WATERSHED & INTEGRATED COASTAL ZONE MANAGEMENT

CHARACTERIZATION OF POND EFFLUENTS AND BIOLOGICAL AND PHYSICOCHEMICAL ASSESSMENT OF RECEIVING WATERS IN GHANA

Watershed& Integrated Coastal Zone Management/Study/07WIZ01PU

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ABSTRACT

The interaction of pond aquaculture with the aquatic environment has the potential to be detrimental to the natural environment and in turn hurt the industry which depends on the same water sources for survival. Major problems may arise if pond effluents are not properly managed and could result in harsh regulations that can threaten the profitability of the industry. This study was conducted in the Ashanti and Brong Ahafo regions of Ghana, the leading regions in aquaculture production, to characterize the quality of potential pond effluents and the quality of receiving streams and use biological assessment techniques to investigate effects of ponds, if any, on receiving waters. A combination of standard questionnaire survey, field sampling, and laboratory analyses of pond water, receiving and reference stream water, fish and benthic macroinvertebrate sampling were used to generate needed data.

Statistical analyses were preceded by a detailed graphical analysis in Minitab®15. Pond typologies were developed through the K-means clustering procedure. A mixed-effects ANOVA with farm as random blocks and fixed location effects was the main model used to analyze data involving comparisons of pond, upstream, downstream, and reference sites; the Tukey procedure was used for post-hoc analyses of location effects. Other analyses simplified to t-tests or paired t-tests. Statistical significance was decided as $p \leq 0.05$ but marginal situations up to $p \leq 0.15$ were noted and incorporated in discussions.

Results indicate that ponds in the Ashanti and Brong Ahafo regions of Ghana generally hold a different water quality compared to receiving streams and that the receiving streams are of more natural total phosphorus, total nitrogen, suspended and settleable solids, and BOD_5 status. We found no evidence that receiving stream water quality or biota (fish and benthic macroinvertebrates) are adversely affected at the moment by aquaculture activities. Ancillary

information obtained from the survey indicates a rapidly growing industry with most farms started less than 10 years ago. Any potential effects of aquaculture in the future will depend on how effluents are managed, including the frequency and volume of releases and the conditions under which effluents are handled before reaching receiving waters. As farms increase in number, so will effluent burdens of receiving waters. Majority of farms already have some environmental Best Management Practices (BMPs) in place, including, water reuse mechanisms, vegetated ditches/canals, settling basins, draining into natural wetlands, and top release of pond water. Continuing to implement broadly focused environmental BMPs can obviate any need for regulations on aquaculture effluents in Ghana in the foreseeable future.

INTRODUCTION

In its interaction with natural water bodies, aquaculture as an industry is unique in the sense of being a user of water and a potential polluter as well. Given this reciprocal relationship, aquaculture practitioners should have a special interest in protecting their surrounding aquatic ecosystems (Baired et al. 1996). The search for a balance between growth and intensification of aquaculture and protection of natural fisheries and the environment continues. Four main components of aquaculture waste water are of interest; nutrients (including nitrogen (N) and phosphorus (P)), Biochemical Oxygen Demand (BOD), suspended solids, and pathogens (Cripps and Kelly 1996). Additions of nitrogen and phosphorus to natural freshwaters can cause eutrophication. In the United States, for instance, threats of nutrients from pond aquaculture was seen as significant enough to trigger rule-making process for aquaculture effluents by the Environmental Protection Agency (USEPA) (Boyd and Queiroz 2001). High concentration of settleable solids may be generated by harvesting methods draining from bottom of ponds and seining; ponds with heavy blooms of algae may discharge organic suspended solids in the form of plankton that will contribute to BOD. Natural organic fertilizers are commonly used in fish ponds. A test of a sample of 11 common feeds and four organic fertilizers used in Ghana indicated three of the feeds (biscuit waste, groundnut husk, and dried termite) and three of the organic fertilizers (cow manure, pig manure, and poultry manure) contained significant counts of fecal coliforms (Ampofo and Clerk 2003). Additionally, four out of 11 feeds (biscuit waste, cassava, groundnut husk, and termites) and all organic fertilizers (poultry manure, cow manure, pig manure, and cow blood) contained fecal streptococci (Ampofo and Clerk 2003). These and many pathogens may be passed on in effluents to receiving waters.

Environmental impacts of aquaculture on aquatic ecosystems are related to the species cultured, location of installations, intensity of operations, the morphology, limnology and hydrology and trophic status and assimilative capacity of the receiving water (Costa-Pierce 1996; Cripps and Kelly 1996; Boyd and Queiroz 2001). Thus, for example ponds located in relatively pristine watersheds are likely to alter receiving waters to a larger extent than those located in heavily agricultural watersheds. Consequently, to understand the potential threats of pond effluents it is necessary to characterize the background quality of the receiving water as well. Based on data synthesis, Costa-Pierce (1996) concluded that during normal operations of channel catfish ponds, total phosphorus (TP) releases are comparable to precipitation whereas during harvesting, mean TP discharges are comparable to concentration in runoff from intensive agriculture. The wide range of factors determining pollution potential of aquaculture necessitates a different way of categorizing aquaculture systems, even for those that culture the same or similar species; categorization will need to include management practices, such as stocking, draining and harvesting regimes. In Africa for instance, it is already recognized that the strategies for addressing problems arising from small-scale and large-scale commercial aquaculture operations will probably be different (Jamu and Brummett 2004). Environmental management practices for pond aquaculture will be most effective if developed for specific systems that have differing pollution potentials.

Without understanding of the differences among aquaculture systems, there is a tendency on the part of environmental advocacy groups and consequently decision makers to lump all systems together and exaggerate the impact of the industry. Such was the case after the publication of 'murky waters' by the Environmental Defense Fund and the subsequent decision by the USEPA to regulate virtually all aquaculture operations in the United States (Boyd and Tucker 2000). It is only a matter of time before the growing aquaculture industry in Africa will be confronted with competition for water and regulation of effluent discharges. Characterization of effluents would allow for a proactive management of the environmental effects of aquaculture. Proactive action will forestall the restrictive regulations that could result from regulatory agencies acting on insufficient or exaggerated assessments of the industry (Cripps and Kelly 1996; Muir 1996).

Pollution can limit the uses of water and aquatic resources, and water quality criteria have therefore been formulated on the bases of various uses (e.g., drinking water supply, agricultural use, bathing and amenity, and aquatic life). Quality criteria for aquatic life are generally considered as the most important and protective of the overall environment (Biney 1997). In recent years, quality criteria have been established by consolidating the view that an aquatic ecosystem in which structure and functions [ecological integrity] are not disrupted possesses a quality which is immediately suitable or suitable after simple treatment, for a variety of uses (Biney 1997). Such is a receiving water body whose assimilative capacity for pollutants has not been exceeded. It is now recognized that the aquatic biota themselves provide the most reliable signals of the effects of pollutant or habitat alteration, providing the basis for direct biological assessment and monitoring (Karr and Chu 1999). Biological monitoring is a feasible and low-cost alternative or complement to chemical measurements and toxicological bioassays that should be developed for resource-poor countries. Previous successes in application of biological monitoring have been documented from West Africa under the Onchocerciasis Control Program, where fish and benthic macroinvertebrates were used to monitor the effects of pesticides on aquatic communities of rivers (Leveque et al. 2003).

Some general characteristics of aquaculture effluents like relatively low concentrations of pollutants, large volume, and high flow rates, make conventional treatment options cost-prohibitive or even technically infeasible (Cripps and Kelly 1996). Best management practices (BMPs) are widely proposed as the alternative and these require a thorough understanding of not only the effluent quality but also operational characteristics like amount and frequency of discharges, whether discharges are released from top or bottom of ponds, through drainage ditches or directly into receiving waters, and whether there is discharge after every production cycle or water is reused. For example, most catfish ponds in the United States are drained twice in 15-20 years, implying much lower nutrient loading rates than would be assumed from feed conversion ratios (Boyd and Queiroz 2001). Likewise, baitfish farmers in Arkansas, United States are increasingly reusing water to minimize the cost of pumping dwindling ground water, with a desirable consequence of reducing effluents (Frimpong and Lochmann 2006). Among baitfish farms, the use of pond drainage ditches varied widely as did effectiveness of the ditches in reducing effluent concentrations before they enter receiving waters (Frimpong et al. 2003; 2004).

