertainty in the other

scenarios with loans and sinking feed, coupled with their relatively lower probabilities of making

a profit, should convince existing farmers in these scenarios to switch over to the relatively

newer combination of commercial feed with no loans (Rogers 2003).

All analyses pointed to one result: the more-expensive, commercial feed type was found to be the

more profitable option when compared to sinking feed. The higher profitability results from the

relatively fast rate of fish growth resulting from the higher bioavailable protein content in

commercial feed (Bell and Waagbø 2008). Commercial aquafeed is prepared with a good

balance of macro and micronutrients needed by fish for growth (Bell and Waagbø 2008).

Although proximate analysis conducted on the feed in this study indicated an equal crude protein

content in both feed types (30%), commercial feed processing removes anti-nutritional factors

and makes commercial feed more palatable and utilizable to fish (Drew et al. 2007, Hardy 2010).

Commercial feed also is extruded and pelletized, allowing it to float on the pond water surface

for long periods and remain available to feeding fish.

The sinking feed type usually is prepared on site as a mixture of agricultural and food-industry

wastes, such as corn meal, wheat or rice bran, and peanut husk. The mixture then is milled into

powdery form, which quickly sinks to the pond bottom when administered. Fish growth is

hampered not only by the unavailable feed and nutrients, but sinking feed accumulates on the

pond bottom, where it decomposes to set off physico-chemical reactions that degrade the water quality of the pond (Frimpong *et al.*, 2014). Therefore, commercial feed is expected to result in faster growth, larger yields, and greater revenues.

Comparison of the scenarios with and without loans revealed that the high interest/lending rates in Ghana could have a negative impact on the profitability of the fish farming enterprise. Fish farmers in the country have complained of the lack of both startup and operational capital for their operations (Anane-Taabeah 2012). We are aware of a few banking agencies that provide loans to the agricultural sector, but the exorbitant terms, such as strict collateral and high interest rates, which is influenced by a high and unstable inflation rate, make these loans practically unavailable to farmers. Our results clearly show that the most profitable scenario involves self-financing.

By definition, an FCR of 2 implies that 2kg of feed resulted in fish weight gain of 1kg (Boyd and Polioudakis 2006), and a smaller value indicates a higher efficiency and less feed wasted (Boyd et al. 2007). Feed can be wasted either by a higher-than-optimum feeding rate and/or under-utilization of the feed in the gut of the fish. Both cases could lead to poor water quality, which retards fish growth. Using commercial feed led to lower FCRs compared to sinking feed, and stochastic analysis indicated potential for even lower FCRs in the commercial feed scenario. Any reductions in feed used will directly translate into decreased costs, since floating feed costs constituted about 70% of total costs on a commercial feed farm.

The decision to use commercial feed resulted in disproportionately large total costs, and any reductions in these costs will result in further increases in net returns. An effective and efficient way of improving profitability on a commercial feed farm is to target input variables that have

the greatest influence on key output variables through a sensitivity analysis. Focused effort then can be put into varying these influential input variables to improve the particular output variables of interest.

The variables with the largest impact on the output mean of FCR were feeding rate, pond depth, and feed type. Reducing amount of feed used, while maintaining the rate of growth was the most direct means of achieving a lower FCR. Most farmers strictly follow a feeding chart that specifies how much fish feed to administer every day, based on the average fish weight. In most cases, no consideration is given to factors such as changes in weather condition and water temperature, which influence feeding activity of fish and efficient utilization of feed. According to studies such as Bolivar et al. (2006), it is possible to maintain current growth rate with up to 50% of the feeding rate (alternate-day feeding) for floating feed. Primary production in earthen ponds also could serve as a significant supplement to reduce the amount of floating feed needed.

Approximately 80% of all tilapia earthen ponds in Ghana are hand-dug (Nunoo et al. 2012). One disadvantage of manual pond construction is relative shallowness, which results in low pond volumes. Effectively, stocking fingerlings according to the recommended number per unit surface area results in over-crowding. Experience from our demonstration experiments show that fish in shallower ponds were more susceptible to bird predation than those in deeper ponds (Ansah, Y.B. unpublished data). This finding implies that one way of increasing harvest sizes and yield of tilapia in Ghana is to increase the depth of already-existing ponds, and ensuring that new ponds are constructed with increased depth.

Mean net returns above total cost (profitability) were most sensitive to the same variables that had the greatest impact on FCR above: mean pond depth and feeding rate. This observation

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shows the direct impact on profitability of increasing tilapia harvest weight and using commercial feed more efficiently. These can be achieved by improving factors that increase harvest weight (such as water quality and fingerling genetic quality), making ponds deeper, and reducing the amount of feed administered, without compromising on the rate of growth.

Levels of water quality parameters, such as dissolved oxygen and ammonia, have been correlated with rate of fish growth (Frimpong et al. 2014). Therefore, effective water quality management will create a pond environment conducive towards increasing harvest sizes. Inferior genetic quality of tilapia fingerlings on the African continent has been the subject of a number of studies (e.g. Ponzoni et al. 2011, Ansah et al. 2014). Ghana has developed a higher-performing tilapia strain, the Akosombo strain, which is utilized mostly by the more intensive cage farms on the Volta Lake (Ansah et al. 2014). Most pond farmers persist in their use of lower-quality fingerlings sourced either from the wild or from small founder stocks (Ponzoni et al. 2011, Ansah et al. 2014). Our other experiments associated with this study showed that using either all-male fingerlings or a predator to check reproduction has the potential to increase the harvest weights of fish. Both alternatives reduce or prevent the precocious breeding common in the species, thus preventing overcrowding and other behavioral changes associated with breeding that reduce feeding activity (Frimpong et al. 2014).

Conclusions

Although the more expensive floating feed had significantly higher cost implications, net returns, breakeven price and breakeven yield, along with their individual probabilities for profits all showed that floating feed was superior to sinking feed in terms of profitability. The analyses also revealed that whether a farmer took a loan or self-financed also had a large bearing on

probability of profitability. The most profitable scenario, therefore, is a self-financed farm, which relied on commercial fish feed.

To improve profitability of tilapia farming in Ghana, use commercial fish feed is encouraged. However, efforts are needed to check the costs involved in switching from sinking feed. Effective water quality management, improvements in fingerling quality, and increasing pond depths will result in larger harvest sizes, which implies increased gross revenue. Future research could determine the most effective method of lowering feeding rate, without decreasing current growth rates. Reuse of pond water after harvesting, along with appropriate fertilization rates and schedules, could contribute significantly to the lowering of the total amount of commercial feed needed for each production cycle. Also, the utility of fish feeds with lower protein concentrations or less costly sources of protein are possibilities for increasing profitability. The resulting lower feed cost will encourage diffusion of commercial feed by tilapia farmers, and also make self-financing of farms more likely.

Additionally, considering the high probability of profitability with the commercial feed type, financial institutions in Ghana could advance 'feed loans' to fish farmers at reasonable interest rates. Our analysis shows that these farmers could then achieve increased profitability and then be able to repay loans.

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Appendix 5.1. Summary of input data for enterprise budget calculations for a tilapia farm in Ghana

Production Characteristic	Unit	Value	Info Source, notes
Stocking density	Tilapia/m^2	3.00	Demonstration data
Initial weight of tilapia stocked	g	5.00	Demonstration data
Tilapia fingerling cost	US$	0.0005*FingWt^2+0.0101*FindWt+0.29	Demonstration data
Survival	%	2.449*FIngWt+66.122	Demonstration data
Cycle length	days	160.00	Demonstration data
Year	days	365.00	
Tilapia sale price	US$/kg	2.621*ln(HarvestWt) – 11.798	Equation from sale price
FCR (commercial feed)	ratio	2.06	Total feed/total weight gain
FCR (Sinking feed)	ratio	4.18	Total feed/total weight gain
Feed cost (commercial)	US$/kg	1.25	40GHC/20kg bag
Feed cost (Local)	US$/kg	0.18	13GHC/50kg bag
Feeding rate (average)	% body weight	2.50	5% - 1.4% adjusted biweekly
1 U.S. Dollar	Cedis (GHC)	3.80	3/3/2014 rate
Specific growth rate (commercial)	g/day	1.97	Weight gain/cycle length
Specific growth rate (sinking feed)	g/day	1.50	Weight gain/cycle length
Individual harvest weight (commercial)	g	300.00	Demonstration data/logistic modelling
Individual harvest weight (local)	g	150.00	Demonstration data/logistic modelling
Interest on operating capital (average)	%	25.00	Ghana bank rates 18% - 32%
Annual inflation rate (September 2014)	%	16.5	Ghana Statistical Service (statsghana.gov.gh)
Annual depreciation on equipment	years	10.00	Engle and Neira (2005)
Annual depreciation on ponds	years	20.00	Engle and Neira (2005)
Terms of loans for equipment and ponds	years	10.00	Engle and Neira (2005)
Investment cost of			
Machinery and equipment	US$	289.47	Directed queries
Ponds	US$	1,994.46	Directed queries; GHC5/sqm

Total farm area	ha	0.60	Survey; 4 ponds + extra land (size of one pond)
Area of individual ponds	ha	0.12	Survey average
Cost to build ponds	US$/ha	15,789.47	Directed queries; GHC 6/sqm
Land			Directed queries
Cost	US$/ha	2,601.05	
Cost for quantity	US$	1,560.63	
Number of ponds	#	4.00	Survey average
Labor			Directed queries/calculation
Permanent			
Cost	US$/person/month	39.47	
Number needed	#/4 ponds	2.00	
Temporary			
Cost	US$/person day	2.63	
Quantity	person days/ cycle	16.00	
Month	days	30.00	
Batch cycle length	months	5.00	
Average pond depth	m	0.50	
Urea			Directed queries/calculation
Cost	US$/kg	0.26	
Quantity	Kg/ha	30.00	
Monoammonium phosphate			Directed queries/calculation
Cost	US$/kg	1.58	
Quantity	Kg/ha	20.00	
Chicken manure			Directed queries/calculation
Cost	US$/kg	0.04	
Quantity	Kg/ha	50.00	
Agricultural lime			
Cost	US$/kg	0.21	Directed queries/calculation
Quantity	Kg/ha	634.00	Yusoff and McNabb (1989)/calculation

Appendix 5.2. Deterministic Enterprise Budgets (No loans taken)

Deterministic enterprise budget for a 0.60 ha fish farm in Ghana that is self-financed, with four 0.12 earth ponds, fed with commercial floating feed for two production cycles (one year), and with an average fish harvest weight of 300g

Item	Description	Unit	Quantity	Price/Unit	Total
Gross receipts					
Tilapia	Live	kg	6,787.38	3.16	21,434.45
Total gross receipts		US$			21,434.45
Variable costs					
Tilapia fingerlings	Hatchery-raised, all-male	Individuals	28,800.00	0.09	2,652.63
Fish feed (floating)	30% crude protein	kg	10,991.44	1.25	13,739.30
Fish feed (sinking)	30% crude protein	kg	10,991.44	0.18	1,978.46
Fertilizer	Urea	kg	28.80	0.26	7.58
	Monoammonium phosphate	kg	19.20	1.58	30.32
	Chicken manure	kg	48.00	0.04	1.89
Agriculture lime	Lime	kg	608.64	0.21	128.13
Permanent labor: security, stock, feed, fertilize, harvest		US$	24.00	39.47	947.37
Temporary labor: weed, harvest, levee repair, etc		US$	32.00	2.63	84.21
Interest on operating capital		US$	-	0.09	-
Total Variable Cost (TVC)		US$			17,591.44
Net returns above TVC		US$			3,843.01
Fixed Costs		US$			
Depreciation	Straight-line depreciation				
Equipment	10 years	US$			28.95
Ponds	20 years	US$			99.72
Interest on investment	8.5%; Equipment & Ponds	US$			-
Total Fixed Costs (TFC)		US$			128.67
Total Costs (TC)		US$			17,720.11
Net returns above TC		US$			3,714.34
Net returns/farm		US$/farm			3,714.34
Breakeven price per kg sold					
Above TVC	TVC/quantity	US$/kg			2.59
Above TC	TC/quantity	US$/kg			2.61
Breakeven yield at GHC/kg					
Above TVC	TVC/price	kg/farm/yr			5,570.46

| Above TC | TVC/price | kg/farm/yr | 5,611.21 |

Deterministic enterprise budget for a 0.60 ha fish farm in Ghana that is self-financed, with four 0.12 earth ponds, fed with 'local' feed for two production cycles (one year), and with an average harvest weight of 150g

Item	Description	Unit	Quantity	Price/Unit	Total
Gross receipts					
Tilapia	Live	kg	3,399.29	1.35	4,573.96
Total gross receipts		US$			4,573.96
Variable costs					
Tilapia fingerlings	Hatchery-raised, all-male	Individuals	28,800.00	0.09	2,652.63
Fish feed (floating)	30% crude protein	kg	10,991.44	1.25	13,739.30
Fish feed (sinking)	30% crude protein	kg	10,991.44	0.18	1,978.46
Fertilizer	Urea	kg	28.80	0.26	7.58
	Monoammonium phosphate	kg	19.20	1.58	30.32
	Chicken manure	kg	48.00	0.04	1.89
Agriculture lime	Lime	kg	608.64	0.21	128.13
Permanent labor: security, stock, feed, fertilize, harvest		US$	24.00	39.47	947.37
Temporary labor: weed, harvest, levee repair, etc		US$	32.00	2.63	84.21
Interest on operating capital		US$	-	0.09	-
Total Variable Cost (TVC)		US$			5,830.59
Net returns above TVC		US$			(1,256.63)
Fixed Costs		US$			
Depreciation	Straight-line depreciation				
Equipment	10 years	US$			28.95
Ponds	20 years	US$			99.72
Interest on investment	8.5%; Equipment & Ponds	US$			-
Total Fixed Costs (TFC)		US$			128.67
Total Costs (TC)		US$			5,959.26
Net returns above TC		US$			(1,385.30)
Net returns/farm		US$/farm			(1,385.30)
Breakeven price per kg sold					
Above TVC	TVC/quantity	US$/kg			1.72
Above TC	TC/quantity	US$/kg			1.75
Breakeven yield at GHC/kg					
Above TVC	TVC/price	kg/farm/yr			4,333.20
Above TC	TVC/price	kg/farm/yr			4,428.82

Appendix 5.3. Deterministic Enterprise Budgets (50% of capital borrowed)
Deterministic enterprise budget for a 0.60 ha fish farm in Ghana, with four 0.12 earth ponds, fed with commercial feed for two production cycles (one year), with an average fish harvest weight of 300g, and with 50% of capital borrowed

Item	Description	Unit	Quantity	Price/Unit	Total
Gross receipts					
Tilapia	Live	kg	6,787.38	3.16	21,434.45
Total gross receipts		US$			21,434.45
Variable costs					
Tilapia fingerlings	Hatchery-raised, all-male	Individuals	28,800.00	0.09	2,652.63
Fish feed (floating)	30% crude protein	kg	10,991.44	1.25	13,739.30
Fish feed (sinking)	30% crude protein	kg	10,991.44	0.18	1,978.46
Fertilizer	Urea	kg	28.80	0.26	7.58
	Monoammonium phosphate	kg	19.20	1.58	30.32
	Chicken manure	kg	48.00	0.04	1.89
Agriculture lime	Lime	kg	608.64	0.21	128.13
Permanent labor: security, stock, feed, fertilize, harvest		US$	24.00	39.47	947.37
Temporary labor: weed, harvest, levee repair, etc		US$	32.00	2.63	84.21
Interest on operating capital		US$	8,795.72	0.09	747.64
Total Variable Cost (TVC)		US$			18,339.07
Net returns above TVC		US$			3,095.38
Fixed Costs		US$			
Depreciation	Straight-line depreciation				
Equipment	10 years	US$			28.95
Ponds	20 years	US$			99.72
Interest on investment	8.5%; Equipment & Ponds	US$			97.07
Total Fixed Costs (TFC)		US$			225.74
Total Costs (TC)		US$			18,564.81
Net returns above TC		US$			2,869.64
Net returns/farm		US$/farm			2,869.64
Breakeven price per kg sold					
Above TVC	TVC/quantity	US$/kg			2.70
Above TC	TC/quantity	US$/kg			2.74
Breakeven yield at GHC/kg					
Above TVC	TVC/price	kg/farm/yr			5,807.21
Above TC	TVC/price	kg/farm/yr			5,878.69

Deterministic enterprise budget for a 0.60 ha fish farm in Ghana, with four 0.12 earth ponds, fed with 'local' feed for two production cycles (one year), with an average harvest weight of 150g, and with 50% of capital borrowed

Item	Description	Unit	Quantity	Price/Unit	Total
Gross receipts					
Tilapia	Live	kg	3,399.29	1.35	4,573.96
Total gross receipts		US$			4,573.96
Variable costs					
Tilapia fingerlings	Hatchery-raised, all-male	Individuals	28,800.00	0.09	2,652.63
Fish feed (floating)	30% crude protein	kg	10,991.44	1.25	13,739.30
Fish feed (sinking)	30% crude protein	kg	10,991.44	0.18	1,978.46
Fertilizer	Urea	kg	28.80	0.26	7.58
	Monoammonium phosphate	kg	19.20	1.58	30.32
	Chicken manure	kg	48.00	0.04	1.89
Agriculture lime	Lime	kg	608.64	0.21	128.13
Permanent labor: security, stock, feed, fertilize, harvest		US$	24.00	39.47	947.37
Temporary labor: weed, harvest, levee repair, etc		US$	32.00	2.63	84.21
Interest on operating capital		US$	2,915.30	0.09	247.80
Total Variable Cost (TVC)		US$			6,078.39
Net returns above TVC		US$			(1,504.43)
Fixed Costs		US$			
Depreciation	Straight-line depreciation				
Equipment	10 years	US$			28.95
Ponds	20 years	US$			99.72
Interest on investment	8.5%; Equipment & Ponds	US$			97.07
Total Fixed Costs (TFC)		US$			225.74
Total Costs (TC)		US$			6,304.13
Net returns above TC		US$			(1,730.17)
Net returns/farm		US$/farm			(1,730.17)
Breakeven price per kg sold					
Above TVC	TVC/quantity	US$/kg			1.79
Above TC	TC/quantity	US$/kg			1.85
Breakeven yield at GHC/kg					
Above TVC	TVC/price	kg/farm/yr			4,517.36
Above TC	TVC/price	kg/farm/yr			4,685.12

Chapter 6: Impacts of the adoption of BMPs on social welfare: a case study of commercial floating feeds for pond culture of tilapia in Ghana

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Abstract

Best management practices (BMPs) are the most cost-effective means of mitigating negative impacts of pond aquaculture on the environment. A number of studies have determined the impacts of BMPs and other innovations on fish farm profits. This study goes beyond the individual farm, to estimate impacts of BMP adoption on social welfare. We employed the Economic-Surplus model to determine net present value (NPV) of adopting the more-expensive, but less-polluting commercial floating fish feed in the pond culture of Nile tilapia (*Oreochromis niloticus*) in Ghana. We also conducted a sensitivity analysis to determine which variables had the greatest influence on mean NPV. Our results indicate an NPV of US$11 million from the adoption of commercial floating feed in pond farming alone in Ghana. The variables with the biggest impacts on NPV were level of change in tilapia yield, and level of change in production costs, with the adoption of the new feed type. We conclude that adoption of yield-enhancing

BMPs and innovations in Ghana will result in significant social welfare benefits. Considering the high marginal benefits of investments in floating feed, we recommend that credit programs and other financial packages be set up by governments or non-governmental organizations (NGOs) to help farmers meet the increased cost of fish feed and to accelerate diffusion of commercial fish feed in pond farming.