Clearly, generalizations on an individual farm's impact will be difficult for pond aquaculture anywhere; a thorough understanding of farms and their operational characteristics as well and the quality of receiving waters is required to begin effective development of BMPs. The AquaFish CRSP funded this study of pond aquaculture in Ghana with the goal of developing environmental BMPs for the industry. The specific objectives were to: 1) characterize effluent or potential effluent quality according to type of system, 2) characterize receiving water quality in terms of nutrients, suspended solids, and pathogens, 3) investigate the biological effects of ponds on receiving waters using structural and functional composition of fish and macroinvertebrate assemblages, and 4) develop environmental BMPs for pond aquaculture in Ghana.

METHODS AND MATERIALS

Study area

The study was conducted in the Ashanti and Brong Ahafo regions. These two regions host most of the pond aquaculture operations in Ghana. Centrally located side-by-side in the middle belt of Ghana with Kumasi and Sunyani as their capitals, respectively, these two are among the most populated of the 10 regions of the country. The regions lie between longitudes 0.15W and 2.25W, and latitudes 5.50N and 7.46N, with more than half of this area located within the moist, semi-deciduous forest zone between 150 and 300m above sea level. The regions have an average annual rainfall of 1270mm. Ghana has two rainy seasons; the major season starts in March, with a peak in May, and the minor starts from July with a peak in August. The average daily temperature across the regions is approximately 27^{o}C. The climate of the regions similar to that of most of the forest zones of West African. The study regions are drained by the Rivers Offin, Pra, Tano, Mankran and Owabi, and Lake Bosomtwe. There are several other smaller rivers and streams which serve both domestic and industrial purposes. Common species cultured include several species of tilapia such as *Oreochromis niloticus, Tilapia zillii*, *Sarotherodon galilaeus* and *Hemichromis fasciatus* (Cichlidae); *Heterotis niloticus (*Arapaimidae) and the catfishes, including *Clarias gariepinus* and *Heterobranchus isopterus* (Clariidae) (FAO 2009).

Field and laboratory methods

Major study design components included a) administration of a survey to characterize farms, farmers, ponds, and management practices in the Ashanti and Brong Ahafo regions, b) sampling of ponds, receiving, and reference streams in the Ashanti region for physicochemical and microbial assessment, c) sampling of benthic macroinvertebrates and fish in receiving and reference streams in the Ashanti region for biological assessment, d) a post-stratification of ponds by cluster analysis of survey data and characterization of potential effluent quality by pond types, e) analysis of relations among management practices and downstream physicochemical and microbial levels, and f) development of environmental BMP guidelines and dissemination through a workshop.

Most aspects of the study were completed in 2009. In the process of selection of farms and ponds for study, it became apparent that a formal survey was needed since most vital data on farms were not systematically documented or accessible. A 4-page survey was developed and administered in person to 32 farms and farmers who were voluntary participants. Questions in the survey covered demographics of farmers and farm-level practices, including feeding, fertilizing, and harvesting regimes, and a detailed documentation of information on all ponds on each farm. Detailed pond-level information included size, source of input water, drainage design and frequency of effluent releases, species currently stocked, and stocking densities. As anticipated, draining was not a frequent event and therefore we focused on characterizing potential, rather than actual, effluent quality. Of the 32 farms surveyed, 12 in the Ashanti Region were chosen for potential effluent quality and biological assessment studies. The restriction of laboratory studies to the Ashanti region was based on logistical considerations, in particular, accessibility of farms by road and travel time required back to the laboratory while maintaining the integrity of samples. Three ponds were randomly selected from each of the 12 farms for sampling (i.e., a total of 36 ponds). We applied the control impact design (Karr and Chu 1999), using the site-specific reference (Thorne and Williams 1997) for comparisons between sites. Upstream and downstream sampling stations within 100m of each farm were established on the receiving streams. A reach on a stream closest to each farm and similar in size to the receiving stream, but with no apparent influence of aquaculture was identified as site-specific reference site.

Water samples were collected from pond, upstream, downstream, and reference sites. A 2.75-L sample was collected close to the water surface for physicochemical analysis and a 0.5-L sample was also taken for microbiological analysis. Within pond samples were vertically stratified, one near the surface (limnetic) and one near the bottom (benthic). At the downstream stations, three samples were taken at 0m, 5m and 100m from the farm to capture a potential rapid change in physicochemistry and microbial loads. All samples were collected between 0800 and 1100. Samples were transported to the laboratory and analyzed within 24 hours. Water temperature, pH, pressure, conductivity, total dissolved solids, salinity and dissolved oxygen were determined on-site with a portable multi-parameter water quality meter. Laboratory analysis of water samples followed the standard procedures in Clesceri et al. (1998) for the following variables: total nitrogen (TN) (Macro-Kjeldahl method), total phosphorus (TP) (acid persulfate digestion method), total suspended solids (glass fibre filtration), total settleable solids (gravimetric method), 5-day biochemical oxygen demand (BOD_5) (20^oC incubation). Total fecal streptococci and coliform counts also followed standard methods (Clesceri et al. 1998) and the most probable number of bacteria was determined based on Lindquist (2008).

In relation to the ponds we collected fish and macroinvertebrate samples from upstream, and downstream and the reference stream of each farm in 50-100m reaches. We used a multi-gear approach for fish sampling, including seining and hook-and-line fishing, focusing on species inventories rather than proportional abundances of individuals of each species. For benthic macroinvertebrate sampling, we collected jab samples using a rectangular dip net (500um mesh size). Based on preliminary sampling we settled on 25 as the most appropriate number of jab samples to be collected from each site. The effort was distributed in proportion to available microhabitats (riffles, submerged vegetation, etc.). We then combined the 25 jab samples into one composite per site. Fish were mostly identified in the field to species level and then counted and released, but on a few occasions, an individual with taxonomic uncertainty was retained for identification in the laboratory. Fish identifications were based on established keys such as Holden and Reed (1972), Dankwa et al. (1999), and Fishbase descriptions. Functional and reproductive traits of fish species in assemblages (e.g., detritivore-herbivores feeders, open substrate spawners, etc.) were determined from Breder and Rosen (1966), Davies and Walker (1986), and Lowe-McConnel (1987). Because constraints on time and expertise, composite macroinvertebrate samples were preserved in ethanol and shipped (with permission from Ghana and US Customs) to Virginia Tech University for later analyses. Identification of macroinvertebrates complete to taxonomic family for most orders was accomplished but some taxa, such as Hirudinea, Decapoda and Oligochaeta, were left at a higher level due to the paucity of information on those. Identifications were based on recognized keys, including Brown (1994) and Merritt et al. (2008). We calculated Ephemeroptera, Tricoptera, Plecoptera (EPT) taxa and Chironomid taxa metrics, and taxa richness and Shannon and Weaner diversity (H')/dominance indices.

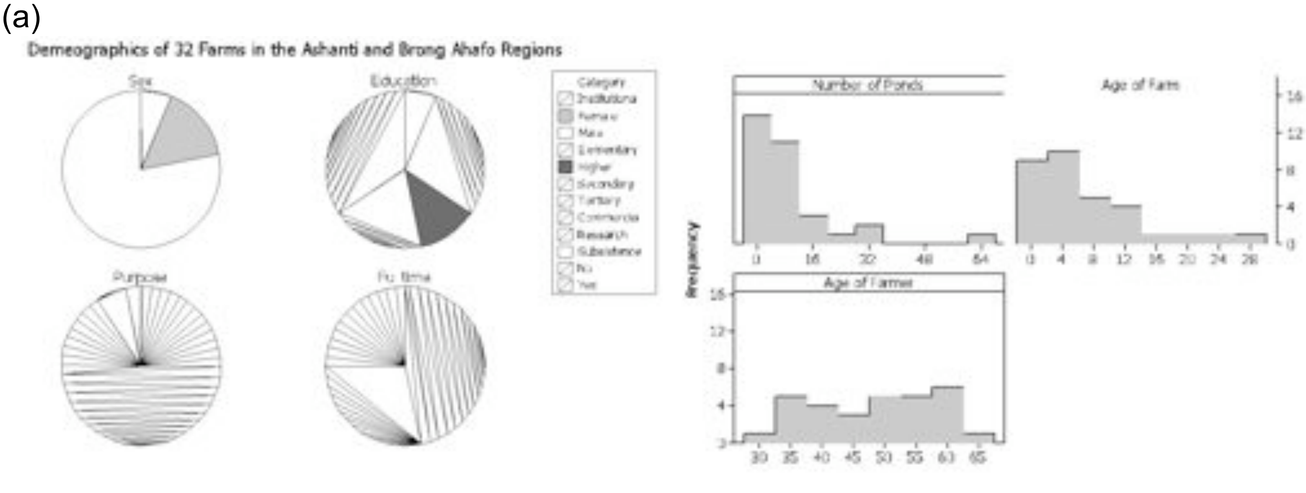
Statistical analyses were preceded by a detailed graphical analysis in Minitab®15. The optimal number of pond types was identified by the K-means clustering procedure. A mixed-effects ANOVA with farm as random blocks and fixed location effects was the main model, using the Tukey procedure for post-hoc analyses of location effects. Other analyses simplified to t-tests or paired t-tests. Statistical significance was decided as $p \leq 0.05$ but marginal situations up to $p \leq 0.15$ were noted because of inherent variability in biological data, our relatively small sample sizes, and the consequent low power in some tests to detect significant differences unequivocally.