Keywords

Economic-surplus; Monte Carlo Simulation; Net present value; Aquaculture

Introduction

Ghana is classified by the World Bank (2014) as a 'lower middle income' country, with an economy largely dependent on agriculture. The agricultural sector contributes 23% of the country's gross domestic product (GDP) annually, whereas 42% of the population was employed in the agricultural sector in 2013 (World Bank, 2014). Ghana's 2.3% annual population growth rate (World Bank, 2014) requires a sustained increase in food production. The country has increased food production per capita by more than 80% since the early 1980s, and is largely self-sufficient in staple crops such as maize, cassava, plantain, and yam (Overseas Development Institute, 2011). The Overseas Development Institute (2011) forecasts that Ghana will meet the United Nation (UN)'s Millennium Development Goal (MDG) 1 of eradicating extreme poverty and hunger by 2015. However, it is important to go beyond meeting this goal of 'food quantity' to target 'food quality', both of which are components of food security (Food and Agriculture Organization, 1996).

The World Food Summit was hosted by the UN's Food and Agriculture Organization (FAO) in 1996 to discuss ways to end hunger. The summit resulted in the Rome Declaration on World Food Security. By this declaration, member countries reaffirmed "the right of everyone to have

access to safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger" (Food and Agriculture Organization, 1996). Fish is recognized as an inexpensive and effective source of protein (Dey *et al.*, 2011). This importance of fish, coupled with declining production from wild fisheries stocks (Subasinghe *et al.*, 2009), has led to efforts by development agencies to encourage fish farming worldwide. Aquaculture, especially of tilapias, has the potential to play a leading role in the fight against food insecurity, malnutrition, and poverty in Africa (Béné and Heck, 2005).

Ghana is one of the countries in the sub-Saharan Africa region with the potential to dramatically increase its fish production through aquaculture. This is the result of a high fish demand, and the combination of a stabe political environment and its commissioning of the only commercial fish feed mill in West Africa (Ainoo-Ansah, 2013; Frimpong *et al.*, 2014). The country derives a majority of its dietary protein from fish (Brashares *et al.*, 2004), with an estimated per capita fish consumption of 20 – 30 kg per annum in 2009 (Food and Agriculture Organization, 2012). This is higher than the global estimate of about 18 kg (Food and Agriculture Organization, 2012).

However, the global aquaculture industry has been blamed widely for its negative impacts on natural aquatic ecosystems (Burridge *et al.*, 2010; Klinger and Naylor, 2012). There have been several studies on the negative impacts of fish farming. These include: escapes of both genetically-altered and unaltered farmed fish into the wild with both ecological and genetic consequences; chemical pollution from pesticides and prescribed drugs, antifoulants, anesthetics and disinfectants; and eutrophication from nitrogenous and phosphoric compounds in fish feed and pond fertilizer (Burridge *et al.*, 2010; Klinger and Naylor, 2012; Ansah *et al.*, 2013).

Therefore, it is imperative that adoption of innovations to mitigate these negative impacts be encouraged as aquaculture production is increased to meet social and economic goals.

Aquaculture environmental best management practices (BMPs) are widely believed to be the most feasible means to reduce the negative impacts of pond fish farming on the environment. This is because pond effluents are relatively dilute, and as such not amenable to conventional treatment technologies. Aquaculture management practices affect the volume of water, nutrient, solids, and oxygen-demand loading rates from ponds to effluent-receiving waterbodies (Tucker *et al.*, 1996; Louisiana State University AgCenter, 2003). Generally, these practices are grouped into nutrient management and effluent management. Frimpong *et al.* (2014) showed the effect of two BMPs on the growth of Nile tilapia (*Oreochromis niloticus*) and their effectiveness at preventing the transport of nutrients and solids from fish ponds to waterbodies in Ghana. Specifically, these two BMPs were the use of commercial floating feeds and pond water reuse. That study showed that reused pond water resulted in the same growth rates as the usual practice of draining and refilling pond with new water before stocking. This result was in contrast to the widely-held belief among Ghanaian pond fish farmers that reusing water from a previous cycle could harm cultured fish.

Two main types of fish feed are used by fish farmers in Ghana. The recommended commercial feed type is pelleted, smooth and mostly floating, unlike the farm-made type, which is coarse, powdery and sinking (Awity, 2013). Frimpong *et al.* (2014) showed that the commercial floating feed type resulted in up to a 100% increase in fish growth compared to the farm-made sinking feed. Analysis of revenues and costs on a typical tilapia farm in Ghana also indicated that using commercial floating feed resulted in a higher probability of profitability (45%) than using the farm-made alternative (25%) (Chapter 5).

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Demonstrating profitability of better management practices will encourage their adoption by fish farmers, which will both protect the environment and further increase farm profits. Widespread adoption of profitable innovations is expected to have an impact not only at the farm household level, but also the welfare of the society as a whole, including both producers and consumers. Positive outcomes of adopting BMPs such as commercial floating feeds include achievement of an 'environmentally-friendly' image by the aquaculture industry, increased tilapia production, and lower fish costs in the country (Klinger and Naylor, 2012; Ansah *et al.,* 2013). This study sought to quantify the economic impact of the adoption of floating feeds in pond culture of tilapia in Ghana on social welfare. Specifically, we were interested in the net present value (NPV) of BMP adoption. Also, it was of interest to determine factors greatest influence on NPV from adoption of the BMP.

Generally, according to economic theory, an innovation (a new technology) shifts the supply function for a commodity downwards, resulting in a larger equilibrium quantity at a lower price (Masters *et al.*, 1996). This development may have a significant bearing on the level of poverty or welfare of a particular community where a new agricultural technology is diffused. The conventional framework for applied welfare economics is provided by a three-part assumption (Harberger, 1971): the demander's perceived value of a unit of a good or service is indicated by the competitive demand price of that unit; the supplier's perceived value of a unit of a good or service is indicated by the competitive supply price of that unit; and the net benefits and costs of a given action to a group of people is the total of the benefits and costs to each member.

We employed the economic surplus method, which is the most common method for analyzing the welfare impacts of agricultural research in a partial equilibrium framework according to Masters *et al.* (1996) and (Alston *et al.* (1998). The popularity of this method stems

from the fact that it requires the least data, can be applied to the broadest ranges of situations, is easy to grasp, and can be used both *ex ante* and *ex post* (Masters *et al.*, 1996; Alston *et al.*, 1998).

The economic surplus approach uses the concepts of *supply*, *demand* and *equilibrium* to turn agronomic data into economic values. While *supply* represents producers' production costs, *demand* represents consumption by consumers. These two forces interact to produce the so-called *equilibrium* quantity and price. Economic welfare depends on the equilibrium price and quantity and also on the producers' production costs and consumers' consumption values. Equilibrium price and quantity may be observed directly in the market, but the production costs of producers and the consumption values of consumers must be imputed from their actions (Masters *et al.*, 1996).

Economic surplus is the monetary value of production and consumption – the money value that consumers would have paid for each consumed unit, less the monetary value that producers would have paid for each produced unit, up to the actual market price and quantity (Masters *et al.*, 1996). Generally, the economic surplus approximates the social value of a given production and consumption level. This is the area bounded by the supply and demand curves and the equilibrium quantity. The difference between the situation with or without a new technology can be evaluated with the economic surplus model, as a single measure (Alston *et al.*, 1998). Any change in economic surplus with the adoption of a new technology is a measure of the social benefits derived from that innovation. Therefore, using the economic surplus method, the impact of the innovation on social welfare can be determined *ex ante*.

The most essential determinant of the impact assessment results is the magnitude in the shift of the supply curve with the new technology (Masters *et al.*, 1996). This magnitude is measured in terms of money per unit of output. For a given cost of inputs, increased production is

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represented by a horizontal shift of the supply curve. However, the adoption of an innovation may require some investment in new inputs. For a given level of output, this increased cost is referred to as *adoption costs*, and it represents a vertical shift in the supply curve. In order to obtain a net shift in terms of costs per unit of output it is necessary to pool data on both changing quantities and changing input costs.

Methods/Data Analysis

Model

Using the economic surplus model, we estimated the potential benefits of switching from farm-made sinking fish feed to commercial floating feed in pond-based tilapia farming in Ghana. The economic surplus model has been used to study the benefits of a number of new technologies in different countries, e.g., marker-assisted rice breeding in southeast Asia (Alpuerto *et al.*, 2009), and cassava breeding in sub-Saharan Africa (Rudi *et al.*, 2010). The economic surplus model is laid out as follows, according to Masters *et al.*, (1996) and Alston *et al.*, (1998). The total economic benefits from the adoption of a new technology for a non-traded commodity (or commodity from a "small-country producer") is estimated by the formula:

$$\Delta TS = PQK (1 + 0.5Zn), \tag{1}$$

where **P** and **Q** are the initial equilibrium price and quantity, respectively; $\mathbf{Z} = Ke/(e + n)$ is the relative reduction in price due to the supply shift resulting from the new technology; **e** is supply elasticity, and **n** is demand elasticity (absolute value), which reflect how responsive the quantity supplied and quantity demanded are to changes in prices, respectively; and **K** is the shift in the supply curve as a proportion of the initial price. **K** is calculated as:

$$K = \left(\frac{E(Y)}{\varepsilon}\right) - \left(\frac{E(C)}{1 + E(Y)}\right) p \, A \, (1\text{-}d), \tag{2}$$

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where **E(Y)** is the expected proportional yield increase per hectare after the adoption of the new technology; **E(C)** is the expected proportional change in variable input cost per hectare; **p** is the probability of success associated with the technology or innovation; **A** is the adoption rate for the technology; and **d** is the depreciation rate of the new technology (Alston *et al.*, 1998). The rate of depreciation of an innovation indicates the reduction in its value from the impact of the development of superior technologies and the decline in its *appropriability* with diffusion and time (Park *et al.*, 2006).

'Economic benefits' is the change in total economic surplus for each year, and the costs are the expenditures on the research plus estimated after-project costs related to developing and disseminating the new innovation. The annual costs and benefits are netted and totaled using the social discount rate to calculate a net present value (NPV) using the standard NPV formula:

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t} \qquad (3)$$

where: **R_t** is the benefits in year **t**; **C_t** is research, development, and dissemination cost in year **t**; and **i** is the discount rate. In other words, the NPV is calculated as the sum of future benefits, minus the costs associated with the project discounted over time.

Data and Key Assumptions

To effectively run the economic surplus model, both physical and market data must be collected on the following: (1) the proportion of farmers who adopt the innovation over time; (2) the price of the commodity; (3) the change in yield of the commodity with the new technology; (4) the nature of the market, as products that are traded may not experience price declines if production increases (Alston *et al.*, 1998; Dey, 2000); (5) the time it takes to develop the

innovation, and the number of years for maximum adoption to be reached; and (6) the discount rate for future benefits compared to current benefits.

We raised Nile tilapia (*Oreochromis niloticus*) on five demonstration earthen-pond farms in central Ghana. Stocking, feeding, and other management practices employed for the production of tilapia on these demonstrations were consistent with those used on typical tilapia farms in Ghana. These demonstrations provided both physical data on the effects of two BMPs on the growth of Nile tilapia (see Frimpong *et al.* 2014) and budgeting data for profitability analysis. The two BMPs were use of commercial, floating feed (as opposed to farm-made feed prepared on site from food and agro-industrial wastes), and reused water (as opposed to draining and refiling ponds with new water before each production cycle). Frimpong *et al.* (2014) concluded that of the two BMPs, only feed type significantly influenced fish growth and yield. Using floating feed resulted in average yields 100% higher than using sinking feed. Since there was no significant difference in fish growth with water type (reused or fresh water), we analyzed only the welfare impacts of the adoption of floating feed as a new technology. Reusing pond water for multiple production cycles is clearly environmentally beneficial. However, we did not detect any significant differences in fish yields or farm costs from this BMP. The quantification the environmental impacts of reusing pond water is the subject of a separate study (Chapter 7). Without resulting in differences in growth, the only potential source of economic benefits of water reuse is saving input cost from refilling emptied ponds. The vast majority of pond farmers in Ghana obtain water at no direct cost from diverted streams or groundwater seepage. Cost savings to the farmer are therefore not readily apparent.

The unit cost of the recommended feed type is almost eight times that of the farm-made alternative, and the cost of fish feed makes up over 50% of total costs on a typical fish farm (De

Silva and Anderson, 1995). The implication is that the adoption of the new feed technology will result in a 350% increase in total annual farm costs.

The rate of adoption of each BMP was tracked over three years though a comprehensive survey that was administered from 2011 to 2013, to 363 fish farmers in Ghana. Respondents came from the central and southwestern parts of Ghana, specifically in the Ashanti, Brong-Ahafo, Central, Eastern, and Western Regions. Pond farms in Ghana are located mostly within these regions, due to conducive biophysical factors (Kapetsky *et al.*, 1991). Average adoption rates over this period were 58.2% for commercial floating feed and 27.4% for pond-water reuse (Chapter 4). It is worth noting that most farmers who claim to use the former technology presently do not use it exclusively, but the trial of the technology is an indication of their desire to fully adopt it if it proves superior and affordable (Awity, 2013). We assumed 70% as the maximum adoption rate, which is a realistic figure for an aquaculture innovation (e.g. Dey *et al.* 2000).

Aquaculture production in Ghana occurs in two main systems – floating cages in the Volta Lake and dug-out earthen ponds. Floating cage systems are intensive operations that rely solely on commercial floating feed through the production cycle, and these systems account for about 90% of the country's aquaculture production (Ainoo-Ansah, 2013; Awity, 2013). Total production from cages alone was 24,250 metric tons (mt) in 2013. Current BMP dissemination efforts are targeted at the less-intensive earthen-pond systems that rely more on the farm-made, sinking feed type. Effectively, the adoption of the new feed technology will likely impact the production from earthen ponds, since the innovation is already being used in the cage systems. Analysis of data from Ainoo-Ansah (20130, Awity (2013), and Food and Agriculture Organization (2013) allowed separation of the estimated Nile tilapia production from the total

aquaculture production for 2013 in Ghana to be 1,500 mt. We calculated the price per ton of production as $2,646 by dividing FAO's 2011 estimate of the value of tilapia production ($48,159,000) by the annual production that year (18,200 mt, Food and Agriculture Organization, 2013).

A supply elasticity of 0.5 usually is applied to economics of production of perennial crops and other livestock, and demand elasticity of 1 can be used for most livestock production (Alston *et al.*, 1998). Since the floating feed technology exists already, the probability of success of research was assumed to be 100%. Analysis of our demonstration farm data indicated that feed conversion ratios (FCRs) and costs (by extension) in our demonstration ponds and in Ghana were higher than optimum for tilapia culture (Frimpong *et al.*, 2014). Possible ways to reduce FCRs and costs is to reduce the crude protein content in the feed to 25% and to reduce the amount of feed used for production. There is, therefore, the need for continuous studies in order to improve and optimize the use of the technology. To achieve this goal, we estimated average annual research and development (R&D) costs at $30,000 (plus sensitivity analysis). Also, an effective and sustained dissemination campaign needs to be organized, to enable a rapid diffusion of the commercial floating feed technology.

Survey respondents were asked to rank which dissemination method was the most influential in their adoption of either BMP. For both BMPs, mean rankings indicated that the most effective method was workshops (central media), followed by demonstration farms, and farmer-to-farmer (lateral) dissemination' in that order. These were the three dissemination methods that AquaFish CRSP used to diffuse BMPs in Ghana as part of this project. On average, annual expenditure to organize a workshop was US$25,000, so we included this as the average annual recurrent dissemination cost for this analysis. We also assumed that the dissemination campaign will be

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sustained throughout the simulation period, commencing in 2014, to both accelerate and maintain adoption. With this sustained effort to promote diffusion we assumed 10 years (from 2014) for the maximum adoption rate to be reached. Hence, total annual recurrent costs for R&D and dissemination was estimated at US$55,000.

Historically, different values of the social discount rate (SDR) have been given in the literature to represent the most appropriate present value of future investments (e.g. Lind, 1990). For the NPV analysis, we used an average discount rate of 5% (according to Moore *et al.* (2013), with a range of 2.5% – 10% in the sensitivity analysis. This range captures most of the figures quoted for the SDR in the literature (e.g. Caplin and Leahy (2000) and Moore *et al.* (2013)).

Analysis

We included the data and assumptions above in an Excel spreadsheet that incorporates all the model formulas obtained from George Norton at Virginia Polytechnic Institute and State University. We added a possible minimum and a possible maximum value to the average values based on the information in the preceding section to create a triangular distribution for each variable. In order to incorporate uncertainty distributions were constructed to include the likely full range of variables (Table 6.1). We ran the model to calculate the net present values (NPVs) of the annual economic benefits of the commercial floating feed technology for 20 years in Microsoft Excel. The total net present value (NPV) then was calculated as the sum of these annual benefits. We then conducted economic risk analysis by running Monte Carlo simulations using the @Risk 6 software (Palisade Corporation, Ithaca-NY, USA) for 5,000 iterations. We also conducted sensitivity analysis to determine the influence of key variables (Table 6.1) on the average NPV.

Table 6.1. Triangular distributions of key variables used in the Monte Carlo simulation to estimate net present value of adopting commercial floating fish feed in Ghana.

Variable	Minimum	Most likely	Maximum
Recurrent costs ($)	40,000	55,000	70,000
Increase in production costs (%)	150	350	500
2013 Nile tilapia pond production (metric tons)	1,000	1,500	2,000
Peak adoption rate (%)	60	70	80
Yield change (%)	50	100	150
Discount rate	2.5	5	10

Results

The estimated average net present value (NPV) of adopting commercial floating tilapia feed for tilapia farming in earthen ponds in Ghana over twenty years was almost US$11 million (Figure 6.1). The probability that the NPV is a positive value was about 70% (Figure 6.2). Additionally, there was a probability of about 48% that the NPV is greater than the estimated mean value of 11 million (Figure 6.2). Sensitivity analysis showed that the variables (and direction of correlation) with the greatest impacts on mean NPV were the change in yield of tilapia (+) and the change in production costs (-), resulting from the adoption of commercial floating fish feed (Figure 6.3). To a less significant extent, mean NPV also was sensitive to the 2013 tilapia earthen-pond production level (+), the chosen discount rate (-), the level of peak adoption rate (+) and the specific amount of recurrent costs (+), in that order. A plus sign indicates that increasing that variable will increase NPV, while decreasing a variable with a minus sign will increase NPV.
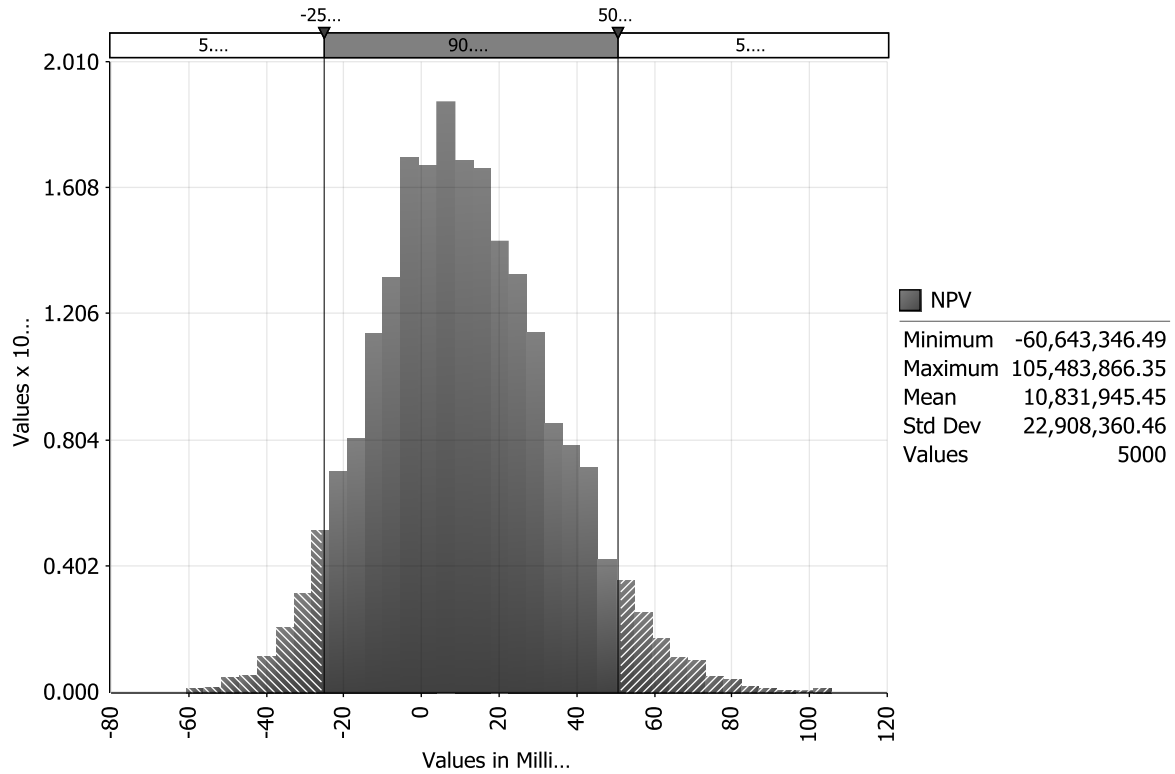
Figure 6.1. Summary of results of Monte Carlo simulation to determine net present value (NPV) in US$ for the adopting commercial floating fish feed in Ghana, showing a 90% confidence interval.
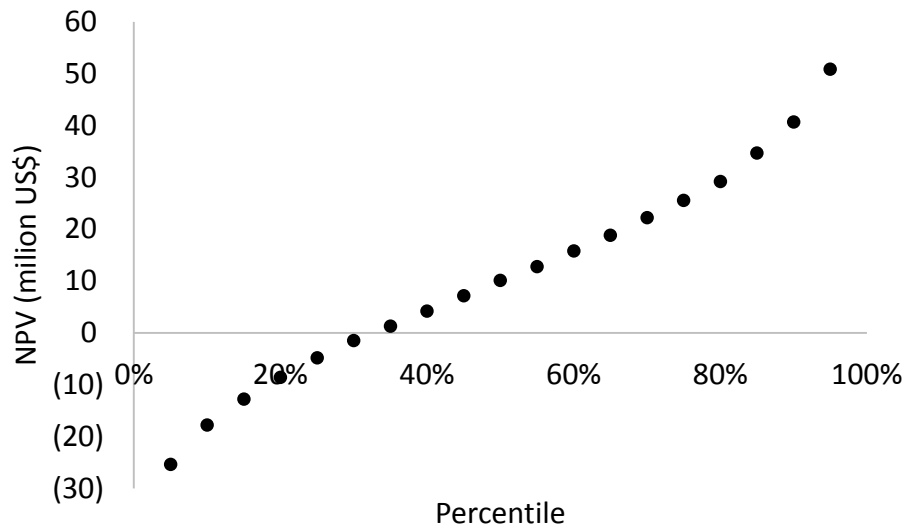
Figure 6.2. Net present values (NPV) at different percentiles for adopting commercial floating fish feed in Ghana.

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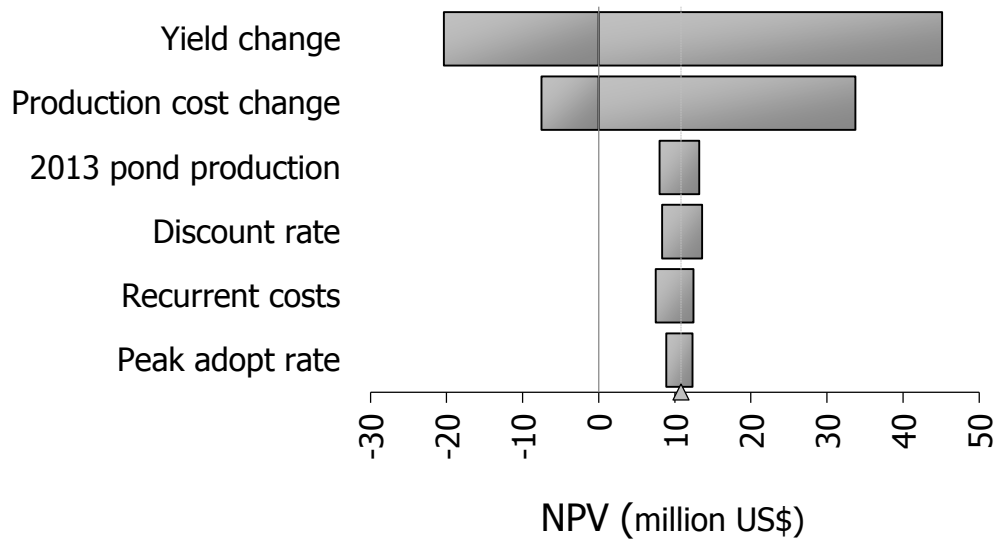
Figure 6.3. Relative impacts of key variables on the mean net present value for adopting commercial floating fish feed in Ghana across the range of key variables.

Discussion

From the results, it emerges that that Ghana's economy has a high probability of profiting significantly from adoption of BMPs, such as use of floating fish feed in earthen-pond farms. The gross domestic product (GDP) for the country in 2013 was US$48 billion (World Bank, 2014). Ghana's agriculture sector contributes about 22% of the country's GDP. This implies that an average NPV of $11 million represents a social benefit of > 0.02% of the country's GDP and > 1% of the portion of GDP contributed by the agricultural sector.

Extrapolations based on figures from Ghana's National Aquaculture Development Plan (Ghana Fisheries Commission, 2012) indicate that the current value of commercially-farmed fish in the country to be approximately $40 million (Ansah *et al.*, 2014). This implies that our calculated average benefit (US$11 million over 20 years) will annually add

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> 25% of the current value of commercially-farmed fish. Clearly, Ghana stands to benefit substantially from the increased fish yield, which will result from adoption of the recommended, floating fish feed. Ansah *et al.* (2014) identified possible key socio-economic benefits or impacts of higher fish yields, to include increased employment within the improved aquaculture industry, higher incomes, reduced poverty, possible foreign exchange, lower fish cost, better nutritional diet (more protein), improved health and welfare. Additionally, women in Ghana's fisheries sector are involved more in processing and marketing of fish, and as such, they too will benefit from the increased fish yields from the adoption of the recommended feed type.

The two most influential determinants of NPV were level of change in yield (+) and level of change in production cost (-), with the new feed type. Ansah *et al.* (2014) conducted a similar analysis, which concluded that Ghana stands to make an NPV of about $375 million from the adoption of genetically-improved farmed tilapia strains in Ghana. That figure is >300% higher than the calculated NPV in this study for adopting commercial floating feed. Both studies found the change in yield as the most influential variable determining mean NPV. However, although this study considered the welfare impacts of an innovation in the significantly smaller, earthen-pond sub-system, Ansah *et al.* (2014), calculated the welfare impacts of an innovation that can be used by the bigger pool of tilapia farmers from both production sub-systems. This result from the two studies also indicates that any BMP or innovation that significantly increases fish yield also will considerably increase mean NPV and social welfare.

The recommended commercial floating feed type is known to cost almost eight times as much as the alternative feed type produced on farms from a mixture of by-products of

local agro-food industry. It is also not unusual for the cost of fish feed to make up > 50% of variable or total costs of a fish farm (De Silva and Anderson, 1995; Jamu and Ayinla, 2003; Engle and Neira, 2005). Therefore, it is expected that adoption of the recommended feed type will be accompanied by a substantial investment of capital, and principles of innovation adoption (e.g. Rogers, 2003) predict that the higher cost implications could discourage rapid diffusion of this feed innovation among pond farmers in Ghana. However, considering the significant positive social welfare implications of adopting this feed type in earthen pond farming, both governmental and non-governmental agencies could invest in reducing feed cost in order to facilitate diffusion. Our results indicate that the marginal benefits from any investments made to reduce feed costs and facilitate farmers' use of the new feed type is high.

The acceptable value of the social discount rate (SDR) has been a long-standing debate (e.g., Caplin and Leahy, 2000, and Moore *et al.,* 2013). Lately, this debate has been rekindled, especially because of the sensitive nature of current analyses of environmental issues, such as global climate change versus global population growth. The SDR allows effects occurring at different future times to be compared by converting each future dollar amount into equivalent present dollars (Weitzman, 2001). The difficulty in this comparison is compounded by the usual uncertain nature of future events. Besides the arguments of which value of social discount rate to use in calculations, another controversy is whether to use a constant number for an analysis or to allow this number to change. Our Monte Carlo simulation (sensitivity analysis) allowed us to use a range of discount rates instead of a constant number, and results show that although a lower rate will increase NPV, the SDR

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was not as influential as yield changes or production cost changes in determining mean NPV of the feed innovation.

The least influential variables determining mean NPV were amount of the recurrent costs of improving and disseminating the relatively new feed type, and the level of the peak adoption rate. Whereas our results imply that investing in recurring costs (R&D and dissemination) of the new feed technology will not have a direct increasing effect on mean NPV, awareness of an innovation is well known to be the primary requirement for diffusing that innovation (Rogers, 2003). As such, active dissemination of this BMP to farmers will facilitate its adoption. Only then will the attractive NPV estimated in this study be achieved.

Also, adoption rates of the recommended feed type had a non-significant but positive effect on mean NPV. However, adoption rate links indirectly to change in yield. Change in yield is the physical change in the average weight of fish fed the new feed type, but the more farmers that adopt the technology the higher the chances of increasing production in order to realize the calculated NPV.

Conclusions

This study projected that adoption of yield-enhancing aquaculture BMPs and innovations in a developing country such as Ghana would result in significant social welfare benefits. Considering the high marginal benefits of investments in floating feed, we recommend that credit programs and other financial packages be set up to help farmers meet the current price of fish feed. We also recommend that investment into research and development projects to reduce the amount of feed wasted from over-feeding. The focusing of extension effort on production technologies will lead to the realization of benefits and

reduction in risk. These efforts will result in the country reaping high social benefits from the increased yield. Also, active dissemination of this and other BMPs will create the awareness required for rapid diffusion of these innovations.

Acknowledgements

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Chapter 7: Impacts of Aquaculture BMP Adoption on Loading of Nutrients and Sediment in Ghana

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Abstract

Adoption of environmental best management practices (BMPs) in aquaculture has potential to

ameliorate water quality, such as reductions in the amounts of nutrients and sediment that enter

natural waterbodies in effluents from fish ponds. We applied two aquaculture best management

practices (BMPs) – commercial floating fish feed (as opposed to local mixtures from agro-

industrial wastes) and reuse of pond water (as opposed to draining ponds after each production

cycle) to the culture of Nile tilapia (*Oreochromis niloticus*) in earthen ponds on eight

demonstration fish farms in Ghana over two production cycles. Concentration of a number of

water quality variables was monitored, along with fish growth and farm-level production costs

and revenues. We used the minimum-data method of the Tradeoffs Analysis (TOA-MD) to

estimate the proportion of farms in Ghana that will adopt the floating feed BMP, and associated

changes in loading of potential aquaculture effluent pollutants that will occur nationally at that

adoption rate. An adoption rate of 38% was predicted for the floating feed BMP in the absence of

any incentives provided to encourage adoption, and this would result in significant reductions in

the loading of nitrogen, phosphorus, sediment, and BOD_5, which would be discharged from

ponds. Further analysis of the possible reduction in pollution from 19% adoption of pond water

reuse indicated reductions of between 200% and 3,200% in these potential pollutants over the

reductions obtained from the floating feed BMP. Increasing adoption rates will lead to further decreases in loading of potential pollutants, but will require a policy of payment of incentives. Payments could take the form of subsidies on the expensive commercial fish feed in order to encourage adoption of the BMP.

Keywords: Effluent management; Positive externalities; Tradeoffs analysis; Agricultural policy

Introduction

Humans' exploitation of ecosystems to meet increased demand for food, fresh water, energy and natural resources has been blamed for degradation of ecosystem services worldwide. In aquaculture, the major physical resources required are all finite - energy, land, water, and feed (Tucker et al. 2008a). As such, the impacts of the industry on resource availability depend to a large extent on the overall rate and efficiency of use.

Adoption of best management practices (BMPs) holds the potential for pollution control regarding the amounts of nutrients and sediment that will enter natural waterbodies from earthen pond effluents (Boyd et al. 2008). BMPs can be classified into two general groups, nutrient management and effluent management. Frimpong et al. (2014) characterized the effects of two BMPs on growth of Nile tilapia and on preventing the transport of large amounts of nutrients and solids from fish ponds to waterbodies in Ghana. Specifically, the two BMPs studied were the use of commercial floating fish feed, and pond water reuse (each BMP representing of one of the two general BMP groupings). Characterization and impacts of the adoption of these BMPs on farm profitability and social welfare are the subjects of other studies (Chapters 3 and 6). This study is primarily aimed at quantifying environmental benefits of adopting these BMPs in fish farming in Ghana.

Emphasis of agricultural policy is gradually shifting from traditional subsidy and trade policies to incentivizing farmers to encourage environmental protection from the negative impacts of agriculture (Antle and Valdivia 2006, Lipper et al. 2009, Antle et al. 2010). This development is the result of growing public demand for ecosystem services, such as wildlife habitat, visual amenities and open space, water quality protection, and greenhouse gas mitigation (Antle and Valdivia 2006). Developing countries are recognized as unique producers of natural resources (Nalukenge et al. 2009). The expected priority for least developed countries (LDCs) is utilization of natural resources to increase agriculture production, and to build industries towards economic development. However, economic development is correlated with the reduction in both stock of natural resources and in supply of ecosystem services (Kneese and Bower 2013).

One way to prevent the reduction of stock of natural resources and to maintain the supply of ecosystem services, especially from LDCs, is to link monetary compensation for environmental protection to economic development and poverty reduction (Nalukenge et al. 2009). Since the 1990s, a number of studies have been aimed at integrating physical and economic models to analyze agriculture-environment interactions and related policies (e.g. Just and Antle 1990, Wu et al. 2004). However, such analyses require high-resolution and site-specific data, which are generally lacking, especially in LDCs.

A minimum-data (MD) approach was developed by Antle and Valdivia (2006) as a multi-dimensional impact assessment tool to simulate adoption of an innovation and change in the supply of ecosystem services from agriculture with the lower-resolution data obtainable in most parts of the world from secondary sources. According to the authors, although this approach allows timeliness in getting results for policy decisions, there is an obvious tradeoff between timeliness and accuracy of results. However, the resulting level of accuracy, which the authors

showed as being within an order of magnitude of the results of more data-hungry methods, is adequate for policy decisions because several unquantifiable uncertainties have to be incorporated into *ex ante* policy analyses anyway.

The minimum-data method of the Tradeoffs Analysis (TOA-MD)

According to the minimum data method of the Tradeoffs Analysis (Antle and Valdivia 2006) the reduction in the loading of a particular potential pollutant is a cumulative density function of the spatial distribution of the opportunity cost of providing those services. Application of the minimum-data approach of deriving the amount of pollution reduction from the spatial distribution of the opportunity cost of adopting BMPs, adapted from Antle and Valdivia (2006) and Antle et al. (2010), is as follows: Consider a fish farmer faced with two land (pond) use options **a** and **b** in a geographical region. Let **a** be the *status quo* aquaculture practice (baseline pollutant loading), and **b** aquaculture with BMPs (reduced pollutant loading, **e**). The farmer's decision will depend on the expected value, *v (p, s, z),* where: *p* = parameter (more generally a vector), interpreted here as an output price; *s* = indexes the site; and *z = a, b* (index of the farmer's decision practice). Practice **a** is chosen (the farmer rejects the BMP) if the opportunity cost of adopting the BMP, *ω*, is zero or positive, i.e., if *ω (p, s) = v (p, s, a) − v (p, s, b) ≥ 0.* Practice **b** (the BMP) is chosen otherwise.

A density function, **φ (ω)**, can be defined by ordering all land units according to the value of the opportunity cost, *ω (p, s),* for a given value of output price, **p**. This is the spatial distribution of opportunity cost, which is assumed to exhibit a normal distribution. Using the above-mentioned variables, the proportion of land units that have already adopted practice **b** is given by

$$(4) \qquad r(p) = \int_{-\infty}^{0} \varphi(\omega) \, d\omega, \; 0 \leq r(p) \leq 1$$

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From this proportion, the expected private-equilibrium (baseline / no-payment) reduction in the loading of a potential pollutant per time period in the region with H hectares of pond surface area can be calculated as

$$(5) \qquad S\,(p)\ =\ r(p)\,H\,e,$$

where e = expected loading amount (kilograms of sediment, oxygen demand, nitrogen or phosphorus prevented from entering effluent-receiving streams) produced with practice b.