RESULTS

Characteristics of farmers, farms, and management practices in the Ashanti and Brong Ahafo regions

Over 75% of farms were owned by males, with females constituting about 10%. The remainder was institutional owners. Two-thirds of farmers had secondary, tertiary, or higher (post-graduate) level of education and 90% of farms were operated commercially, although just a little over 50% of farmers engaged full-time in aquaculture (Figure 1a). Farmers averaged 48 years of age with a range of 29 – 67. Farms were generally small; number of ponds on individually owned farms ranged from 1 to 32 with a median of 5 ponds on a farm. The fisheries department-owned Pilot Aquaculture Center was the largest facility with 65 earthen ponds and concrete holding tanks; however, several private farms were equally large in terms of farm area. Majority of farms had been in operation for less than 10 years. A variety of management practices were employed alongside a variety of sources and types of input. Feeds were almost an equal mix of imported, locally manufactured, and homemade. Fifteen major types of feed ingredients were reported, some of the most frequent being groundnut meal, fishmeal, rice bran, and wheat bran (Figure 1b). Ponds were predominantly filled by groundwater seepage. Most farms partially released effluents 1–6 times per year for harvesting but about 20% of ponds were designed to never drain. For those that had drainage pipes, the commonest design involved variable-level standpipes that could drain from both surface and bottom. About 20% of ponds were designed to drain into other ponds, which made water reuse an option although some of these designs were also dictated by distance of ponds to the receiving water. Besides the possibility of water reuse twenty-two out of the 32 farms used at least one effluent management practice: 50% of these used drainage canals and the remaining used settling ponds or drained into natural vegetated wetlands (Figure 1b).

(a)



(b)

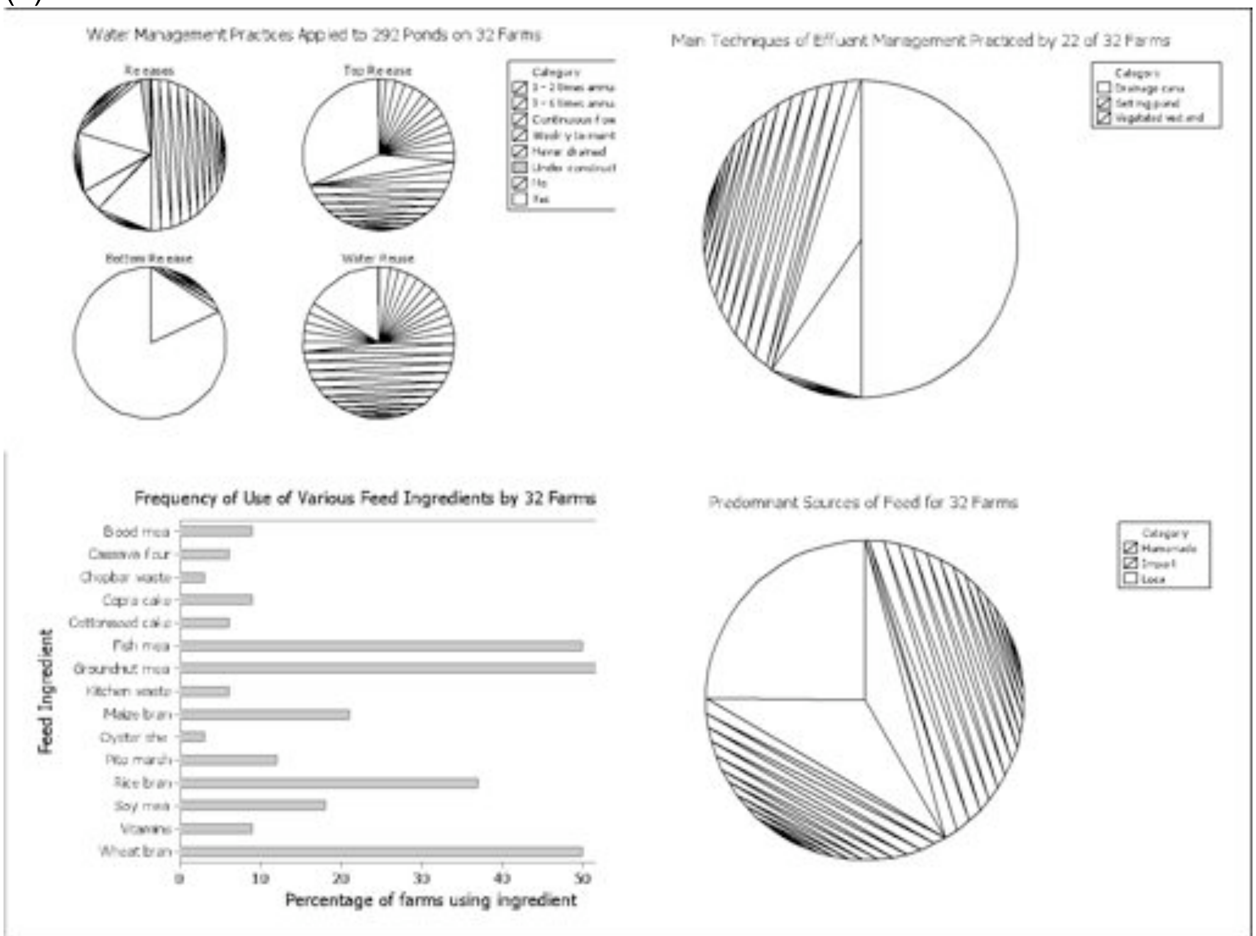


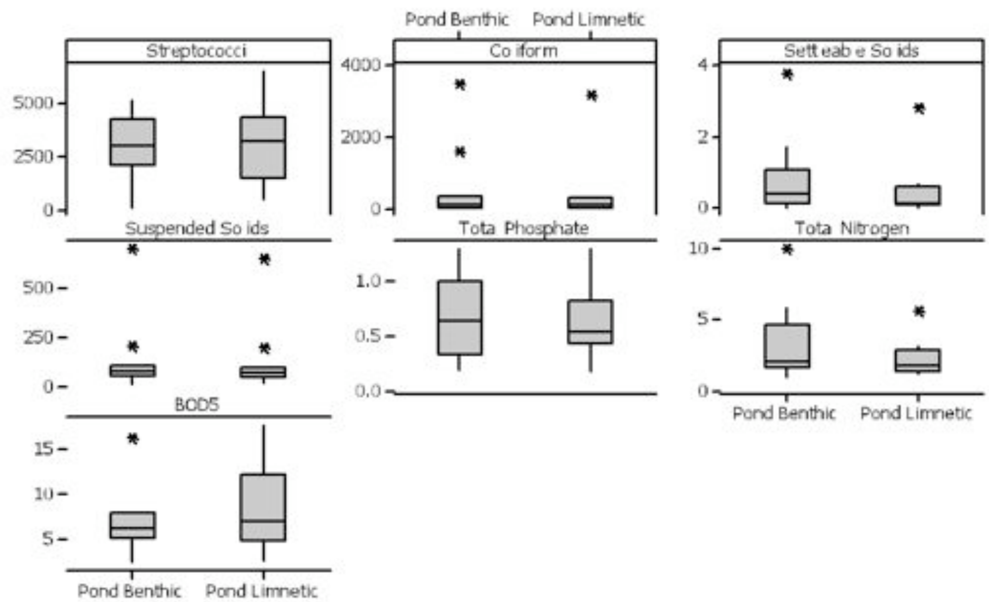
Figure 1.- Characteristics of farmers, farms, and management practices.