To obtain further reductions in pollutant loading above the baseline quantity, $S\,(p)$, a payment P_e (\$/e) is offered (e.g. feed subsidies) to land managers by a private or government entity for purposes of increasing pollution reduction. This framework assumes that farmers own the property rights to discharge fish pond effluents into water bodies, as is the case in Ghana, where enforcement of water quality regulations has been difficult and ineffective (Keraita et al. 2003, Ansah et al. 2013). The land owner (fish farmer) now is faced with a new decision. He could receive $v\,(p,\,s,\,a)$ for practice a, or $v\,(p,\,s,\,b) + p_e\,e$ for using practice b. With this new arrangement, the farmer now will choose activity b if the environmental payment for each unit of loading reduction outweighs the opportunity cost for supplying that unit. That is:

$$(6) \qquad\qquad \omega(p,s)\ -\ p_e\,e\ <\ 0$$

With these payments, three possible scenarios will arise for each site, s. Case 1 will constitute those sites where practice b is more profitable even without payments. That is,

$$(7) \qquad \omega\,(p,s) < 0.$$

For this group of land units, environmental payments will just result in higher profitability, and as such, farmers will adopt an innovation even without an environmental payment. Case 2 represents those sites where practice a is more profitable without payments, but practice b is more profitable with payments. That is:

$$(8) \qquad \omega\,(p,s) > 0, \text{ but } \omega\,(p,s) - p_e\,e < 0$$

A farmer in this group will switch to practice **b** with the payments. Case 3 constitutes those sites where practice **a** remains more profitable with or without payments. That is:

$$(9) \qquad \omega\,(p,s) > 0, \; \omega\,(p,s) - p_e\,e > 0$$

This last case implies that the opportunity cost per unit of pollutant reduction is always positive and greater than the payment per unit of pollutant reduction, or

$$(10) \qquad \frac{\omega\,(p,s)}{e} > p_e$$

Hence, the farmer will reject the new technology.

The spatial distribution of opportunity cost per unit of pollutant reduction ($\frac{\omega\,(p,s)}{e}$) can be defined as:

$$(11) \qquad \phi\left(\frac{\omega}{e}\right) = \varphi\,(\omega)e$$

The proportion of land area that will be switched to practice **b**, which corresponds to the range of opportunity cost between zero and p_e (Case 2), can be defined as:

$$(12) \qquad r(p, p_e) = \int_0^{p_e} \phi\left(\frac{\omega}{e}\right) d\left(\frac{\omega}{e}\right).$$

Therefore, at price $pe > 0$, the reduction in pollutant loading is equal to:

$$(13) \qquad S\,(p, p_e) = S\,(p) + r(p, p_e)H\,e,$$

which shows that the total quantity of pollutant reduction is equal to the baseline quantity $S(p)$, plus the additional quantity supplied, $r\,(p, p_e)\,H\,e$, due to the positive incentive.

Methods/Analysis

We compiled information on the general characteristics of tilapia farms in Ghana mostly from a survey that we conducted of 393 pond farmers in Ghana from 2011 to 2013. The average farm and pond sizes were 0.6 ha and 0.12 ha (averagely, each farm could fit 5 ponds),

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respectively, with respective coefficients of variation (CV) of 228.7% and 300%. Frimpong and Anane-Taabeah Attu (*in press*) estimate the current total surface area of fish ponds in Ghana as 1,000 ha. From the survey we also determined mean fish farm household size (and CV) as 7.28 (45%).

We cultured Nile tilapia (*Oreochromis niloticus*) in experimentally-controlled ponds on five demonstration farms over two production cycles from 2011 to 2012. These were already-existing fish farms in central Ghana, from which ponds were selected and set aside for this study. Stocking, feeding, and other management practices employed for the production of tilapia on these demonstrations were consistent with those used on typical tilapia farms in Ghana. A main goal of these demonstrations was to obtain physical data on the effects of two best management practices (BMPs) – use of commercial, floating feed (as opposed to locally-made sinking feed prepared on site from agro-industrial wastes), and reused or 'green' water (as opposed to fresh water) – on the growth of Nile tilapia and on water quality variables, such as nutrients and solids. See Frimpong et al. (2014) for details on the experimental design and methods.

Adoption of the commercial floating feed BMP resulted in an average of 100% increase in fish weight and yield (Frimpong et al. 2014), which resulted in significant differences in profitability of using either feed type. There were no significant differences in fish weight or yield with the adoption of the water re-use BMP. Because we lack information on cost savings resulting from reusing pond water, we worked with the assumption of equal costs between new and reused water. As such, only adoption of the feed BMP could be used in the analyses of the direct impacts of BMP adoption on farm profitability and on the reduction in pollutant loading from fish farms. However, this study includes a scenario, which estimates amount of reduction in

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the concentration of potential pollutants that will be achieved if half of the proportion of farmers who adopt the new feed BMP also adopt the water reuse BMP (according to Chapter 4).

Differences between the mean levels of fish pond water quality variables from using the commercial feed and the local alternative were calculated from Frimpong et al. (Table 5; 2014). Mean concentration of each parameter after one production cycle also was extracted from that study to represent the amount of pollution that would be saved if the farmer chooses to re-use pond water instead of the usual practice of draining (Table 7.1).

Table 7.1. Reductions in concentration of concentration of water quality variables resulting from using two aquaculture BMPs input into the Tradeoffs Analysis (minimum-data) model, from Frimpong et al. (2014)

Parameter	Meaning	Feed switch impact	No-drain impact
PO4 (mg/L)	Orthophosphates	0.19	0.86
PO4^{-3} (mg/L)	Total phosphates	0.40	1.52
SS (mg/L)	Suspended solids	20.55	99.15
TSS (ml/L)	Total Settleable solids	0.26	1.30
BOD$_5$ (mg/L)	Biochemical oxygen demand	0.15	10.08
DIN (mg/L)	Dissolved inorganic nitrogen	-0.24	3.20
DON (mg/L)	Dissolved organic nitrogen	0.96	6.50
TDN (mg/L)	Total dissolved nitrogen	0.72	9.78

Ansah and Frimpong (Chapter 5) compared profitability of switching to each of these two BMPs on a typical tilapia pond farm in Ghana using enterprise budgets and incorporating risk analyses. They used a mean real interest rate of 8.5% for their calculations. Other data on farm production variables extracted from that study can be seen in Table 7.2.

Table 7.2. Farm production variables for two tilapia production systems in Ghana, based on feed type, from Chapter 5. Values in brackets represent the standard deviation

Variable	System 1 (Sinking feed)	System 2 (Floating feed)
Production (kg/ha/year)	5,796 (2300)	11,553 (2,288)
Fish price (US$/kg)	1.35	3.16

Variable cost (US$/ha/year)	9,902	29,942
Fixed cost (US$/ha/year)	215	215

The expected adoption rate of the commercial floating feed BMP then was determined

using TOA-MD Model 6 (J.M. Antle, J.J. Stoorvogel, R.O. Valdivia, Oregon State University,

Corvalis). The adoption rate was estimated as the proportion of Ghana's fish farm surface area

that is expected to use system 2 (commercial floating fish feed). The model then was used to

estimate the reductions in the loading nutrients and sediments that will occur at the national scale

at this adoption rate of this feed type.

Chapter 4 indicates that the adoption rate for the water-reuse BMP is about 50% that of the

floating feed BMP. A scenario where this proportion of farms adopt the water reuse BMP also

was analyzed, in the absence of any direct linkage of the adoption of water reuse on the

profitability and opportunity cost of adoption on these farms, which is the basis for the TOA-MD

model. Other variables needed to run the model were: within-system correlation of returns

(0.80), and between-system correlation of returns (0.75). The whole country was modelled as

one stratum, since available data were not differentiated by region.

Results

The predicted maximum adoption rate of the commercial floating feed BMP was 38%

without any incentives or payments (Figure 7.1). An annual payment of about US$ 6,000 per 0.6

ha pond surface area is needed to increase adoption rate of this BMP to 50%, and about US$

12,000 to achieve 70% adoption.
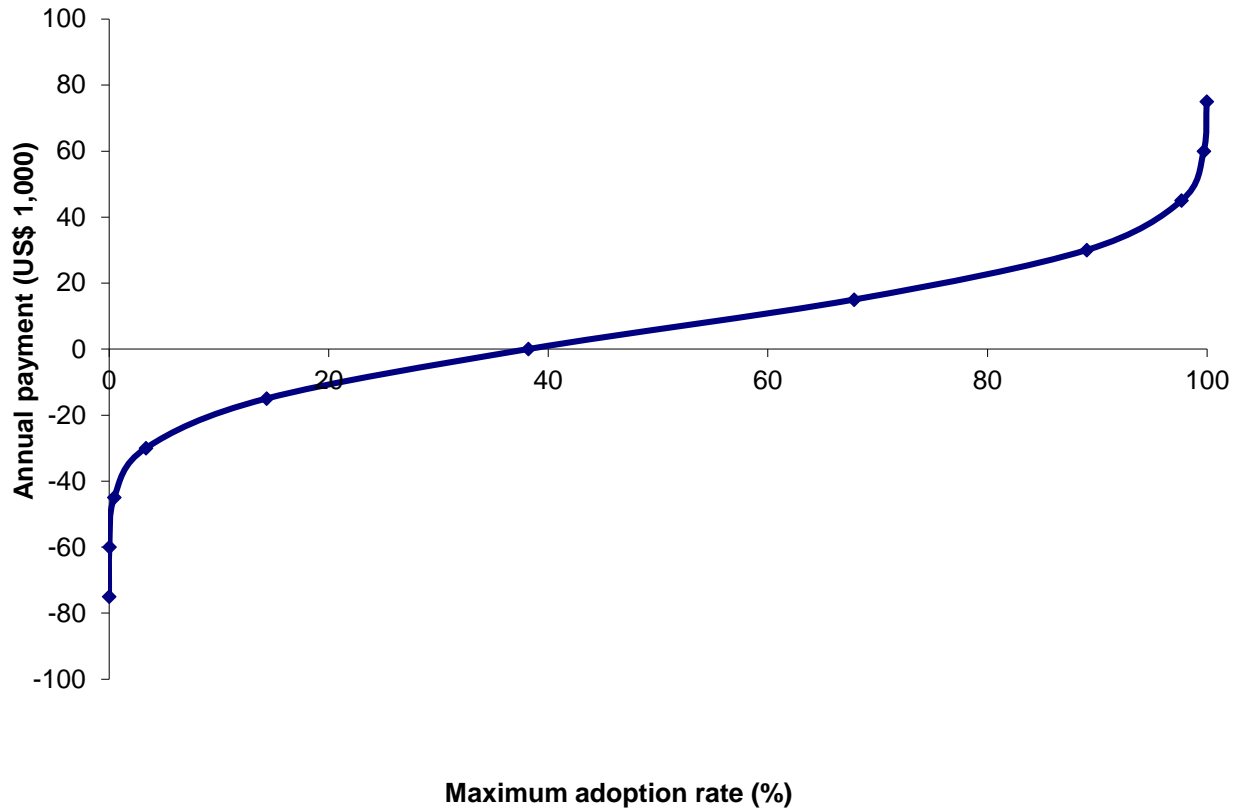
Figure 7.1. Predicted maximum adoption rates of commercial floating fish feed at different levels of annual payments to pond fish farmers in Ghana.

If 38% of tilapia pond farms in Ghana were to adopt the commercial floating feed BMP significant reductions in pollution from all selected effluent components, with the exception of dissolved inorganic nitrogen (DIN), will be realized (Table 7.3). At the 38% adoption rate, approximately 1 kg/ha of DIN will be added to effluent-receiving streams annually when fish ponds are drained at the end of the production cycle.

Assuming that half of the 38% of tilapia farms (i.e., 19%) in Ghana adopt the water-reuse BMP, between 200% and 3,200% more of each potential pollutant will be prevented from entering effluent-receiving streams (Table 7.3), compared to adoption of the floating feed BMP.

Table 7.3. Predicted annual amounts of ecosystem service resulting from the adoption of two BMPs - commercial fish feed and pond water re-use – in Ghana

Variable	Meaning	No drain	Feed switch
PO4 (kg/ha/year)	Orthophosphates	1.64	0.73
PO4-3 kg/ha/year)	Total phosphates	2.90	1.53
SS (kg/ha/year)	Suspended solids	189.32	78.48
TSS (L/ha/year)	Total settleable solids	1,241.13	496.45
BOD5 kg/ha/year)	Biochemical oxygen demand	19.25	0.57
DIN (kg/ha/year)	Dissolved inorganic nitrogen	6.11	-0.92
DON (kg/ha/year)	Dissolved organic nitrogen	12.56	3.67
TDN kg/ha/year)	Total dissolved nitrogen	18.67	2.75

Discussion

The most influential determinants of the adoption of aquaculture BMPs in Ghana are farmer's awareness, the perceived profitability of the BMP relative to the existing practice, and the farmer's years of experience in fish farming (Chapter 4). According to data presented in Chapter 4, Ghanaian fish farmers were well-aware of the floating feed BMP. Therefore, it is unlikely that non-awareness is the cause of the predicted low maximum adoption rate of this BMP in this study. The remaining two main determinants of BMP adoption could provide insights into the low adoption.

Years of experience in the industry allow a fish farmer to form a positive or negative perception about profitability of a new technology relative to an existing technology. A number of Ghanaian fish farmers have been observed to switch between the sinking and the floating feed even within a single production cycle. This 'trialability' (Rogers 2003) of the feed BMP speeds up the decision of the farmer to either adopt or reject this BMP. Commercial floating feed is known to be about eight times more expensive than the same weight of the local sinking feed alternative. Despite the significantly higher net returns reported for using floating fish feed (Chapter 5), the resulting higher variable costs with this feed type are presumed to result in a

negative perception of lower relative profitability, and hence contribute to low adoption. Possible ways to reduce feed cost are: reduction in the feeding rate (if it can be accomplished without reducing the growth rate), and the use of cheaper substitutes for fish meal, which is by far the most expensive ingredient in commercial feeds. Awareness of the finding that although far more expensive, commercial floating feed results in bigger fish in a shorter time, more production cycles in a year, and significantly higher profits (Chapter 5) will embolden more fish farmers to take the risk to adopt this BMP.

Another method of estimating BMP adoption rates in Ghana (Chapter 4) found maximum adoption of the feed BMP to be 58%, which is higher than the 38% reported in this study for the same BMP. A number of reasons could explain this contrast. Chapter 4 involved the modelling of the trajectory of the stochastic system of floating feed adoption (farmers can decide to use, discontinue, or continue using either type of feed type several times even within a single production cycle) as a Markov process. The Markov process predicts a future state based, to a large extent, on the current state of a process with no memory of past conditions. A stationary transition probability matrix was assumed in that study, without verification due to the lack of data to do so. In contrast, the adoption rate in this study was predicted solely on the opportunity cost of switching from the sinking feed to the floating alternative. Antle and Valdivia (2006) conceded that a number of factors exist in developing countries, such as market imperfections, which could impose unobserved costs (or benefits) and distort the calculated or expected adoption of certain practices using the TOA-MD model.

Both modeling approaches used in this study, however, agree that maximum adoption of commercial floating fish feed in pond farming in Ghana will remain low under current economic conditions, depending on feed costs and market prices of produced tilapia. Our results indicated

that incentives of about US$ 6,000/year need to be paid to each 0.6 ha to push adoption of the

feed BMP to 50% for production of two cycles within each year, whereas about US$

12,000/year/0.6 ha will be needed to ensure 70% adoption in Ghana.

Significant reductions in the loading of pollutants from fish farms potentially would be

achieved at the estimated adoption rate of commercial floating feed. Aquaculture has been

blamed for being the source of nutrients and sediment that pollute streams and other waterbodies.

Pollutants result from uneaten feed, fish excretions, eroding earthen ponds, and applied organic

and inorganic fertilizer (Klinger and Naylor 2012). Nutrients such as nitrogen (DON, TDN) and

phosphorus (PO_4, PO_4^{-3}) cause eutrophication of natural aquatic ecosystems, depending on which

nutrient is limiting (Ansah et al. 2012). Because aquaculture effluents contain both nutrients,

eutrophication of receiving water bodies is likely if concentrations exceed assimilative capacity

of the receiving water. Sedimentation and increased turbidity (from suspended and settleable

solids) of receiving water bodies are also environmental issues common with aquaculture.

Sedimentation clogs the gills and limits the effective vision of aquatic organisms and changes the

state of stream beds, reducing their suitability as habitat for aquatic organisms (Shaw et al.

2001). Increased turbidity in streams that receive effluents from fish farms reduces effective

distance of sunlight into those water bodies. Reduced sunlight has implications for primary

production in particular and the food web in general. Biochemical oxygen demand (BOD_5),

which will be reduced significantly from the adoption of the floating feed BMP, is due largely to

respiration by live plankton (Boyd and Dhendup 1995). Respiration uses up a large amount of

dissolved oxygen, stressing fish and other aquatic organisms in effluent-receiving bodies from

the resulting inadequate dissolved oxygen (Mallin et al. 2006).

Unlike the seven above-mentioned water quality pollutants that could be reduced with the adoption of the floating feed BMP, there will be an increase in the amount of dissolved inorganic nitrogen (DIN) in effluents from fish farms in Ghana. One advantage of using this feed type is the added processing to make it more nutritional and palatable to fish (Drew et al. 2007, Hardy 2010). However, this processing could be responsible for the higher dissolved inorganic nitrogen content, because sinking feed is made of non-processed agro-industrial wastes. Despite the higher DIN concentration, significant reductions in DON will ensure an overall reduction in total dissolved nitrogen (TDN) concentrations in effluents from Ghanaian fish farms from the adoption of commercial floating feed.

If 19% of fish farms in Ghana were to adopt the water-reuse BMP, reductions in all the above-mentioned effluent components will be several times higher than that for the feed BMP. This BMP involves no draining of pond effluents after the production cycle. The only draining that might occur would be from pond overflow (maintenance of pond water level 6 – 8 inches below the top of drain pipe, especially in the event of high-rainfall) or for maintenance of pond bottoms every few production cycles. As such large quantities of pollutants could be prevented from leaving the farm altogether even if pond water is reused for just one more production cycle, as in this study. Frimpong et al. (2014) found that fish ponds could be a net user of nutrients and organic materials because although concentrations of water quality variables were higher in the water reuse ponds at the end of the study (two production cycles), these concentrations were less than double of the concentrations found in the fresh water ponds. This comparison implies that the increased retention time allows ponds more time to process wastes through hydrological cycles (Tucker et al. 2008b). A survey of Ghanaian fish farmers indicated that only a small proportion of them were aware of this BMP (Chapter 3). Besides the limited awareness, pond

fish farmers are convinced that reused water is not a clean environment for fish culture, and that ponds need to be filled with fresh water for each production cycle. However, Frimpong et al. (2014) showed that there was no significant difference in the growth of fish in either water type.

Conclusion

Appreciable reductions in pollutant loading from fish farms would be realized from adoption of commercial floating feed in pond fish farming in Ghana. Increasing adoption rates will lead to even further reductions in pollutant loading, but significant financial investments need to be made to increase adoption. Payments could be in the form of subsidies for feed costs, with the policy objective of increasing the reductions in pollutant loading from fish farming.

Considering the immense amount of reductions in pollutant loading that could be achieved from adoption of pond water reuse, some form of policy of payments for environmental protection is recommended to make water reuse more profitable than using fresh water for every production cycle. Net returns, and hence opportunity cost associated with switching to reusing pond water, results in minimal adoption according to the TOA-MD model. This is because of the assumption of equal costs between using the new and old water types. Future analyses could quantify differences in production costs between using the two water types, which will allow for the calculation of relative profits and the application of the TOA-MD model to the water reuse BMP.

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Chapter 8: Genetically-Improved Tilapia Strains in Africa: Potential Benefits and Negative Impacts

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Abstract: Two genetically improved tilapia strains (GIFT and Akosombo) have been created with *Oreochromis niloticus* (Nile tilapia), which is native to Africa. In particular, GIFT has been shown to be significantly superior to local African tilapia strains in terms of growth rate. While development economists see the potential for food security and poverty reduction in Africa from culture of these new strains of tilapia, conservationists are wary of potential ecological and genetic impacts on receiving ecosystems and native stocks of tilapia. This study reviews the history of the GIFT technology, and identifies potential environmental and genetic risks of improved and farmed strains and tilapia in general. We also estimate the potential economic gains from the introduction of genetically improved strains in Africa, using Ghana as

a case country. Employing a combination of the Economic-Surplus model and Monte Carlo simulation, we found the mean net present value (NPV) of the introduction of the GIFT strain in Ghana to be approximately 1% of the country's gross domestic product. Sensitivity analysis indicated that the difference in growth or yield between the GIFT and locally-available strains has the largest effect on mean NPV. We conclude that improvements in management practices and infrastructure could increase the yield and profitability of the local strains even if genetically-improved strains are not introduced. These improvements also will ensure the realization of the full potential of introduced strains.

Keywords: sustainable aquaculture; native species; genetic improvement; Monte Carlo simulation; economic surplus; risk analysis; Ghana

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The importance of aquaculture to Africa's development

Capture fisheries production has levelled off and is no longer considered capable of sustaining the supply of fisheries products needed to meet growing global demand [1]. Aquaculture, especially of tilapias, has the potential to play a leading role in the fight against food insecurity, malnutrition, and poverty in Africa [2]. The continent has an immense biological diversity of native fish resources. However, due to poor management and genetic erosion, most aquaculture stocks in current use on the continent are genetically inferior to wild, undomesticated stocks [3,4]. It is widely accepted that successful aquaculture development in Africa requires improvements in feed quality and availability, business and marketing models, and local technical capacity. Another important factor that should be considered is the effective utilization and management of fish genetic resources [4,5]. Specifically, improved strains that are faster

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growing, resistant to disease, and suited for culture in a variety of fish farming conditions could go a long way to meet the demand for fish protein [6].

Tilapia characteristics and production

Tilapias (Family: Cichlidae) are suitable for various aquaculture systems due to their ease of propagation, tolerance to handling, fast growth on both natural and manufactured feeds, tolerance of a wide range of environmental conditions, and high palatability, marketability and nutrient content [7]. They are especially well-suited for culture in developing countries due to their fast growth and short generation time, tolerance to a wide range of environmental conditions, resistance to stress and disease, ability to reproduce in captivity, and their acceptance of artificial feeds right after yolk-sac absorption [8].

Global aquaculture production of tilapias increased from 28,000 tonnes to over 3 million tonnes from 1970 to 2010 [9]. Globally, the tilapias were the dominant species group caught in inland fisheries between 2000 and 2005 (the tilapias were surpassed in 2005 by the cyprinids [10]). In terms of aquaculture production, the tilapias comprise approximately 5 percent of total global fish farming, second to the carps, which account for more than 70 percent [11]. However, aquaculture of tilapia in Africa constitutes only approximately 19% of the world's tilapia production [12].

Social benefits of tilapia

Historically and from a social standpoint, the most important use of tilapias has been production for home consumption, with millions of small-scale fish farmers in more than 100 countries supplementing their diets with tilapia [13]. There also has been a steady increase in the number of family-owned tilapia marketing microenterprises in many countries. The fish often are retrieved from nearby ponds or tanks, cleaned, fried, and offered for sale. This fried tilapia

provides a considerable proportion of dietary protein and calories in these developing countries [13]. More commonly, fresh tilapia also is provided for sale either at the farm gate or in local markets. However, tilapias have grown in importance from being just a low-cost, high-protein food fish ("aquatic chicken" [14]) employed by development agencies to feed the poor in the world's rural areas, to a highly-domesticated "livestock" with annual sales amounting to over $2 billion globally [10,13]. In terms of economic importance, tilapia surpassed the salmonids in 2004, and they are expected to eventually equal the carps [13]. The tilapias have been referred to as the "most important global whitefish commodity" [15].

Distribution of tilapias

The natural distribution of tilapias is restricted to Africa, Jordan, and Israel, where 112 species and subspecies of the genera *Oreochromis*, *Sarotherodon*, and *Tilapia* have been identified [8,16–19]. However, only a few of these species are commercially important, and fewer still are of aquacultural importance [11]. *Oreochromis niloticus*, *O. aureus*, and various hybrids of these with *O. mossambicus* are regarded as the most important aquaculture species [11]. For example, in China, of the reported 1.1 million tonnes of *O. niloticus* produced in 2008, approximately one-quarter was a hybrid between Nile tilapia (*O. niloticus*) and blue tilapia (*O. aureus*) [10]. All of the important aquaculture species have been introduced extensively outside of their native range. In the 20th century alone, tilapias were introduced into 90 countries for aquaculture, fisheries, the aquarium trade, or inadvertently [20–22]. However, their intolerance to low temperatures (below 20 °C) restricts culture to warmer areas [11].

Background to genetic improvement of tilapias

Due to the increasing importance of the tilapias in global fish farming, the intensity and diversity of efforts to improve the genetic baseline of these species have intensified over the last

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few decades. Ponzoni *et al.* [23] showed that genetic improvement is one of the most powerful and least expensive means of increasing the efficiency of aquaculture. Both traditional animal breeding and science-based quantitative genetic approaches have been used to improve tilapia phenotypes [24]. Other important genetic improvement methods include innovative chromosomal manipulations, physiological alteration of sex determination, gene transfer, and genetic marker-assisted breeding [24,25]. Traditional animal breeding approaches are still the most practical means of improving tilapia stocks for low-tech producers in most countries, and these approaches basically exploit additive and non-additive gene effects [24].

One common traditional approach to genetic improvement is the practice of individual selection, or selective breeding, which is based on the underlying principle that some significant portion of the variation in observable performance is due to individual genotypes, and that a component of these genotypic influences is directly heritable from parent to offspring [24]. Even in cases of high heritability, a measurable amount of phenotypic variation is needed to enhance growth rate through selection. Random genetic drift and excessive inbreeding result in lower heritabilities due to reduced genetic variation, posing a frequent problem in tilapia culture since a large number of broodstock on any particular farm most likely originated from a few individuals [24]. Hence, selection is usually a viable approach for tilapia genetic improvement where sufficient genetic variation exists [24]. According to Ponzoni *et al.* [23], selective breeding has a number of advantages over other genetic approaches: continuous genetic gain is possible, genetic gains can be handed down from one generation to the next, and gains in a nucleus can be multiplied and expressed in millions of individuals in the production sector.

The Genetic Improvement of Farmed Tilapia (GIFT) project, one of the most significant recent innovations in tilapia culture, succeeded in part because it was based upon using selective

breeding of a highly diverse synthetic base population [8]. The GIFT technology has been

applied in a number of countries to improve local strains of tilapia. One example of applying the

GIFT methodology is the Akosombo strain, which was developed in Ghana by the Aquaculture

Research and Development Center (ARDEC) in collaboration with the World Fish Center in

2003 [26–28].

The genetic improvement of farmed tilapia (GIFT) project

The GIFT project was a collaborative research effort involving five separate research

institutions that was implemented in the Philippines from 1988 to 1997 [29,30]. This project had

the overarching goal of "increasing the quantity and quality of protein consumed in low income

rural and urban populations in tropical developing countries, and in all regions of the world,

leading to an increase in the income of low-income producers" [31]. The collaborating

institutions were the International Center for Living Aquatic Resources Management (ICLARM,

now the World Fish Center), the Philippines Bureau of Fisheries and Aquatic Resources

(BFAR), the Freshwater Aquaculture Center of the Central Luzon State University (FAC-CLSU),

the Marine Science Institute of the University of the Philippines (UPMSI), and the Institute of

Aquaculture Research, Ltd., in Norway [30]. Funding for this project was provided by the Asian

Development Bank, the United Nations Development Program, and ICLARM [30].

The GIFT project had three specific objectives: (1) to develop improved breeds of Nile tilapia

(*Oreochromis niloticus*) and provide those fish breeds to national testing programs and then to

the fish farmers; (2) to strengthen national institutions in aquaculture genetics research; and (3)

to establish a mechanism for international exchange and evaluation of improved breeds and

research methods [31]. Nile tilapia was chosen as the focal species for a number of reasons. It

has a short generation time (approximately 8 months), which made it the perfect species for a

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breeding program [32]. This species also was growing rapidly in importance in aquaculture [14,33]. Additionally, the omnivorous diet of the Nile tilapia makes it an excellent fit for low-cost aquaculture, in contrast to carnivorous species that rely heavily on fishmeal or other expensive animal protein [31]. Also, numerous potentially useful Nile tilapia resource stocks existed in several countries in Africa and the Middle East.

Before the commencement of field trials, a number of consultations were held with fish farmers and experts from various disciplines, and the relative importance of the improved stocks was considered for the various tilapia farming systems. Some of the farming systems considered were cage culture, backyard fish pond, rice-fish integrated culture, and more intensive systems [31]. Fingerling size was set at 3–7 g, and the grow-out period was 90 days, with a harvest weight of about 120 g [31].

Even though the natural tilapia resources are restricted mostly to Africa, the world's main tilapia aquaculture industries are located in Asia [10,32]. Due to the generality that established farmed tilapia stocks in Asia were derived from few founder individuals, there was the suspicion that loss of variation through random genetic drift, inbreeding and introgression of genes from other less-desirable feral tilapia stocks had occurred. Hence, the project collected wild Nile tilapia germplasm from Egypt
(May 1988; August 1989; Nile Delta system), Ghana (October 1988; Upper Volta system), Senegal (October 1988; extreme west of distribution) and Kenya (August 1989; Lake Turkana) [34,35].
These collections represented the first-ever direct transfers of *O. niloticus* from Africa to Southeast Asia, with all samples belonging to the sub-species *Oreochromis niloticus niloticus*, with the exception of the Kenyan samples, which belonged to the sub-species *Oreochromis*

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niloticus vulcani. Four commercial Nile tilapia strains were collected from the Philippines (three strains originated from Ghana, and one stock originated from Egypt [34]).

The most important criterion determining the number of strains to be developed by the GIFT project was relative performance (growth, maturation and fecundity, and hardiness) in different target environments, or the genotype x environment interaction (GxE) [31]. An insignificant GxE effect
(in terms of farming relevance) implies that the best strain in one environment will be the best in most or all environments. A high GxE effect, on the other hand, implies that special strains would have to be developed for specific environments. The GxE interaction effect was found to be low, *i.e.*, overall growth performance was found not to differ significantly with environment, in terms of farming relevance. Hence, it would not be necessary to develop different strains for the different farming systems. The principal breeding objective of the GIFT program was growth rate, while monitoring other traits, such as survival, occurrence of disease and maturation rate [31].

Results indicated that, with the exception of the Ghana strain, the strains from Africa performed as well as or better than the then existing commercial or "domesticated" strains in Asia. The Egyptian strain was the best performer in the first generation, while the Kenyan strain was the best in the second. The Ghana strain performed the worst in both generations [34]. One of the widely cultured strains (the Israel strain, originally derived from Ghana) also performed poorly [34]. Crossbreeding (hybridization) of the different strains did not result in significant improvements. Therefore, individuals from the best-performing purebred and crossbred groups were selected, based on the growth performance of a number of different strain combinations, in order to build a stock with a broad genetic base. This constituted the original GIFT strain [31].

It was no surprise that the GIFT project, after just one generation of selection, had generated considerable interest from the tilapia production industry in Asia. Therefore, a consultation meeting was held in 1992 to discuss strategies and safeguards for fish germplasm transfer and distribution [31]. The consultation meeting involved senior scientists from National Agricultural Research Systems (NARS) of developing countries, international experts on fish genetics and biodiversity, representatives of NGOs, and donor institutions. Following the recommendations from this meeting, the improved strain developed in the Philippines was disseminated (from May 1994 to August 1997) to member countries that formed the Dissemination and Evaluation of Genetically Improved Tilapia in Asia (DEGITA).These countries were Bangladesh, People's Republic of China, Philippines, Thailand, and Vietnam. This dissemination allowed detailed evaluation of the genetic and socioeconomic performance and environmental impacts of this strain prior to more widespread commercial production and dissemination [31]. The dissemination was carried out according to standard quarantine procedures developed as part of the GIFT project [36].

Dey [37] studied the potential economic impacts of culturing the GIFT tilapia strain in five Asian countries: Bangladesh, China, the Philippines, Thailand and Vietnam. He concluded that adoption of the improved tilapia strain would benefit both producers and consumers of fish in each of the countries studied. Further investigations concluded that the GIFT strain resulted in body weight 18%−58% higher than "non-GIFT" strains on "average" farms in Asia. The break-even price above variable cost was found to be 7%−36% lower for the GIFT strain than for other *O. niloticus* strains then

being farmed [35].

The GIFT/GenoMar supreme (GST) strain

In 1999, the GIFT Foundation International, which was founded as part of the GIFT project, signed an exclusive agreement with GenoMar, a Norwegian company based in Oslo, for the long-term continuation of the GIFT breeding program [15]. According to GenoMar, and beginning with the 10th GIFT generation DNA marker-assisted selection has been applied in order to increase the selection differential. According to Gjoen [15], the selection differential from this approach, compared to that of the traditional selection approach, was expected to be 40% higher than for the 9th-generation GIFT tilapia in 2000. Genetic maps were generated for tilapia, and experiments were conducted in order to reveal genes that influence traits that are economically important [15,25]. According to Gjoen [15], color, growth, body shape, salt tolerance, and sex determination are some of the traits for which GenoMar detected influential chromosomal regions. GenoMar planned to use this information to facilitate the acceleration of genetic gains, especially for traits such as disease resistance and feed conversion, which are difficult to measure within traditional selective breeding programs [15]. As of 2001, the GIFT/GenoMar strain was officially being distributed in countries in Southeast Asia and Latin America [15]. The GIFT/GenoMar strain is known officially as the GenoMar Supreme Tilapia (GST^{TM}) [8].

Ponzoni *et al.* [5] detail the current state of the GIFT strain and also summarize research that the World Fish Center has conducted on the strain since 2000. The World Fish Center took delivery of 63 full-sib groups of 35 fish each (the progeny of single-pair mated parents) at Jitra, Kedah State, Malaysia, towards the end of 2000 and beginning of 2001, from the GIFT Foundation International, Philippines. The aims of this project included, among others, the maintenance and continuous improvement of the GIFT strain, and the distribution to partner

countries likely to benefit from its use. According to the authors, the strain has achieved

sustained gains of 10%−15% per generation over more than six generations. Importantly, these

gains have not been accompanied by any undesirable correlated response to date [5].

Dissemination of GIFT/GST strains in Africa

The outcome of the GIFT project generated interest from developing countries in Asia, the

Pacific, and Africa, both in terms of developing their own aquaculture strains, and also in gaining

access to the GIFT germplasm [38]. Africa, the origin of the tilapias, benefits the least from the

GIFT strain, even though much of the continent has a high potential for tilapia farming [39]. This

situation arose due to the policy of the WorldFish Center not to introduce the GIFT strain into

countries where *O. niloticus* is indigenous, concerned that interbreeding of the GIFT strain with

locally-adapted native populations might compromise wild aquatic genetic diversity [38]. This

decision by the WorldFish Center was given weight by an expert consultation in 2002 in Nairobi,

which was sponsored by the WorldFish Center, the Food and Agriculture Organization (FAO),

the World Conservation Union (IUCN), the United Nations Environment Program (UNEP), and

the Technical Center for Agriculture and Rural Cooperation (CTA) [40]. The expert consultation

resulted in the Nairobi Declaration, a set of ten recommendations aimed at realizing the potential

of African aquaculture without compromising native ecological and genetic resources [41]. The

WorldFish Center, instead, decided to help these countries apply the GIFT methodology to the

genetic improvement of indigenous tilapias.

The WorldFish Center established the International Network on Genetics in Aquaculture

(INGA) in 1993 to train member-country scientists in quantitative genetics applied to

aquaculture, and to coordinate national breeding programs in the 13 member countries

(Bangladesh, China, Cote d'Ivoire, Egypt, Fiji, Ghana, India, Indonesia, Malaysia, Malawi,

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Philippines, Thailand, and Vietnam) using the GIFT methodology to genetically improve their indigenous cultured species [35,38].

The pressure for the dissemination of the actual GIFT germplasm to Africa seemed to reach a head in 2007, when the WorldFish Center approved the Policy on the Transfer of GIFT from Asia to Africa, making the GIFT strain available to any African government that can demonstrate procedures to manage environmental and biodiversity risks, among other conditions [42]. Such a country also must display compliance with the Convention on Biological Diversity (CBD), an international treaty, while at the same time addressing the development objective it intends to achieve with the GIFT introduction [36,42]. The guiding principle for this new policy was that the genetic risks of introducing the actual GIFT strain to Africa was comparable to those associated with the genetic improvement of indigenous *O. niloticus* strains in Africa [42]. Basically, the new policy acknowledged that there was no point in keeping the GIFT strain from Africa if the genetic improvement of tilapia was going to occur on the continent anyway.

The Nogoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the CBD, a multi-lateral agreement, was adopted in 2010. This protocol aims at:

> *Sharing the benefits arising from the utilization of genetic resources in a fair and equitable way, including by appropriate access to the genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding, thereby contributing to the conservation of biological diversity and the sustainable use of its components* [43].

It can be argued that the World Fish Center has equitably shared with Africa the benefits arising from the utilization of the genetic resources (*O. niloticus* germplasm) collected from Africa to develop the GIFT strain ([6]; p. 139). The center has been training African scientists in application of the GIFT technology to their own national improvement programs, and then eventually allowing African governments' access (at no cost) to the GIFT strain.