Physicochemical and microbial levels in ponds, receiving, and reference streams in the Ashanti region– Physicochemical and microbial assessment

Neither the vertical position in the pond or distance downstream of farms appeared to show much variation in physicochemical and microbial levels except for higher limnetic BOD5 in ponds (Figure 2a&b). This made it possible to pool samples and work with averages of the samples taken from these locations in subsequent comparisons with upstream and reference streams. Temperature, settleable and suspended solids, phosphates and nitrates, and BOD5 showed differences among locations whereas coliforms and streptococci and the remaining ancillary variables did not significantly differ (Figure 3a-d). Post-hoc analysis with Tukey simultaneous tests showed that settleable solids were higher in ponds than reference streams ($p = 0.0166$) and marginally higher than upstream ($p = 0.0707$) and downstream ($p = 0.1102$). Suspended solids followed a close pattern, being higher in ponds than reference ($p = 0.0159$) and upstream ($p = 0.0361$) and marginally higher than downstream ($p = 0.0711$). Phosphates were higher in ponds than reference (p = 0.0274) and upstream (p = 0.0269) and marginally higher than downstream (p = 0.1364). Nitrogen was most clearly higher in ponds than all other locations: p = 0.0016, 0.0086, and 0.0154 for the differences between ponds and reference, upstream, and downstream respectively. Five-day biochemical oxygen demand was also higher in ponds than all locations: p

0.0048, 0.0009, and 0.0012 for the differences between ponds and reference, upstream, and downstream respectively. Temperature was significantly higher in ponds than reference streams (p 0.0402) and marginally higher in ponds than downstream (p = 0.0518). No other significant differences were observed between any pairs of locations for these or any other variables.

(a)



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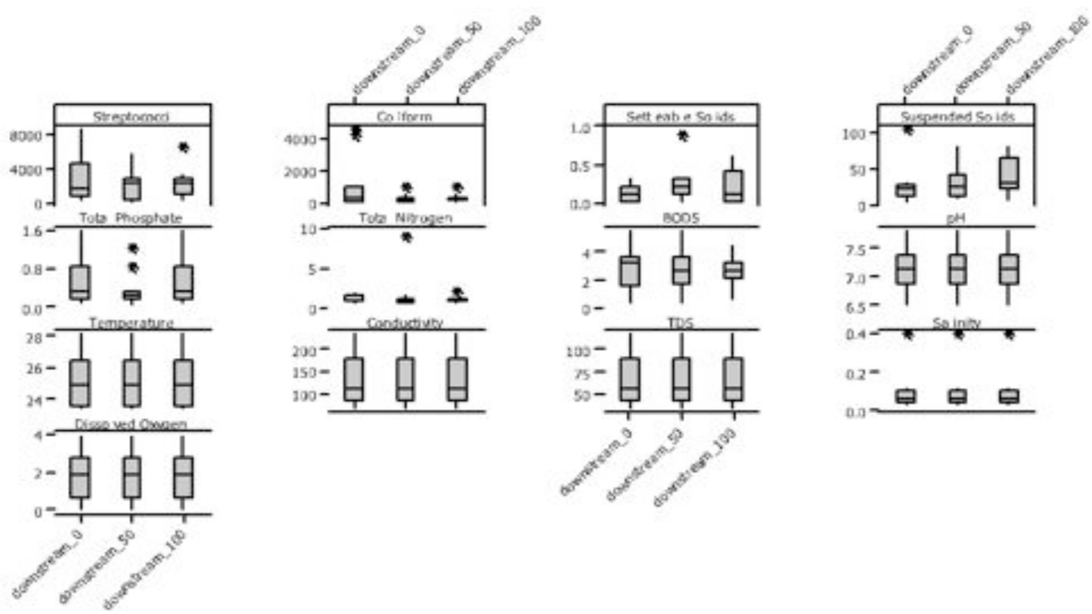
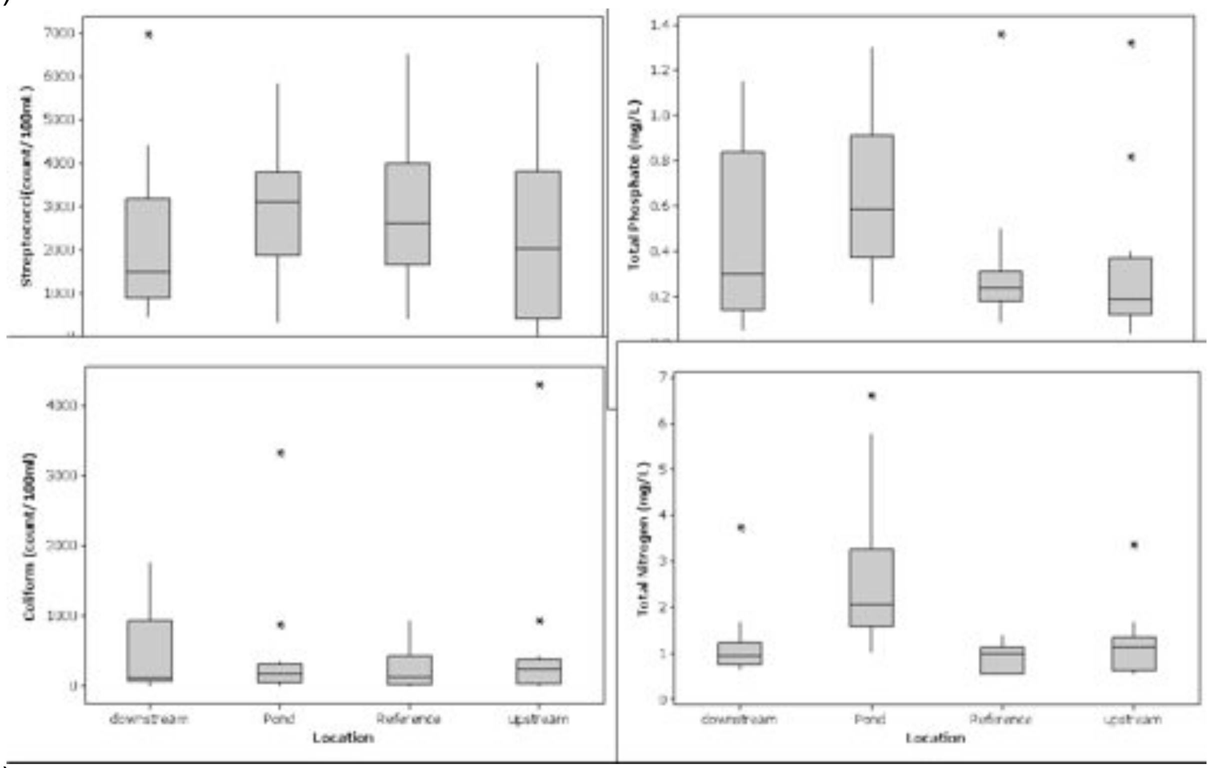
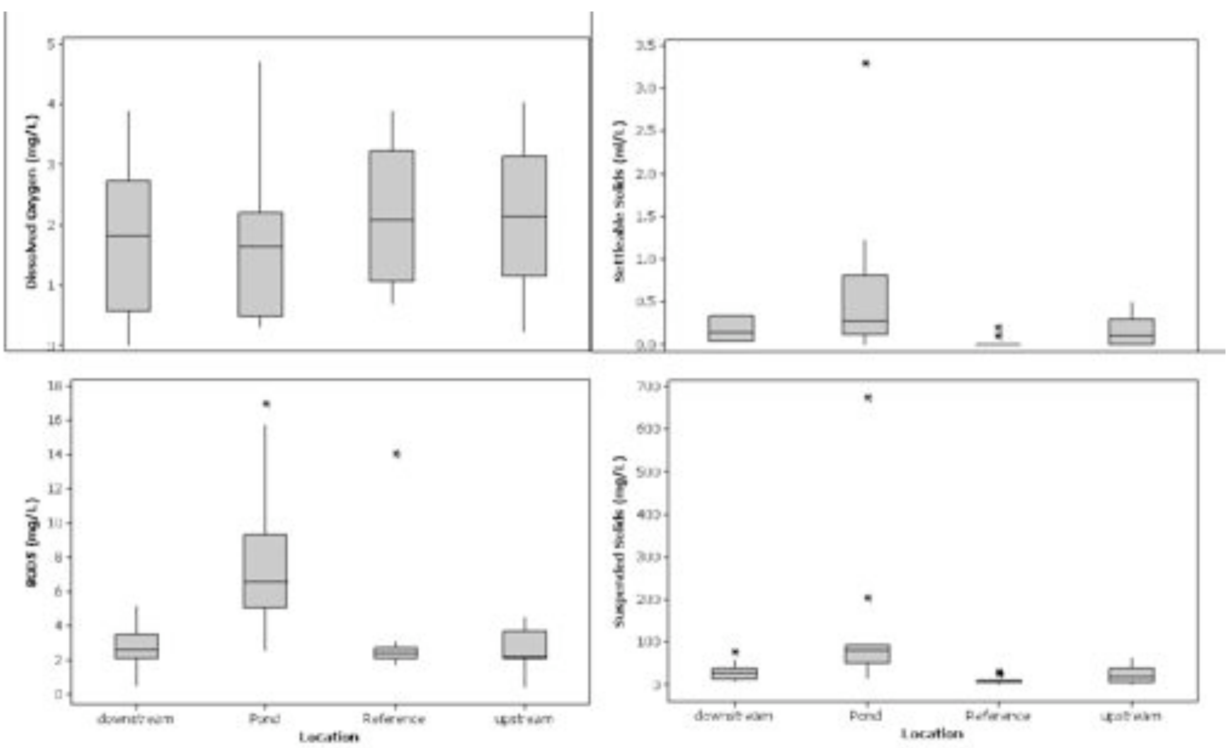