Although the decision to allow the GIFT strain into Africa seems to have been reached through a logical scientific process, the policy evoked mixed reactions in Africa. The Sustainable Aquaculture Research Networks in Sub-Saharan Africa (SARNISSA) is a network of scientists, fish farmers, development partners, and other players in the African aquaculture industry. SARNISSA, hosted by University of Stirling, UK, maintains an online forum on which issues that are pertinent to African aquaculture are discussed, and one of the most hotly-debated topics recently discussed was use of the GIFT strain in Africa. For example, on 29 November 2011, SARNISSA member Hiskia Asino posted an enquiry onto the forum asking from which African countries he could obtain GIFT tilapia fingerlings for farming in Namibia. This request set off a heated debate that lasted several months. While most fish farmers and development agents generally seemed to favor the new policy and its potential benefits towards increasing farm profits and reducing poverty, a number of scientists and conservationists spoke quite passionately against it, citing the potential negative genetic and ecological impacts of the introduction. Instead of the GIFT strain, those against it proposed improvements in the existing aquaculture practices and infrastructure to achieve the same economic goals as with the GIFT. A forum contributor summed up the fears of SARNISSA members opposed to the use of the GIFT strain in Africa, "Once local species or stains are lost to competing non-endemic species or strains, that biodiversity is lost forever".

The GIFT technology has been disseminated to Kenya, Cote d'Ivoire, and Egypt, along with other developing countries in Asia and the Pacific (Dr. Raul Ponzoni, formerly of WorldFish, personal communication). GenoMar also has supplied the GST strain to partner hatcheries in Zambia and Angola, and by 2008 it was carrying out a feasibility study on setting up another partner hatchery in Uganda [36]. In Ghana, the Aquaculture Research and Development Center (ARDEC) took delivery of the GIFT strain officially in 2012, with the expressed objective of comparing its growth performance with the locally improved Akosombo strain (Dr. Joseph Padi, ARDEC, Water Research Institute, Ghana, personal communication).

Considering the porous nature of African borders and inadequate capacity to monitor the transfer of genetic material, we expect that the GIFT/GST strain is currently in several other countries in Africa. An example of the easy movement of non-native species on the African continent is the current production in Omilende, Nigeria, of the Asian catfish *Pangasius* sp. fingerlings for sale, as was reported on the SARNISSA forum on 2 March 2013—another non-native species introduction revelation that was followed by a lengthy and contentious discussion on the forum. It is clear, therefore, that once the GIFT/GST strain is legitimately introduced into a country in Africa, it eventually will be found in unapproved parts of that country or in other unauthorized neighboring countries. It is also clear that both benefits and negative impacts are possible with the introduction of the GIFT strains into Africa (Figure 8.1).
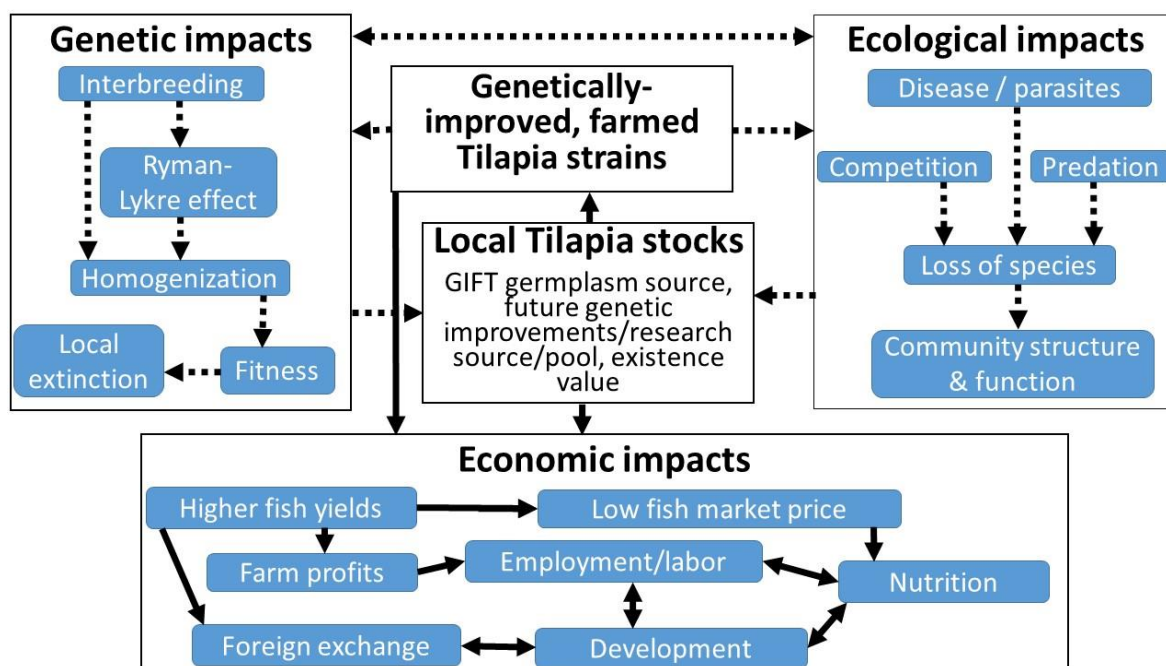
Figure 8.1. Interdependence of the potential ecological, genetic, and economic impacts with the introduction of genetically-improved tilapia into Africa. Broken arrows indicate negative impacts and solid arrows indicate positive impacts.

Potential ecological impacts of tilapia introductions

Tilapia production is well on its way to taking center stage in the global aquaculture industry [13]. However, in the context of development, the success of a species is determined by its social, cultural, economic and environmental impacts, in addition to its contribution to production *per se* [22]. The traditional small-scale, semi-intensive culture of tilapias has proven sustainable in many countries where they are native, with no observable negative ecological impacts on surrounding environments attributable directly to the species (e.g., [8,44]). The recent trend towards intensification, driven by market forces, has been predicted to pose serious environmental and socioeconomic problems [8]. These impacts will arise as a result of the expected increases in use of floating feeds, drugs, hormones [8], and non-indigenous genetic resources in intensive aquaculture. The global transfer of both genetically-altered and unaltered

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tilapia species outside their native ranges for aquaculture purposes also is expected to result in negative impacts upon natural aquatic ecosystems.

The popularity of the GIFT strain will drive its introduction into African countries outside the natural range of *Oreochromis niloticus.* Characteristics that make tilapias the perfect aquaculture species also make them invasive species, keeping in mind that even though Nile tilapia is native to Africa, it is not native to all parts of the continent. Escape of both altered and unaltered genetic resources from aquaculture installations into natural ecosystems occurs relatively frequently [45,46]. For example, Attipoe *et al.* [27] report the loss of the entire control line of the 2003 spawning season from the ARDEC research facility during the development of the Akosombo strain in Ghana as a result of a violent storm.

Pullin *et al.* [21] studied the establishment success of various tilapine species and found that tilapia species, in general, are moderately to highly invasive, with a 60%–90% probability of becoming established in new open waters. The impacts of any invasive species on an aquatic ecosystem differ significantly, depending on the species, the extent of the introduction (*i.e*., propagule pressure), and the vulnerability of the invaded ecosystem [18]. Tilapine species invest in significant parental care that facilitates their establishment in novel habitats. The family Cichlidae is grouped into nest-builders (*Tilapia* spp*.*), and mouth-brooders (*Oreochromis* and *Sarotherodon* spp.) [11]. Mouth-brooders, for example, have no specific substrate requirements for reproduction; they simply carry fertilized eggs and yolk-sac fry in their mouths until yolk sac absorption and dispersal [47,48].

Examples abound in the literature demonstrating the negative impacts of tilapia on natural aquatic ecosystems after their introduction, keeping in mind that Nile tilapia, and tilapia in general, are not native to all parts of Africa. These include predation on eggs and small fish [49],

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rapid total elimination of submerged and floating aquatic macrophytes that served as essential habitat for native fish species in natural and man-made reservoirs [50,51], and eutrophication (bioturbation and nutrient cycling through ingestion and excretion) stemming from the foraging activity of tilapia on benthic algae [52]. Tilapia introductions into Madagascar, Lake Victoria, and Zimbabwe led to habitat alteration, such as declines in aquatic plants and decreases in the availability of breeding areas for native species [53]. Also, the establishment of *Tilapia graham* in Kenya's Lake Nakuru led to the emergence of a fish-eating bird population [54]. Canonico *et al.* [18] provide an excellent review of impacts of tilapia on receiving aquatic systems using specific case studies from around the world.

Another potential impact of introducing the genetically improved tilapia strain from Asia to Africa is the risk of "hitch-hiker" disease-causing vectors and pathogens from Asia. Two possibilities exist. Firstly, the selectively bred strain might not be able to withstand diseases to which local African stocks have evolved resistance, which could lead to high mortalities on farms producing the selected strains. Secondly, the selectively bred strain, if resistant to certain Asian disease vectors, might carry these vectors and pathogens to Africa and infect local fish stocks. Noga [55] provides detailed descriptions of diseases of tilapia and numerous other fish species. Tilapia diseases include those caused by bacteria of the family Eimeriidae, *Mycobacterium* spp., and *Edwardsiella tarda*.

A number of general procedures exist for conducting risk analysis of non-native fishes (e.g., [56]). There are established procedures for analyzing risk regarding pathogen transfer and for quarantine monitoring [57]. Unfortunately, there is no universally-accepted *a priori* procedure for assessing the potential environmental impacts of non-native tilapias. In fact, scientific and policy decisions on new tilapia introductions frequently are polarized and are largely based on

guesswork [21]. As such, a majority of the impacts mentioned above were recognized after introduction and/or establishment.

Potential genetic impacts of tilapia genetic improvement on native populations

There is a paucity of studies on the impacts of aquaculture on locally-adapted gene pools of tilapia in receiving ecosystems. However, potential harms and associated risks stemming from aquaculture escapes have been considered in a more general context, Carvalho and Hauser [58] grouped the genetic impacts of "escapee" genetic resources into direct and indirect effects. Interbreeding of natural fish populations with escaped cultured stocks is arguably the biggest direct effect. When cultured fish escape or are released, the receiving population may experience a reduction in genetically effective population size, N_e, a phenomenon referred to as the Ryman-Laikre effect [59]. In addition, the risk of subsequent inbreeding may be increased if the ratio of "escapees" to the natural population is sufficiently high due to the relatively low N_e of many cultured stocks. Natural selection acts upon alleles at fitness-related loci to ensure adaptation of wild fish populations to their environments.

That is, local differences in natural selection over a wide area result in adaptive genetic divergence of populations over time; further, selective forces that operate across adaptively important loci may result in combinations of alleles, or co-adapted gene complexes, which confer fitness upon their carriers [60].

In contrast, selective breeding acts upon alleles at performance-related loci to ensure expression of valued traits within aquaculture systems. Escape of selectively bred individuals into the wild and interbreeding with wild populations may result in offspring that exhibit low fitness, posing the risk of outbreeding depression at a local scale; further, interbreeding of escaped, cultured stocks at multiple sites across a landscape will tend to homogenize among-

population variation of wild populations and also could lead to loss of fitness and outbreeding depression. The best-demonstrated case studies involve salmonids, and are reviewed by Ferguson *et al.* [61]. Among case studies, McGinnity *et al.* [62] demonstrated that the interaction of farmed with wild Atlantic salmon resulted in lowered fitness, and that repeated fish escapes caused cumulative fitness depression. Araki *et al.* showed dramatic losses of fitness after just two generations of captive breeding in steelhead salmon [63], as well as reduced fitness of their wild-born descendants [64]. Hindar *et al.* [65] reviewed studies of the effects of escape of cultured fish and introgression with local populations upon genetic differentiation, noting that in a subset of cases genetic swamping of local populations led to loss of indigenous stock structure in several salmonids. Conceptual models have been developed to predict the effects of introductions of maladapted individuals into locally-adapted gene pools [66,67] or to predict the relative likelihoods of beneficial or negative impacts of gene flow on receiving gene pools [68]. However, empirical studies of the effects of interbreeding of escaped cultured fish upon wild populations are lacking for most fish taxa, including tilapias. Hence, we lack the empirical data to parameterize models in order to predict the effects of introgression of selectively bred tilapias into native gene pools. Knowledge of gene flow rates and ecological differences among source and recipient populations [69], carefully controlled, multigenerational experiments, and thoughtful use of data from "experiments" created unintentionally [70] will be needed to advance our understanding.

A number of indirect effects also may be posed by the release or escape of cultured tilapia stocks into the wild. Indirect effects generally highlight the strong relationship between the ecology of tilapia species and their genetics (Figure 8.1). Released cultured stock may reduce abundance, and hence the effective population sizes (N_e) of critical species in the receiving

ecosystem through competition, predation, habitat alteration, or changes in community trophic structure or food webs [63]. This decrease in N_e could cause a loss of genetic variability and adaptive ability to changing selective pressure, possibly leading to an increase in the likelihood of inbreeding and extinction.

The level of impact stemming from establishment of these "escapee" genetic resources in an ecosystem is influenced by three factors: the species' invasiveness, the fitness of the selectively-bred stock, and characteristics (specifically, the invasibility or vulnerability to invasion) of the receiving community [71]. Invasiveness refers to the ability of a cultured stock to escape, disperse, and become feral in aquatic communities, and tilapias, along with other aquaculture species, exhibit great abilities to disperse and become established in non-native ecosystems.

Selective breeding that increases fitness may increase the likelihood of a cultured species becoming established in a receiving ecosystem (e.g., significant impacts on native soil, vegetation and animals by feral hogs in southeastern USA [72], and feral horses in Australia [73]). However, experience from selective breeding in domestic farm animals for production purposes suggests that this is not usually the case, and is strictly case-dependent. Physiological imbalances or growth demands in natural environments with limited food availability tend to decrease the fitness of selectively-bred stock in the wild. Nevertheless, it is possible for selectively-bred stocks to overcome one fitness component if other components, such as juvenile viability, adult viability, age at sexual maturity, female fecundity, male fertility, and mating success are enhanced through the selective breeding process [74]. Whether selectively bred tilapia show increased or decreased fitness in the wild has yet to be assessed experimentally.

A stable community is one whose structure and function return to their initial conditions after a perturbation [75]. A stable ecosystem will quickly recover from a fish escape event. It has been

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shown that decreases in native species are more common in low-diversity aquatic ecosystems following introductions of tilapias (e.g., high elevation lakes of Madagascar with few native species), than in high-diversity ecosystems (e.g., coastal lakes with many native species) [76]. Despite widespread introductions into Asian waters, explicit evidence on the ecological and genetic impacts of these

non-native tilapias as a whole is scanty [22]. The scanty evidence of the impacts of tilapias in Asia could be due to the absence of conspecifics and other related fish species in communities of that region.

This lack of information also could be attributed in part to poor assessment of "before" and "after" states of the receiving ecosystems as part of deliberate species introductions, especially for aquaculture.

Release or escape of the GIFT/GST strain into African waters may have the potential to be highly damaging. These selectively-bred strains could mate with wild stocks to set off the genetic impact scenarios described above. Apart from there being related, wild tilapia stocks with which to interbreed, African countries currently lack the capacity to prevent the escape of selectively-bred fish from aquaculture facilities or to prevent the intentional release of these fish into the wild. Also, there is little data on the baseline condition of the receiving ecosystems before the introduction of selectively-bred tilapia.

While Brummett and Ponzoni [77] and Ponzoni *et al.* [23] do not associate use of genetically improved tilapia strains in Africa with a high level of concern, Hallerman and Hilsdorf [78] noted that considerable molecular and adaptive variation exists within the species *O. niloticus*. The species has an exceptional ability to colonize and adapt to a wide range of habitats, ranging from small forest rivers to large drainages and lakes, as well as alkaline pools with hot springs

[79,80]. At a general level, the description of seven subspecies based on eco-morphology [79] reflects adaptive divergence.

Multiple putative evolutionarily significant units (ESUs) correspond more strongly to bioregions, however, than to subspecies. Bezault *et al.* [81] discuss the hypothesis that *O. n. filoa* and *O. n. cancellatus* are differentially adapted ecotypes rather than valid subspecies; they may constitute ESUs. Additional ESUs may be detected upon detailed survey; for example, Nyingi *et al.* [82] found a unique genetic resource in a recently discovered population from a warm water spring, a tributary of the Loboi Swamp in Kenya. Sex determination systems of natural populations adapted to three extreme thermal regimes showed thermosensitivity of sex differentiation [81], indicating either genotype-environment interaction or epigenetic effects [83] upon sex determination. Observation of genetic differentiation among *O. niloticus* populations within regions supports the existence of multiple management units (MUs) within certain ESUs, for example, in the Ethiopian and Nilotic regions. In the latter, analysis of microsatellite variation among five Egyptian populations [84] indicated distinct groups respectively inhabiting the deeper lotic Nile River, the shallow less lotic Delta lakes, and the upstream Nile River. The economic importance of *O. niloticus* worldwide makes detailed knowledge of its genetic resources pivotal for sustainable use of the species in aquaculture operations [85]. Hence, detailed consideration of adaptive differentiation is needed to defensibly assess genetic risk from culture of selectively bred *O. niloticus* in Africa.

Several international and national agreements address management of genetic resources. The major one is the Cartagena Protocol on Biosafety developed to implement the Convention on Biological Diversity, which came into effect in 2003, that which governs the movement of living modified organisms (LMOs) resulting from modern biotechnology from one country to another

[86]; Convention articles 15, 16, and 22 outline guidelines on risk assessment, risk management and capacity building with regards to LMOs. Kapuscinski *et al.* [87] outline the steps to be taken by developing countries to strengthen scientific and technical capacity to address environmental biosafety issues associated with LMOs; while the risks associated with LMOs and selectively bred stocks may differ, the risk assessment framework developed for LMOs could serve as a useful resource for countries considering the prospect of importing existing selectively bred strains or developing their own strains.

Potential economic benefits of the GIFT strain in Africa; case study of Ghana

Model

Against this background, we estimated the potential economic benefits of using selectively bred tilapia strains in Africa. We focused upon the GIFT strain for which production traits and prices are known and approached the benefit assessment by applying the economic surplus model, the most common method for analyzing the economic benefits of agricultural research in a partial equilibrium framework [88,89]. This analysis has been used to study, *ex ante*, the benefits of agricultural research for various innovations and for a number of countries (e.g., marker-assisted rice breeding in Southeastern Asia [90], and cassava breeding in sub-Saharan Africa [91]). Total economic benefits associated with a new technology for a non-traded commodity (Ghana currently exports very little freshwater fish; [92]) can be represented by the formula:

$$\Delta TS = PQK \, (1 + 0.5Zn) \tag{1}$$

where P and Q are the initial equilibrium price and quantity, respectively; $Z = Ke/(e + n)$ is the relative reduction in price due to the supply shift resulting from the new technology; e is supply elasticity, and n is demand elasticity (absolute value), which reflect how responsive the quantity

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supplied and quantity demanded are to changes in prices, respectively; and K is the shift in the

supply curve as a proportion of the initial price. K is calculated as:

$$K = \left(\frac{E(Y)}{\varepsilon}\right) - \left(\frac{E(C)}{1+E(Y)}\right) \times p \times A \times (1 - d) \qquad (2)$$

where E(Y) is the expected proportionate yield increase per hectare after the adoption of the new

technology; E(C) is the expected proportionate change in variable input cost per hectare; p is the

probability of success associated with the research; A is the adoption rate for the technology; and

d is the depreciation rate of the new technology [89].

   "Economic benefits" is the change in total economic surplus for each year, and the costs are

the expenditures on the research projects plus estimated after-project costs related to developing

and disseminating the new varieties. The annual costs and benefits are netted and totaled using

the discount rate to calculate a net present value (NPV) using the standard NPV formula:

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t} \qquad (3)$$

where: R_t is the benefits in year t; C_t is research, development, and dissemination cost in year t;

and i is the discount rate. In other words, the NPV is calculated as the sum of future benefits,

minus the costs associated with the project discounted over time.

Data and key assumptions

   Several factors must be considered to estimate the economic benefits of an agricultural

innovation using the economic surplus model: (1) the proportion of farmers who adopt the

innovation over time; (2) the price of the commodity; (3) the change in yield of the commodity

with the new technology;

(4) the nature of the market, as products that are traded may not experience price declines if

production increases [37,89]; (5) the time it takes to develop the innovation, and the number of years for maximum adoption to be reached; and (6) the discount rate for future benefits compared to current benefits, since for example, a 5% discount rate implies that after 20 years the calculated benefits of the new technology are not sensitive to the usual depreciation of a new technology that occurs with time.

Dey [37] found that the adoption of the GIFT strain in Bangladesh, China, the Philippines, Thailand, and Vietnam led to yield increases of between 24% and 61%. Since this information is not available for Ghana, we used the mean yield change across these five countries (41.4%), bounded by 24% and 61% for our calculations. The Food and Agricultural Organization estimated Ghana's Nile tilapia aquaculture production at 18,200 tons in 2011 [93]. Increases in Nile tilapia aquaculture production in the four preceding years were 1600 t, 1576 t, 2748 t, and 8776 t, respectively. Therefore, we extrapolated the aquaculture production of tilapia in 2012 to be 28,200 t, an increase of 10,000 t over 2011's production value. We calculated the price per ton of production as $2,646 by dividing FAO's 2011 estimate of the value of production ($48,159,000) by the annual production that year (18,200 t).

Experience from tilapia culture indicates that the only production cost variable expected to be directly impacted by the adoption of the GIFT strain is fingerling price. Fingerling cost constitutes approximately 14% of total costs in a typical enterprise budget for a tilapia farm [94]. Also, according to the Asian Development Bank [95], one of the consequences of the introduction of the GIFT strain in the Philippines was the increase in the price of GIFT fingerlings by 150% compared to non-GIFT fingerlings. Assuming this same increase in fingerling price with the adoption of the GIFT strain in Ghana, total production costs will be increased by 20%. This increase in total costs is expected to incorporate increases and decreases

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in all input costs resulting from the adoption of the new strain. We also assumed that the technology will be available to Ghanaian farmers from 2013, since the country took delivery of the strain officially in 2012 (Dr. Joseph Padi, personal communication).), although primarily for research purposes.

Dey [37] defined "early" GIFT adoption rates to be 30%–40% during the initial dissemination of the technology in Asia, peaking at 70% at the latter stages. We are not aware of any data on supply and demand elasticities of tilapia in Ghana. In the absence of such studies, a supply elasticity of 0.5 usually is applied to perennial crops and other livestock, and demand elasticity of 1 can be used for most livestock [89]. Since the GIFT technology exists already, the probability of success of GIFT research can be assumed to be 100%. Research and development costs also can be assumed to be zero.

Following Ponzoni *et al.* [23], we anticipate that a government department, such as the Aquaculture Research and Development Center in Ghana, will have to invest in the establishment and running of a nucleus to continuously maintain and improve the strain. Hatchery operators in Ghana will replace their brood stock annually with the latest version of the strain from the nucleus. This arrangement will ensure that production will benefit from the greatest amount of genetic gain. However, this arrangement will have cost implications. Ponzoni *et al.* ([23]; Table 4) provide values for annual or recurrent costs of such a program, with the most likely value being $60,000. We assume that the initial investment cost component is not necessary in our case, since the strain already has been developed. Recurrent costs include dissemination costs, and the costs of continuous improvement and maintenance. We acknowledge that continuous improvement could result in the continuous increase in growth rate

and other traits, such as survival and disease resistance, and this expectation should be captured in the sensitivity analysis (see next section).

Analysis

We included the data above in a modified version of a spreadsheet that incorporates all the model formulas obtained from George W. Norton (Department of Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA). To the typical or most likely value of each key variable, we added a possible minimum and a possible maximum to create a triangular distribution, based on the assumptions or extrapolations from the preceding sub-section, in order to incorporate uncertainty (Table 8.1), and then conducted economic risk analysis by running Monte Carlo simulations using the @Risk 6 software (Palisade Corporation, Ithaca, NY, USA). We ran the model to calculate the net present values of the annual economic benefits of the GIFT technology for 20 years, at a discount rate of 5%, in Microsoft Excel. The total net present value (NPV) then was calculated as the sum of these annual benefits. We also conducted an analysis to determine how sensitive the average NPV was to the key variables in Table 8.1.

Table 8.1. Values of key variables used in the Monte Carlo simulation to estimate net present value of adopting the GIFT strain in Ghana.

Variable	Minimum	Most likely	Maximum
Recurrent costs ($)	30,000	60,000	90,000
Increase in production costs (%)	10	20	30
2012 Nile tilapia aquaculture production (metric tons)	26,200	28,200	30,200
Peak adoption rate (%)	60	70	80
Yield change (%)	24	41.4	61

Results

 The estimated cumulative net benefits of adoption of the Genetically Improved Farmed Tilapia strain in Ghana (discounted at 5%) over twenty years ranged from over $130 million to about $650 million, with a mean close to $400 million (Figure 8.2). There is a probability of about 40% that the NPV is greater than $400 million (Figure 8.3). Sensitivity analysis indicated that the variable with the biggest impact on the mean NPV (across the variable's range of values from Table 8.1) was the level of change in the aquaculture yield of Nile tilapia resulting from the adoption of the GIFT strain (Figure 8.4). Not as important were the peak rate of adoption of the strain, level of change in production costs with the adoption of GIFT, the production of Nile tilapia in the year preceding the introduction of the GIFT strain, and the recurrent costs associated with maintaining, improving, and disseminating the new strain, in that order.
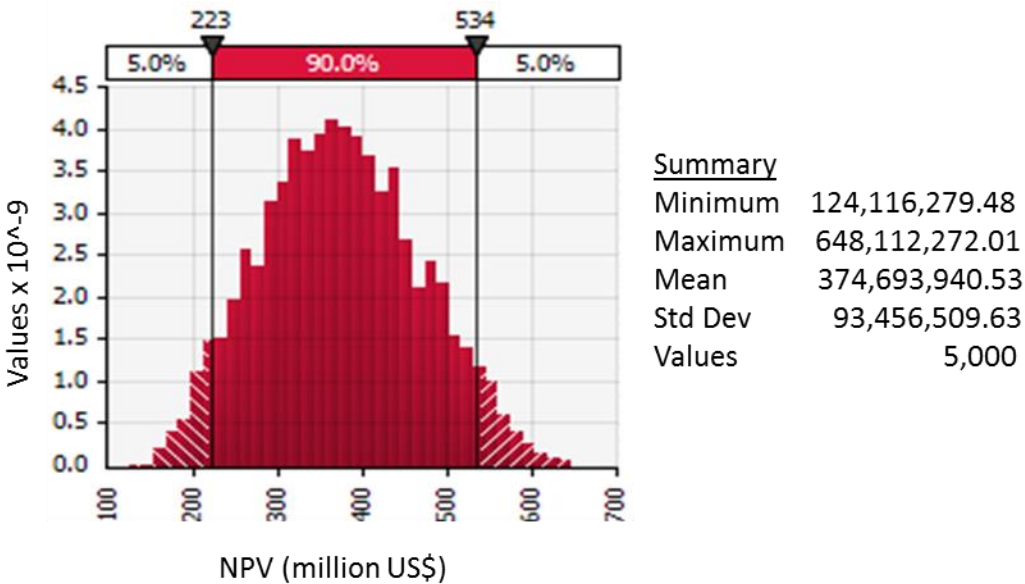
Figure 8.2. Summary of results of Monte Carlo simulation to determine net present value (NPV) in US$ for the adoption of GIFT-strain tilapia in Ghana, showing a 90% confidence interval.
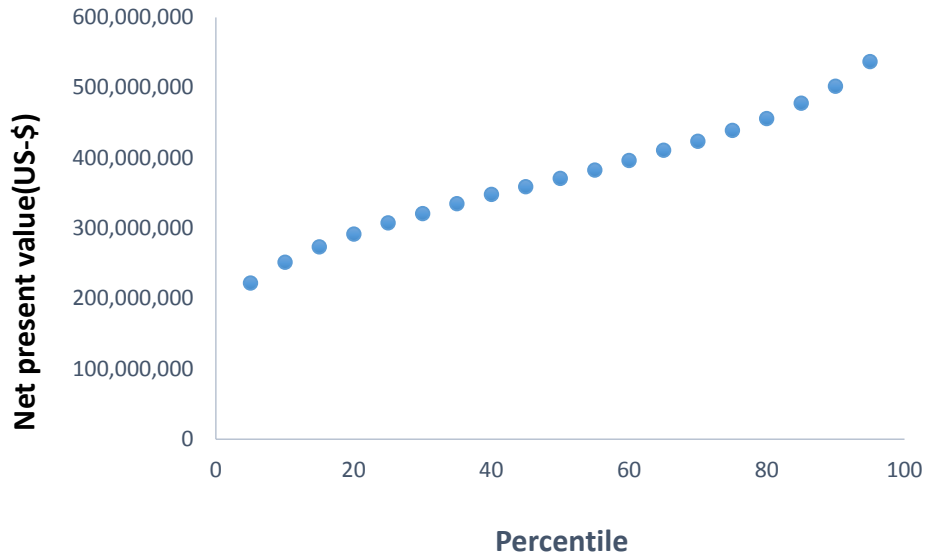
Figure 8.3. Net present values (NPV) at different percentiles for the adoption of GIFT-strain tilapia in Ghana.
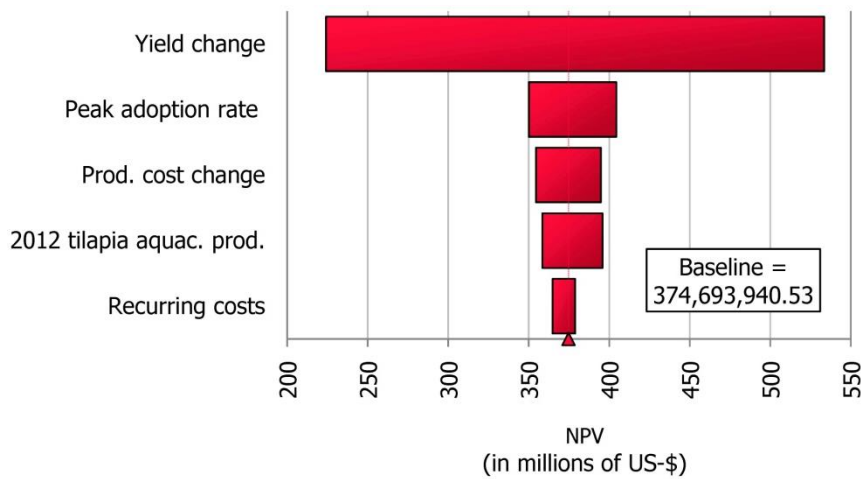
Figure 8.4. Relative impacts of key variables on the mean net present value of adoption of GIFT-strain tilapia in Ghana across the range of key variables.

Discussion

According to the World Bank [96], the gross domestic product (GDP) of Ghana was $40.71 billion in 2012. This implies that Ghana stands to benefit by approximately 1% of the country's GDP from the introduction of the GIFT strain. The calculated NPV is also approximately 2.5%

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of the component of the GDP contributed by the country's agriculture sector [97]. This percentage is significant, given that the total farmed fish share of the Ghana fish market is currently 3% [98]. The Ghana National Aquaculture Development Plan [98] quotes the value of commercially-farmed fish as $28.44 million in 2010. This value should be close to an optimistic $40 million at the time of developing this manuscript (May 2014) if any progress in growth has been made. Our calculated NPV ($400 million over 20 years) indicates that Ghana could achieve or add on about 50% of the annual farmed fish value from the introduction of the GIFT strain alone. Ponzoni *et al.* [23] conducted an investment appraisal of a genetic improvement program in Nile tilapia and found the most conservative estimates of economic benefits ranging between 4 and 32 million US$. Their simulated timeframe was 10 years and included the cost of developing the strain from scratch. However, our analysis was done for a period of 20 years with the assumption that the strain was already developed, which is the case with both the GIFT and Akosombo strains.

The version of the economic surplus model that we used assumed that Ghana exports little to no tilapia, as is the case currently. Therefore, the computed NPV values could be higher if this assumption no longer holds true, as might be the case when there is an abundant supply of tilapia. Clearly Ghana, and hence Africa, stands to gain substantial socio-economic benefits from the adoption of the GIFT strain. Some of the possible key benefits include the increased availability of relatively low-cost,
high-quality animal protein from the increased yield; increased employment within the expanded aquaculture sector; and possible foreign exchange earnings in the long term.

The Monte Carlo simulation technique allowed us to estimate ranges for variables with uncertain values and to analyze economic risk stemming from changes in these values on net

present value.

This approach incorporated the element of uncertainty into our computations. Of the five assumed or extrapolated key variables, the cost of maintenance, continuous improvement, and dissemination of the new strain in Ghana (recurring costs) had the least impact on changes in mean NPV. It is intuitive that not much investment will be needed in the dissemination of the GIFT strain in Ghana to cage fish farmers on Volta Lake and to the most progressive pond farmers in other parts of the country. We have observed that this group of tilapia farmers has widely adopted the locally improved Akosombo strain of *O. niloticus*. However, more work needs to be done to disseminate these relatively new strains of tilapia to the majority of pond farmers, who are still farming inferior, mixed, and unknown stocks of tilapia more than a decade after the development and dissemination of the Akosombo strain by the ARDEC started [28,85]. Our analysis shows how small the investment cost of maintaining, continuous improvement, and dissemination of improved strains of tilapia could be relative to the economic benefits of these strains reaching all farmers. It is a sound policy for the government of Ghana to invest in the dissemination of the improved Akosombo and/or the GIFT strain of tilapia.

On the other hand, the variable with the largest impact on mean NPV was the difference in aquaculture yield between the GIFT and local strains of Nile tilapia. A number of production bottlenecks exist currently in the Ghanaian and African aquaculture industry. The AquaFish Innovation Lab, formerly the Aquaculture and Fisheries Collaborative Research Support Program (AquaFish CRSP) has observed, through on-farm demonstrations in Ghana, that for pond farmers growing the Akosombo strain of *O. niloticus*, improving pond construction and maintenance, supplementary use of commercial feeds, water quality management, and control of excessive reproduction in ponds (by hormonal sex-reversal and polyculture with a predator) could result in

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an increase of 2–4 times the current average yields from unimproved local strains. Other significant bottlenecks observed are institutional, including, inadequate access to urban markets due to bad roads, and unreliable electricity supply leading to absence of cold-storage in the rural tilapia value-chain and therefore inefficient and risky post-harvest handling [99]. Addressing these problems would increase the yield and income from improved local strains of tilapia to the extent that the differences in yield between local and GIFT strains could diminish the calculated NPV for the GIFT strain. Notably, some of these bottlenecks have the potential to limit the production and profitability of the GIFT strain, irrespective of its superior growth rate. For example, a farmer who invests in the necessary better management practices and the extra cost of fingerlings of the GIFT strain but who cannot market his or her fish effectively may become skeptical about the value of investing in increased production at an increased cost. Therefore, the problems currently impeding the production of local strains could also affect the realization of the attractive economic benefit computed for GIFT in this study.

Other socio-economic impacts are possible with the adoption of improved strains (see Figure 8.1). These include higher incomes, better nutrition (more protein), reduced poverty, improved health and welfare. Also, since women are traditionally involved more in processing and marketing of fish, they too will benefit from the adoption of improved strains. This analysis focused generally on the GIFT strain as a representation of an improved tilapia strain. This analysis will still hold true with the Akosombo or any other improved strain. At this time, we are not aware of any completed biological studies comparing the performance of these two strains. These extensions are recommended for future studies.

Conclusions

Clearly, the introduction of the GIFT strain in Africa has the potential for substantial economic benefits. However, the potential ecological impacts of the GIFT strain on African aquatic ecosystems cannot be overlooked. After a country makes the decision to introduce the GIFT tilapia strain, each facility that would like to culture this strain must be able to show the structures it has put in place to prevent escapes and both intentional and inadvertent release into the wild. Of course, facilities prone to such events as flooding should not be allowed to culture the GIFT strain. Possible methods to achieve this goal of non-release of the GIFT strain from farms include physical confinement, reproductive confinement, and operations management [63]. Effective physical confinement involves a combination of measures, such as mechanical barriers (e.g., standpipe screens, gravel traps, *etc.*). Also, effluents could be filtered to exclude any life-stage of the strain. Reproductive confinement is particularly important where physical confinement alone cannot be relied on. Production of GIFT tilapia could be limited to either monosex or sterile individuals. Operations management includes those measures put in place on a tilapia farm to ensure that the activities of all workers are in conformance with the goal of effective confinement, to prevent any unauthorized human access to the facility, and to routinely inspect and maintain all physical barriers to ensure they are constantly operational [63]. Operations management also could ensure that only dead fish on ice are marketed.

African governments, such as Ghana, which have obtained, or are in the process of obtaining, the GIFT germplasm should commission rigorous baseline and ecological risk analyses. Since each country has unique conditions, exhaustive and baseline ecological, genetic, and economic benefit and risk analyses should be conducted separately for each country. Efforts also must be made to improve the culture of locally available strains of tilapia. Improvements in management

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practices and infrastructure could go a long way to increase the yield of local strains even if genetically-improved strains are not introduced. These improvements also will ensure that the full potential of introduced, improved strains are realized.

Governments also must develop the political will to refuse, or to discontinue the adoption of, the GIFT strain if results of environmental, genetic and economic risk analyses point them in that direction. Each country should develop the capacity to prevent the needless exposure of native aquatic ecosystems to preventable risk, while reaping the substantial economic benefits of adopting the GIFT or similar improved strains of tilapia.