Figure 2.- Comparison of microbial and physicochemical levels as a function of vertical location in the pond (a) and distance downstream of farms (b)

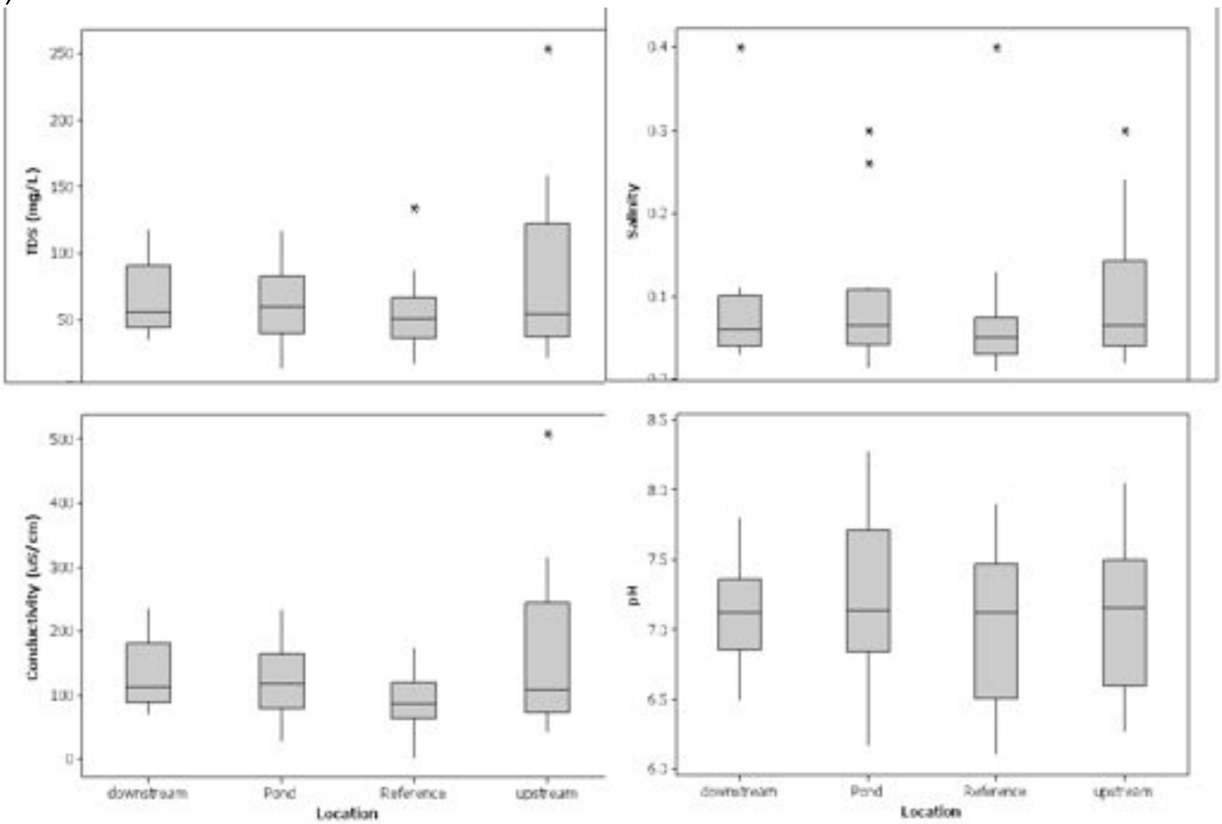
(a)


Streptococci (count/100ml)
Total Phosphate (mg/L)
Coliform (count/100ml)
Total Nitrogen (mg/L)
downstream
Pond
Reference
upstream
Location

(b)


Dissolved Oxygen (mg/L)
Settleable Solids (ml/L)
BOD5 (mg/L)
Suspended Solids (mg/L)
downstream
Pond
Reference
upstream
Location

(c)



(d)

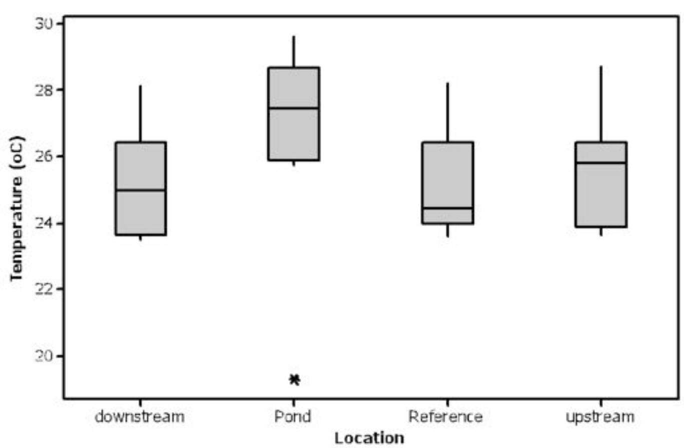


Figure 3.- Levels of microbial and physicochemical variables in ponds, upstream, downstream, and reference locations.

Fish and benthic macroinvertebrate assemblages in receiving and reference streams in the Ashanti region– Biological assessment

A total of 28 different fish species and 54 benthic macroinvertebrate taxa were identified within the study area and analyzed using metrics of assemblage structure and function. Fish species richness in sampled assemblages ranged from 1 to 10 with an average of 4 species. Macroinvertebrate taxa (mostly family) richness in a given sample ranged from 9 to 26 with an average of 17. The Shannon and Weaner diversity index for macroinvertebrates ranged from 0.45

to 0.92 on a scale of 0–1 and averaged 0.74. Structural and functional metrics for both fish and macroinvertebrates showed no significant differences among upstream, downstream, and reference streams, with the exception−percentoftwo nonguarderreproductivespeciesmetricsand percent of species that are sand-detritus spawners (Figures 4 & 5). Nonguarder species were more common in reference streams than downstream (p = 0.0214) and upstream (p = 0.0251) and sand-detritus spawners were less predominant in reference streams than upstream (p = 0.0222) and marginally less in downstream locations (p = 0.0539).