Acknowledgments

Authors' contributions

The study was conceived by Frimpong, and designed with Hallerman. Ansah did the desk study, data collection and economic analysis, and a first draft of results. Frimpong extended interpretation and discussion of economic analysis results. Each author contributed to writing and editing of specific portions of the manuscript as follows: Yaw Ansah (Economics and

Ecology); Emmanuel Frimpong (Ecology and Economics); and Eric Hallerman (Genetics and

Ecology).

Conflicts of interest

The authors declare no conflict of interest.

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Chapter 9: Summary and General Conclusions

Ghana and other sub-Saharan Africa countries could benefit immensely from the adoption of aquaculture best management practices and other technologies that would increase both the profitability and efficiency of resource use on fish farms while reducing negative environmental impacts of aquaculture. This study has made a number of key findings which have implications for agricultural innovation extension, farm management, and aquaculture policy development in this region.

Although considered low-intensity production systems, nutrients and solids in study ponds were found to be higher than levels expected even in intensive culture ponds by wide margins, whereas BOD_5 was within the range expected for semi-intensive ponds. Pond water quality was significantly higher with commercial floating feed. The water-reuse BMP also prevented pollutants from leaving ponds altogether for the number of cycles for which pond water was reused. The adoption rate of these BMPs then was used to extrapolate the reductions in the amount of pollution entering effluents from fish farms. The Markov model estimated the maximum adoption of floating feed to be 58%, while the minimum-data method of the tradeoffs (TOA-MD) analysis estimated 38%. Although the dichotomy in the results is explained by the different assumptions and methods, both results point to the fact that adoption of commercial floating fish feed in pond farming in Ghana is expected to remain low under current economic conditions, with its feed costs and the market prices of produced tilapia. My TOA-MD results further indicated that incentives of about US$ 6,000/year need to be paid per 0.6 ha pond surface area to push adoption of the feed BMP to 50% for two production cycles within each year, while about US$ 12,000/year will be needed to ensure 70% adoption in Ghana. These payments could be considered in policies aimed at further reduction loading of water pollutants from fish farms.

At the 38% adoption rate of the floating feed BMP, there were significant reductions in the loadings of all water quality variables (nitrogen, phosphorus, solids, and BOD_5), with the exception of dissolved inorganic nitrogen (DIN). However, the reduction in dissolved organic nitrogen (DON) was enough to cause an overall reduction in total dissolved nitrogen (TDN). Adoption of the water reuse BMP has the potential to increase the supply of ecosystem services far beyond that obtainable from adopting the floating feed BMP. My results indicated that a 19% adoption rate of water-reuse will result in reductions in the levels of all pollutants by 200% - 3,200% more than that from the floating feed BMP. Incentives and effective dissemination will encourage the adoption of these and other environmental BMPs, which will result in a sustainable fish farming industry in Ghana and sub-regionally.

Two common misconceptions in fish farming circles are that the von Bertalanffy growth model is the best option to model fish growth under all circumstances, and that ponds must be emptied after every production cycle and refilled with fresh water for the next cycle. This study has shown that the logistic model is a better alternative to either the von Bertalanffy model or the common practice of joining average size over time for modelling the growth of *Oreochromis niloticus* under aquaculture conditions. It is not unusual to observe a lower average fish weight from a pond at a later time-step, due to random sampling or observational error, although a fitted growth curve, regardless of model choice, is a monotonically increasing function. A fitted model allows for statistically defensible interpolation of weight-at-age for any time in the observation range and not just the times when fish are observed. Moreover, extrapolations beyond the last observation is often desired, and interpolations and extrapolations are not defensible without fitting a model. Also, because each model fits differently to the same data, model choice has implications for the predicted final weight beyond the data range. If the most appropriate model

is not used, inaccurate values for final weight and yield will be entered on enterprise budgets, which will lead to inaccurate assessments of profitability and subsequent management decisions.

In contrast to popular perception by fish farmers in Ghana, I found no significant differences in fish weight or yield between the water re-use BMP and the use of fresh water for each production cycle. It is conceivable that the reuse of pond water for multiple cycles surely will result in the saving of the cost of water purchase and access and a possible reduction in pond fertilization and feeding costs. However, since I lacked information on the cost savings resulting from reusing pond water, I worked with the assumption of equal costs between new and reused water, and this assumption implied similar profits for the two scenarios when growth rates are not statistically different. Future analyses could quantify the differences in production costs between using the two water types. Such analysis will likely show that the reuse of pond water is more profitable than emptying ponds after each production cycle.

In the absence of cost estimates for water reuse, only the adoption of the feed BMP was used in the analyses of the direct impacts of BMP adoption on farm profitability and social welfare. Adoption of the commercial floating feed BMP resulted in an average of 100% increase in fish final weight and yield through a production cycle. This higher yield resulted in significant differences in profitability between the two feed types, with or without loans. The probability of making a profit with the floating feed BMP was 86% higher than that of using the sinking feed alternative. The probability of profitability without a loan was 32% higher than with a loan. The most profitable feed-loan scenario was commercial floating feed without a loan. This scenario was 140% more likely to be profitable than using sinking feed + loan, 86% more likely than sinking feed + no loan, and 32% more likely than floating feed + loan. However, using the more expensive floating feed resulted in total costs that were about three times that resulting from

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using sinking feed. To enable fish farmers adopt commercial floating feed, especially with no loans, it is imperative that ways be found to reduce feed cost to farmers, which constitutes > 50% of total costs on farms that adopt the floating feed BMP. Reducing the amount of feed used, while maintaining the rate of fish growth is the most direct means of reducing the amount feed used. It may be possible to maintain current growth rate with up to 50% (alternate-day feeding) of the feeding rate for commercial floating feed. Primary production in earthen ponds also could serve as a significant supplement to reduce the amount of floating feed needed. More research is needed on feeding regimes that focus less strictly on percent body weight.

A possible way to reduce the amount of feed needed is better management of genetic resources. The inferior genetic quality of tilapia fingerlings on the African continent has been the subject of a number of studies. Using the approach used to develop the Genetically-Improved Farmed Tilapia (GIFT) line, Ghana has developed a selectively-bred, high-performing tilapia strain, the Akosombo strain. Due to the fast rate of growth of fish from the GIFT and Akosombo strains, market sizes can be reached in a shorter time. Therefore, feed and other resources are utilized more effectively and efficiently.

This study also showed that the effective and efficient use of fish farm inputs such as floating feed and better strains resulted significant social welfare benefits to Ghana. Social benefits that could accrue to the country, in terms of net present value (NPV), are about US$ 11 million from the adoption of commercial floating feed in pond fish farming, and US$ 375 million from the adoption of the GIFT strain in Ghana. These figures represent 0.02 and 1% of the country's gross domestic product (GDP), respectively. This result indicates that any BMP or innovation that has a significant impact on fish yield also will have a significant impact on mean NPV and social welfare.

Due to the promise of substantial social welfare benefits from using genetically-improved strains, there have been recent calls for the introduction of the GIFT strain itself into Africa. But this study revealed a number of potential negative ecological and genetic impacts of this introduction. Thus, African governments, which have obtained, or are in the process of obtaining, the GIFT germplasm should commission rigorous baseline and ecological risk analyses. Since each country has its own unique conditions, exhaustive and baseline ecological, genetic, and economic benefit and risk analyses should be conducted separately for each country. Efforts also must be made to improve the culture of locally available strains of tilapia. Improvements in management practices and infrastructure could increase the yield and profitability of the local strains even if genetically-improved strains are not introduced. These improvements also will ensure the realization of the full potential of introduced strains.

Generally, the characteristics that had the strongest influence on the combined adoption of these BMPs were: farmer's awareness of the feed BMP, perceived necessity and relative profitability of the water reuse BMP, and farmer's years of experience. I also found that the pond water-reuse BMP requires more extension effort to disseminate than the commercial feed BMP, although the high cost of this feed type could be a barrier for its widespread adoption. A combination of central media (workshops), demonstrations, and lateral diffusion was found to be the most effective channel for disseminating these BMPs, although workshops had the highest average ranking. Therefore to ensure the successful adoption of aquaculture BMPs, regular well-planned workshops (incorporating effective demonstrations and opportunities for lateral-diffusion) should be organized to both create awareness and to create an atmosphere conducive to target farmers at multiple stages of the innovation decision process.

General References

The following is a list of references used in the general introduction and general conclusions chapters. All other chapter references appear directly below each chapter.

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Appendices

Appendix A: Baseline questionnaire used to characterize Ghanaian fish farms, farmer, and households

Baseline Questionnaire

I am undertaking a study to characterize the adoption of aquaculture Best Management Practices in Ghana. The information you provide will be used to make recommendations that inform policy-makers on feasible ways to maximize the profitability of small-scale earthen pond operations, with the least environmental impact. Thank you.

Enumerator………………………………… Translator………………………………………….

Region………… District………………Town………………………. Date……………………..

The following questions are designed to learn about your earthen pond aquaculture operations.

Physical characteristics of fish farm

      1. What is the size of your farm land? (Not just fish farm, but all farm land)

_____

      2. What is the land tenure arrangement for your farm?

a. Family land

b. Lease

c. Other, please specify _____

      3. Do you own this farm?

      a. Yes

b. No

4. What is your position at this farm?

a. Director

b. Caretaker

c. Farm manager

d. Other, please specify_____

5. What is the number of earthen ponds?

_____

6. What is the source of water for your aquaculture operations? Check all that apply.

a. River/stream

b. Borehole

c. Sub-surface

d. Other, please specify _____

7. Will you describe the quality (for fish culture) of this/these water source(s) as

    reliable?

	Yes	No	Somewhat reliable
River/stream			
Borehole			
Sub-surface			
Other, please specify			

8. Will you describe the quantity of this/these water source(s) as reliable?

	Yes	No	Somewhat reliable
River/stream			
Borehole			
Sub-surface			
Other, please specify			

9. How many species of fish do you culture on your farm?

a. One

b. Two

c. Three or more

10. If you culture more than one species, please indicate which ponds contain which

species on table on page 14.

11. What was the length of your last production cycle (from stocking to harvest)?

	Tilapia	Catfish	Other
6 months or less			
6 – 8 months			

8 – 12 months			
More than 12 months			

12. What was your average annual fish production (please indicate kilogams or tonnes for

each species) for 2010 or your last year of production (approximate or exact)?

Species	Production
Tilapia	
Catfish	
Other (s)	

13. What proportion of this production is sold? (ie, Subsistence vs commercial)?

_____

14. What is the average sale price of your fish per kg (or whatever unit)?

Species	Sale price
Tilapia	
Catfish	
Other (s)	

15. Is labor for your farm readily available?

a. Very readily available

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b. Somewhat available

c. Not readily available

d. Very difficult to find

e. Totally unavailable

16. How many people are employed on your farm ?

Wage/Salaried workers	
Casual (within the last year) workers	

17. What was the initial source of capital for your farm? Please check all that apply.

a. Personal savings

b. Family loan

c. Bank loan

d. Government loan

e. Cooperative loan

f. Microfinance loan

g. Other, please specify_____

18. What is your current source of funding for the business? Please check all that apply.

a. Personal savings

b. Family loan

c. Bank loan

d. Government loan

e. Cooperative loan

f. Microfinance loan

g. Other, please specify_____

Please use the scale below to indicate how important the following constraints are, in your pond aquaculture operations, especially for your previous production cycle. Please circle the option applicable to you.

Very Important = VI, Slightly Important = SI, Slightly Unimportant = SU, Not Important = NI, Not Sure = NS.

19. Lack of funds   VI   SI   SU   NI   NS

20. Cost of feed   VI   SI   SU   NI   NS

21. Lack of feed   VI   SI   SU   NI   NS

22. Lack of good quality feed   VI   SI   SU   NI   NS

23. Lack of fingerlings   VI   SI   SU   NI   NS

24. Lack of knowledge about pond culture operations

VI   SI   SU   NI   NS

25. Lack of extension services   VI   SI   SU   NI   NS

26. Inability to make profit   VI   SI   SU   NI   NS

27. Conflict over land   VI   SI   SU   NI   NS

28. Lack of market   VI   SI   SU   NI   NS

29. Theft   VI   SI   SU   NI   NS

30. Other, _____   VI   SI   SU   NI   NS

BMPs

31. Are you aware of the following management practices?

	Yes	No
Usage of old-production water		
Usage of pelleted, floating feed		

32. If yes, what was your source of information? Please list all sources.

Usage of old-production water	

Usage of pelleted, floating feed	

33. How many times do you feed your fish in a day? Show on **Page 14** if these times are different for the different ponds.

_____

34. At what times is feeding carried out? Show on **Page 14** if these times are different for the different ponds.

_____

35. What type of feed do you use?

a. floating only (pelleted)

b. sinking only (**skip to Q39**)

c. both (if both, indicate which ponds use which type in table on **page 14**)

d. I switch from one type of feed to the other in one production cycle (please give more details -

why and **how** do you do this switching?) _____

_____

_____

37. If floating, since when have you been using floating feed?

_____

38. If floating, which brand(s) do you use?

_____

39. If floating, please indicate what made you use floating feed. Please check all that apply.

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a. More profitable

b. Easier to use

c. More environmentally-friendly

d. Other, please specify_____

_____

40. What prevents you from switching completely to floating feed? Check all that apply

a. Cost of feed

b. Availability of feed.

c. Other, please specify_____

41. Do you think you would make more profit if you used complete floating feed

throughout your production cycle?

a. Yes

b. No

c. Don't know

42. Do you think it is necessary to use complete floating feed throughout your production

cycle?

d. Yes

e. No

43. If you are using sinking feed, are you planning to switch?

a. Yes

b. No

Why?

_____

_____

44. Where do you get your feed? List all that apply

Feed name or ingredient	Town(s) bought from

45. How much does it cost to buy feed per specified weight (25kg bag, 50kg bag, etc?

Feed name or ingredient	Typical bag weight (approx)	Cost

46. How much does it cost to transport the feed to your farm (specify feed weight from

above)?

Feed name or ingredient	Source town	Transport cost (or approx fuel cost if your own vehicle)

47. Do you drain all your ponds after each harvest?

    a. Yes

    b. No

48. If yes, do you undertake surface or bottom draining

a. Surface

b. Bottom

c. Both (indicate on table for which ponds)

49. If no draining, since when have you been using old-production water?

_____

50. If no draining, could you share what made you use old-production water?

_____

51. If you drain, in your view how easy is it to switch to using old-production water?

   (Perceived ease of switching to no draining)

    a. Easy

    b. Somewhat easy

    c. Somewhat difficult

d. Difficult

52. If draining, in your view is it necessary to switch to using old-production water?

    a. Necessary

    b. Not necessary

53. If draining, will you switch?

    a. Yes

    b. No

Why or why not?

_____

_____

54. Do you think you would make more or less profit if you used old-production water

    for multiple production cycles?

    a. More profit

    b. Less profit

    c. Similar profit.

The next few questions are intended to know a little about you.

Socio-economic characteristics of the farmer

55. What is your gender?

    a. Male

    b. Female

56. How old are you?

57. What is your marital status

    a. Single

    b. Married

58. What is your household/family size?

Please fill out the following table for your household members (that is, those who live under the same roof with you AND share in your daily meals)

Name	Gender M/F	Relationship to respondent	Education	Age	Able to work on farm? (Y/N)

59. Level of education of owner/director

a. No formal education

b. Middle school graduate

c. High School graduate

d. Undergraduate and above

e. Other, please specify_____

60. Level of education of manager/caretaker/supervisor

a. No formal education

b. Middle school graduate

c. High School graduate

d. Undergraduate and above

e. Other, please specify_____

61. Is this this farm the owner's full-time work?

    a. Yes

    b. No

62. If no, please indicate his/her other income generating activities?

_____

_____

63. How many years have you been involved in agriculture?

_____

64. How many years have you been involved in fish farming?

_____

Please use the scale below to indicate how important the following sources of information are in your earthen-pond aquaculture operations. Please circle the option applicable to you.

Very Important = VI, Slightly Important = SI, Slightly Unimportant = SU, Not Important= NI.

65. Government Extension Services	VI	SI	SU	NI
66. NGO(s)	VI	SI	SU	NI
67. Other farmers	VI	SI	SU	NI
68. Personal Knowledge	VI	SI	SU	NI
69. Other_____	VI	SI	SU	NI

70. How many times did you meet a government extension agent within the last year?

a. More than 4 times

b. 3 – 4 times

c. 1 – 2 times

d. Never

71. Do you participate in on-farm trials? (Any fish farming on-farm training)

a. Yes

b. No

72. Are you a member of any farmers' association?

a. Yes

b. No

73. Did you attend any fish farming training programs within the past year?

a. Yes

b. No

74. Are you a member of a credit cooperative?

a. Yes

b. No

PLEASE FILL OUT TABLE ON NEXT PAGE.

Please fill out the following table for each pond on your farm (report on your last production cycle where applicable): Please show for

each species if there are multiple species in a pond

Pond #	Size (show units)	Species	Annual production (each species!) kg (for last prod. cycle)	Surface/ Bottom Drain (S/B/ NA /both)	Floating/ Sinking feed (F or S or NA)	Inflow (pump, gravity, seepage)	Feeding times	Daily quantity of feed used
1		1. 2. 3.	1. 2. 3.					
2		1. 2. 3.	1. 2. 3.					
3		1. 2. 3.	1. 2. 3.					
4		1. 2. 3.	1. 2. 3.					
5		1. 2. 3.	1. 2. 3.					
6		1. 2. 3.	1. 2. 3.					

Thank you very much!!

Appendix B: Follow-up Questionnaire to monitor the adoption rates of aquaculture best management practices in Ghana

Follow-up questionnaire

Hello, my name is _____. I am undertaking a study to characterize the adoption of aquaculture Best Management Practices in Ghana. The information you provide will be used to make recommendations that inform policy-makers on feasible ways to maximize the profitability of small-scale earthen pond operations, with the least environmental impact. Thank you.

Enumerator………………………………… Translator………………………..………………….

Region………… District………………………..Town……………………….. Date……………

1. Are you using floating feed?

    a. Yes

    b. No (**skip to Q6**)

2. If Yes, which brand(s) do you use?

    _____

3. **Please rank how important the following sources of information are in your decision to use floating feed (1 – highest, 2, 3, 4 - lowest) or NA – Not Applicable**

Source	Rank (Please enter only one option for each!)
Workshops	
Other farmers	
Demonstrations	
Other_____	

4. Do you use floating feed only for some ponds but not for others?

   a. Yes

   b. No

5. Do you switch from one type of feed to the other in one production cycle

   a. No

   b. Yes (please give more details - **why** and **how** do you do this switching?)

   _____

   _____

   _____

6. Do you drain all your ponds after each harvest?

   c. Yes

d. No (proceed to next question)

e. No, only some ponds (proceed to next question). Why only some?

_____

_____

7. **Please rank how important the following sources of information are in your decision to use old water (1 – highest, 2, 3, 4 - lowest) or NA – Not Applicable**

Source	Rank (Please enter only one option for each!)
Workshops	
Other farmers	
Demonstrations	
Other_____	

Thank you very much!!