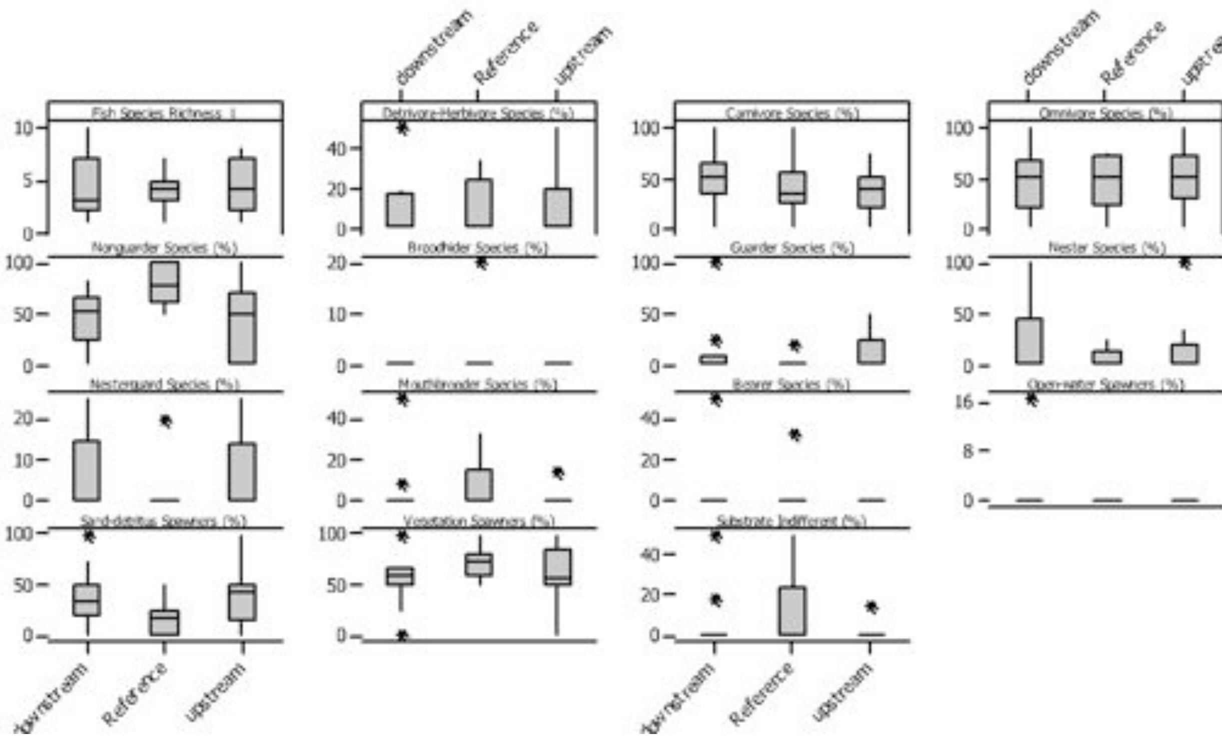


Figure 4.- Comparison of metrics of fish assemblage composition among downstream, upstream, and reference locations.

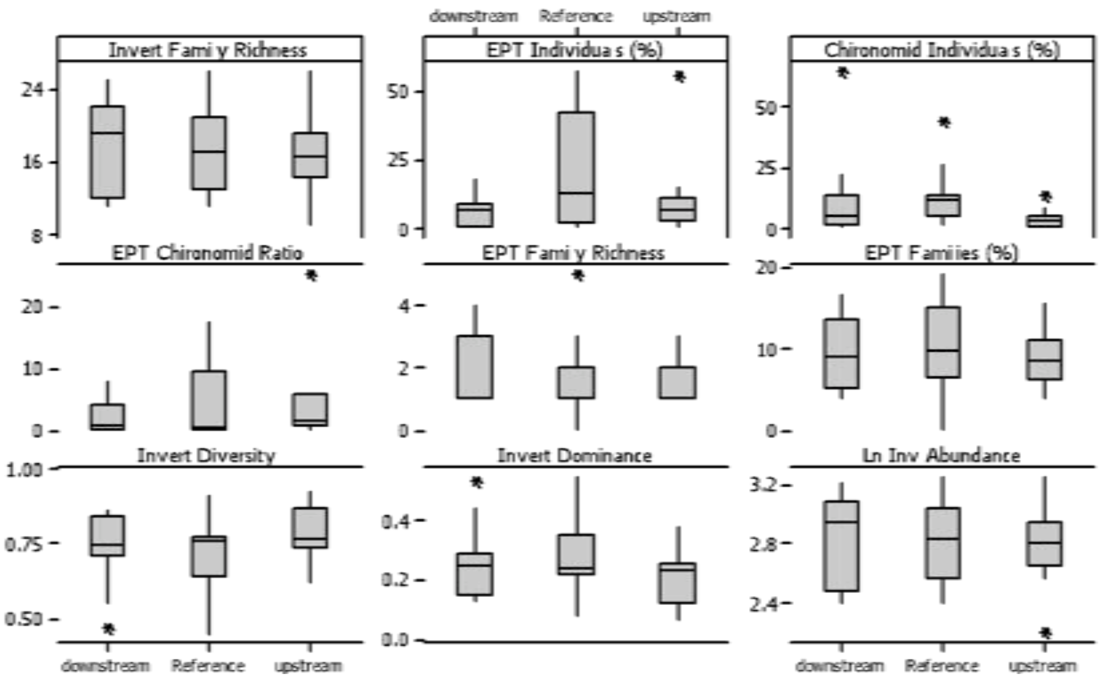


Figure 5.- Comparison of metrics of benthic macroinvertebrate assemblage composition among downstream, upstream, and reference locations.

Typology of ponds in the Ashanti and Brong Ahafo regions and characteristics of potential effluents by pond types

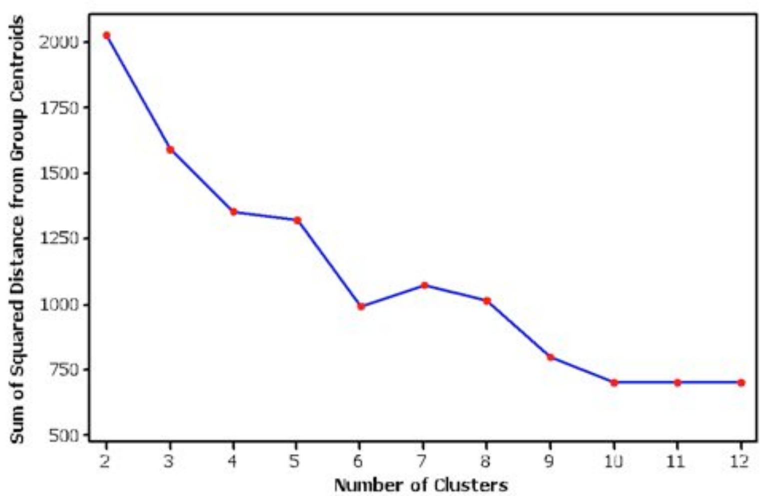


Figure 6.- Rate of reduction in residual error with increasing number of clusters to describe pond types.

The iterative process to determine optimal number of clusters to describe types of ponds showed, as expected, a declining trend of the sum of squared distance from group centroids ('the residuals') with increasing number of clusters (Figure 6). Since too many or too few clusters are not desirable we sought to optimize the number of clusters by choosing the number at which error started declining at a decreasing rate. Six clusters were decided as optimum because there were steep declines in error up to six clusters after which the error actually increased before flattening out.

Table 1 describes the typical characteristics of each cluster or pond type and the number of ponds falling in that cluster. Type 1 is typically a large pond containing *Clarias* in a polyculture with *Oreochromis* and up to 3 other species at a medium to high stocking density, which sees two annual harvest events, mostly by draining. Ponds in cluster 2 are generally smaller without Oreochromis, but with Clarias and one other species stocked at medium to high densities, which are completely drained for harvest, at least twice annually. Cluster 3 consists of small ponds with Oreochromis at medium to high stocking densities, which experiences up to 3 annual harvest events, mostly without draining. Cluster 4 is characterized by a very small pond size with a high stocking density for a monoculture of Clarias that is 'harvested' more than three times in a year, without draining. Ponds in cluster 5 are generally small in size, most are under construction, and so have not yet been stocked. Cluster 6 is made up of small ponds with a polyculture of Oreochromis, Clarias and possibly one other species, stocked at medium to high densities that sees 2 to 3 harvest events in a year, with draining about half the time. The additional species that characterize some clusters besides *Clarias* and *Oreochromis* were commonly *Heterotis niloticus*,*Parachanna obscura* and species of the genus *Chrysichthys*.

Table 1.Typical characteristics of six clusters (types of ponds or culture systems) defined by pond size, species cultured, stocking density, and harvesting practices

	Average Pond Size (m^2)	Oreochromis present	Clarias present	Number of Species	Stocking density	Annual harvests	Drain for Harvest?
Type 1 (n = 13)	8,249	Yes (92%)	Yes	2 - 5	Medium to High	2 times	77%
Type 2 (n = 8)	1,574	No	Yes	1 - 2	Medium to High	2 or more	100%
Type 3 (n = 151)	415	Yes	No	1	Medium to High	2 - 3	41%
Type 4 (n = 17)	261	No	Yes	1	High	More than 3	No
Type 5 (n = 26)	1,067	No	No	0	Not stocked	N/A	N/A
Type 6 (n = 77)	824	Yes	Yes	2 - 3	Medium to High	2 - 3	47%

Table 2.- Microbial and physicochemical levels in the two most common types of ponds

Variable	Pond Type	N	Mean	SE of Mean
Streptococci				
(count/100ml)	Type 3	14	2800	420
	Type 6	19	3032	479
Coliforms				
(Count/100ml)	Type 3	14	241	171
	Type 6	19	682	481
Settleable Solids				
(ml/L)	Type 3	14	0.31	0.09
	Type 6	19	0.47	0.19
Suspended Solids				
(mg/L)	Type 3	14	86.2	15.3
	Type 6	19	79.6	15.3
Total Phosphates				
(mg/L)	Type 3	14	0.6	0.12
	Type 6	19	0.64	0.07
Total Nitrogen				
(mg/L)	Type 3	14	1.96	0.388
	Type 6	19	2.992	0.879
BOD5				
(mg/L)	Type 3	14	5.8	1
	Type 6	19	8.5	1.1
pH				
	Type 3	14	7.2	0.2
	Type 6	19	7.1	0.3
Temperature				
(oC)	Type 3	14	27	0.3
	Type 6	19	28	0.3
Conductivity				
(mS/cm)	Type 3	14	102.2	22.3
	Type 6	19	132.3	17.7
TDS				
(mg/L)	Type 3	14	51.2	11.5
	Type 6	19	66	8.8
Salinity				
(%)	Type 3	14	0.15	0.05
	Type 6	19	0.06	0.01
Dissolved Oxygen				
(mg/L)	Type 3	14	1.9	0.41

The two most common types of ponds were 3 and 6. Not surprisingly, 33 out of 36 of the ponds we sampled belonged to one or the other of these two types. Therefore, we focused on these two types of ponds to characterize potential effluent quality by pond type (Table 2; Figure 7). No significant differences were found in the microbial levels of the two types of ponds, although streptococci were moderately high across pond types compared to coliforms. Salinity was significantly higher in pond type 3 (p = 0.046) and temperature (p = 0.057), BOD_5 (p = 0.083), and total nitrogen (p = 0.135) were only marginally higher in type 6.

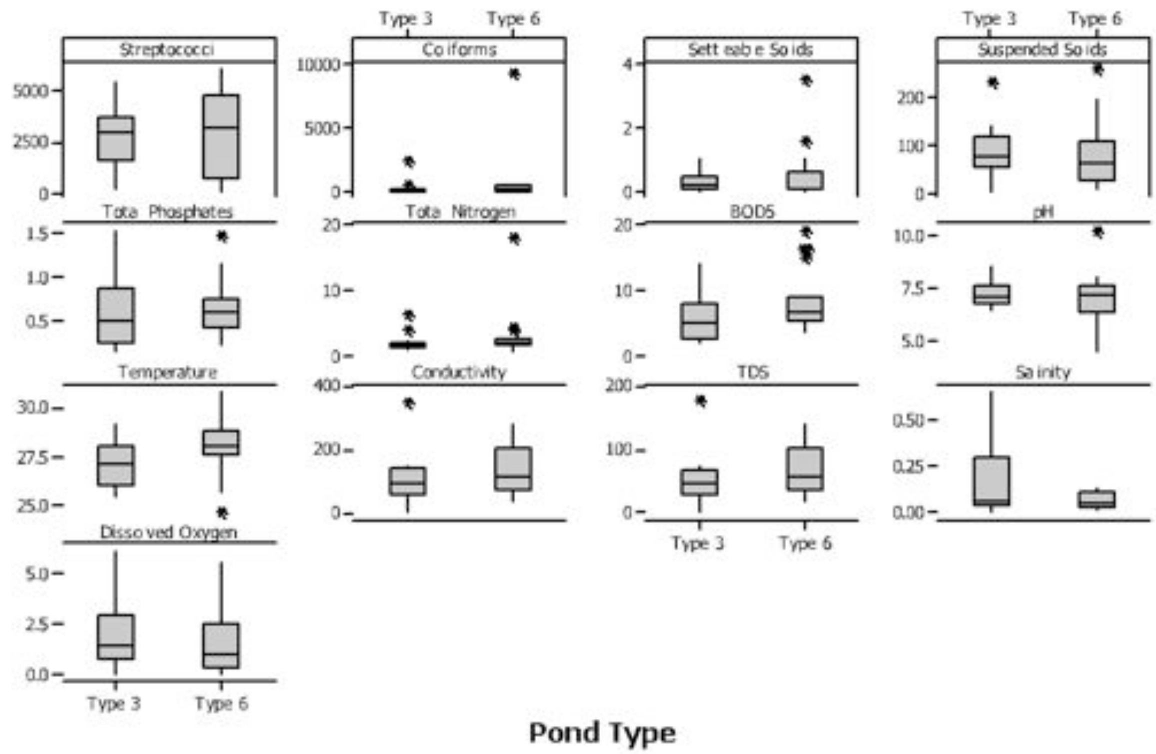


Figure 7.- Comparison of microbial and physicochemical levels in the two most common types of ponds.

Relations among management practices and downstream physicochemical and microbial levels
A Spearman's rank correlation analysis of relations between a set of management practices and downstream physicochemical and microbial levels revealed a number of significant associations of some practices with physicochemistry. Interpreting correlation≥≤0.50 coefficient of -0.50 as significant, all physicochemical variables had at least one significant association except temperature. No such associations were found between microbial levels and management practices (Appendix table A-1). There were some intuitive relationships such as positive associations between the number of species present on a farm and average pond size with downstream levels of total nitrogen; these relationships were tracked closely by the level of total phosphates, although correlations were slightly below the cutoff we imposed for significant associations. Another intuitive positive association was the proportion of ponds with top effluent release and downstream dissolved oxygen. However, other associations that were found may not be clearly interpretable. In fact, a negative relationship between the practice of draining ponds to harvest and the level of total phosphorus downstream seems counterintuitive.

DISCUSSION

The male domination of aquaculture in Ghana is not unlike commercial land-based agriculture in the country where males, who are usually the heads of families, are undertake production of cash crops while dedicating land for subsistence farming to their spouses. Under this arrangement, males usually take responsibility for land clearing (this is regarded as the most labor intensive part of farming) whether personally or through paid labor. Pond digging and associated site preparation activities are labor intensive in Ghana and not surprisingly attracts more males to the business than females. Females are more involved with processing and trading aquaculture products, which is a facet of the industry we did not study. A surprising aspect of the profile of fish farmers in Ghana is that the average farmer is young (in their mid to late 40's) and relatively well-educated. Coupled with the observation that most farms were started less 10 years ago, it is clear that the industry is rapidly−youngrecruiting a new profile of farmers , with at least secondary education. There is a new growth phase of building up farm infrastructure and this is happening with increasing literacy level of farmers. Design of education and training programs for Ghanaian fish farmers should use this shifting demography advantageously.

There was a palpable level of consciousness among farmers regarding potential effects of farming practices on the surrounding aquatic environment. The observed level of use of effluent management practices such as water reuse, vegetated drainage canals/ditches, settling ponds, natural wetlands could be characterized as the industry being ahead in terms of adoption of environmental BMPs. The BMP workshop held in Ghana in November 2009 reinforced the usefulness of these practices and any farmers who were oblivious to the need for BMPs learned and appreciated the new insights offered at the workshop through presentations, breakout group discussions, and farmer-to-farmer interactions.

Overall, farms had a different level of physicochemical quality but the same levels of microbial levels compared to receiving streams. Temperature, nutrients, solids, and oxygen demand were all at elevated levels in ponds. This was expected because these ponds are actively managed, including fertilizing and daily feeding. Activity of concentrated fish in ponds would also be expected to keep solids suspended even in the absence of harvesting activities. High temperature in ponds can be explained by standing water exposed to the sun. There was no evidence that the elevated level of nutrients, solids, and oxygen demand on farms caused high levels of these variables downstream. Although this conclusion is made on statistical grounds, we noticed a pattern of pond water and downstream water being the least statistically distinguishable compared to pond versus upstream or reference. Thus, how effluents are managed over time may well make the difference in avoiding future detectable effects of ponds on receiving stream water quality.

The biological assessment showed that fish and macroinvertebrate assemblages are similar in receiving and reference streams. The overall high diversity of macroinvertebrate assemblages suggests that the study area as a whole maintains a relatively natural aquatic environment. The lower nonguarder fish presence in the reference assemblage may be the beginning of assemblages around ponds evolving toward species with complex reproduction patterns. This pattern could be predicted in the face of a change in the aquatic environment around farms that demands more protection of eggs or offspring to improve reproductive success and persistence. This single metric cannot be used to make sweeping conclusions, though; in general signals of changing assemblages in several related metrics makes for a more robust conclusion of impact. It is not surprising also that fish assemblages upstream and downstream of ponds were not different even for the nonguarder species metric. Fish are mobile and any alterations downstream would eventually be observed upstream as well because assemblages mix. A seemingly plausible explanation for the absence of significant differences in fish and macroinvertebrate assemblages between reference and receiving streams is possible insensitivity of the metrics chosen to characterize differences. However, these metrics have been shown to be sensitive to various other impacts in the bioassessment literature. Because we saw no differences in water quality either, we are more confident that ponds have not thus far exerted any appreciable impacts on their receiving water environment.

Some of the patterns of management practices that led to clustering ponds into six types appear to have intuitive explanations. Complete draining in type 2 can be attributed to the fact that seining in a *Clarias* earthen ponds is generally unsuccessful because *Clarias* can bury itself in the pond bottom out of the reach of the seine. This is also the case with other clusters that culture *Clarias*, where some level of draining must accompany harvesting. Type 4 presents a different scenario, where the monoculture of *Clarias* sees no draining with harvest. This resembles the situation in nursery ponds and tanks, which is supported by the extremely small sizes of ponds, high stocking density, and a large numbers of harvest events in this cluster. In the study area, fry production was more common for *Clarias* than *Oreochromis*. Most farmers started with a parent stock of *Oreochromis* and relied on the prolific breeding of this species to sustain the stock, unlike *Clarias* ponds, which have to be stocked with fry for each production cycle.

Interestingly, the two pond types that we had sufficient data on did not differ in the quality of key effluent components. At least for these two types of ponds (*Oreochromis* only and *Claria-Oreochromis* polyculture) management does not appear to be different enough to result in differences in water quality. We have no data to make the same conclusion across all the pond types. It will be interesting in future studies to collect data for all pond types. In particular, pond type 1 that are larger and have more than two species appear to be the most intensively managed and, though not as common, would need to be studied closely in future investigations.

A direct link between management practices and downstream water quality was challenging in this study for three reasons. Firstly, farms were quite similar in various ways and did not present sufficient contrast for comparing effects of practices. Secondly, the downstream had not been altered significantly as concluded from other analyses, also adding to the range issue in receiving water. Finally, sample size was too small for rigorous farm level analysis and even nonparametric analyses had short comings of low power. We think the concept was laid out clearly by our approach in this study and future studies should expand sample sizes, howbeit at much higher cost, to afford the needed analytical rigor. All three problems outlined above will be ameliorated by using a larger sample size for the water quality and farm survey studies.

In the light of this study and what is internationally recognized as good practices to reduce adverse interaction of aquaculture with surrounding aquatic environments, initial BMP guidelines were developed and brochures/leaflets prepared for farmers and other workshop participants covering effluent management, feeding and nutrient management, and biodiversity. These are designed to be used as posters on farms and in institutional offices to be constant reminders and also create awareness. We believe adherence to these simple guidelines will keep the aquaculture industry in Ghana free of regulations for the foreseeable future.

CONCLUSIONS

- Ponds in the Ashanti and Brong Ahafo regions of Ghana generally hold a different water quality compared to receiving streams and the receiving streams are of more natural nutrient, solids, and BOD_5 status.
- We found no evidence that receiving stream water quality or biota (fish and benthic macroinvertebrates) are adversely affected at the moment by aquaculture activities
- Any potential effects in the future will depend on how effluents are managed, including the frequency and volume of releases and under what conditions effluents are handled before reaching receiving waters
- Majority of farms already have some environmental Best Management Practices (BMPs) in place, including, water reuse mechanisms, vegetated ditches/canals, settling basins, draining into natural wetlands, and top release of pond water
- Continuing to implement broadly focused environmental BMPs can obviate any need for regulations on aquaculture effluents in the foreseeable future in Ghana

Anticipated Benefits

This study has provided a solid baseline of information about pond aquaculture environment interaction in the forest zone of Ghana. To our knowledge, this is the first of its kind in the humid forest zone of sub-Saharan Africa and will serve as an important reference for regulatory institutions, researchers, environmental organizations, and donor agencies when considering development of environmentally friendly aquaculture in the region. The protocol used for this study is available for replication in other countries of the region. As peer-reviewed publications emerge from this study in the next year, we expect this study to contribute to international understanding of pond aquaculture-environment interactions in a developing country context. Because of effective dissemination of the result of this study through a 2-day workshop, the Environmental Protection Agency, Water Research Institute, and Fisheries Commission are all aware of the existence and key results of this study. Farmers likewise have gained awareness of this study and are expected to put them into practice to further improve already good environmental record of the industry. Farmers' enthusiasm about working with scientists and with each other was heightened at the workshop. This study is the basis of an MS thesis of Mr. Yaw Ansah who is completing his studies at Virginia Tech University in May 2010 and supported by Aquafish CRSP and Virginia Tech. Mr. Ansah will be an asset in the future for environmentally sustainable aquaculture development in the region. At least six Ghanaian students received non degree training at KNUST through participation in this project; one American student volunteer was also trained by the project in Ghana and two American graduate students who were involved in laboratory analysis of samples transported to Virginia tech were also trained thereby. The Fisheries and Watershed Management department at KNUST has seen a rapid increase in student interest in majoring in Fisheries and Aquaculture and in getting involved with CRSP research. These are capacity building outcomes of this project that is beyond what was originally projected.

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Appendix Table A-1: Correlation of management practices with physicochemical and microbial levels downstream of farms. The correlation coefficient is nonparametric (Spearman's rank type).

	Strep	**Coli**	**Settleable Solids**	**TSS**	**TP**	**TN**	**BOD5**	**pH**	**Temp**	**Conductivity**	**TDS**	**Salinity**	**DO**
Age of farm	-0.33	-0.36	-0.34	-0.21	0.06	-0.13	**-0.55**	-0.06	-0.21	-0.32	-0.32	-0.01	0.33
Number of ponds	0.02	-0.37	0.35	0.39	0.05	0.24	-0.25	**-0.56**	-0.11	**-0.82**	**-0.82**	-0.36	-0.35
Integrated farming	-0.26	0.41	-0.02	0.14	-0.06	0.13	0.15	0.36	-0.12	**0.60**	**0.60**	0.27	0.48
Frequency of feeding	-0.31	-0.30	-0.23	-0.15	-0.27	-0.02	-0.49	-0.47	0.05	-0.42	-0.42	**-0.53**	0.36
Average pond size	-0.18	-0.37	-0.39	**-0.53**	0.41	**0.59**	0.40	**0.51**	0.40	0.35	0.35	0.14	-0.09
Drain to Harvest	0.08	0.25	0.08	0.04	**-0.66**	-0.37	-0.04	-0.30	0.12	-0.06	-0.06	-0.32	0.12
Frequency of effluent releases	0.34	0.18	0.49	0.36	-0.15	0.29	0.07	-0.34	0.36	-0.18	-0.18	-0.47	-0.28
Proportion of ponds with top release	0.11	-0.02	-0.19	-0.12	-0.06	-0.12	-0.16	-0.04	-0.33	-0.15	-0.15	-0.19	**0.53**
Bottom Release	0.06	-0.05	0.07	0.07	-0.02	0.07	0.03	0.21	0.28	-0.05	-0.05	-0.08	-0.10
Water Reuse	0.18	-0.02	0.14	0.30	0.32	0.30	0.42	0.22	-0.01	0.04	0.04	-0.16	0.04
Species Present	-0.02	-0.12	0.41	0.38	0.45	**0.63**	-0.36	0.07	0.12	-0.21	-0.21	0.08	-0.24