Fish farm and water quality management

Lúcia Helena Sipaúba Tavares[*] and Rachel Magalhães Santeiro

*Centro de Aquicultura, Universidade Estadual Paulista "Júlio de Mesquita Filho", Via de Acesso Prof. Paulo Donato Castellane, s/n, 14884-900, Jaboticabal, São Paulo, Brazil. *Author for correspondence. E-mail: sipauba@caunesp.unesp.br*

ABSTRACT. Fish farms' water quality management is analyzed with regard to the management employed and the different trophic states are compared within the system during the dry and rainy seasons. Six sites were marked two in the water supply (P1 and P2), and four within the fish farm (P3 to P6). Whereas sites P1 and P2 (water supply) were characterized as oligotrophic, the others were mesotrophic and eutrotrophic sites. Environmental variables, mainly nutrients, conductivity, COD, BOD5 and TSS tended to increase as from P3 due to management and fertilization. Greater impact has been registered in the fish farm under analysis for variables COD, ammonia, total phosphorus and TSS during the discharge and pond emptying period. Frequent monitoring of water quality should be undertaken in fish breeding and plankton production ponds, especially in those close to P3 and P4. Removal of sediment in decantation lake or P5 is also recommended to decrease nutrient concentrations, especially phosphorus, accumulated on the bottom soil.

Keywords: physical-chemical variables, trophic index, dry and rainy seasons.

Piscicultura e manejo da qualidade da água

RESUMO. Este estudo objetivou avaliar a qualidade da água em uma piscicultura em função do manejo adotado e comparar os diferentes graus de trofia dentro deste sistema nas estações de seca e chuva. Seis pontos foram delimitados sendo dois na água de abastecimento (P1 e P2) e quatro dentro da piscicultura (P3 ao P6). Os pontos P1 e P2 foram caracterizados como oligotróficos e os demais como mesotróficos e eutróficos. Houve tendência das variáveis ambientais principalmente, nutrientes, condutividade, DQO, DBO5 e STS aumentarem a partir do P3 em função do efeito do manejo e fertilização. As variáveis DQO, amônia, fósforo e STS foram de grande impacto dentro da piscicultura estudada, principalmente, no período de descarga e esvaziamento dos viveiros e tanques. Frequente monitoramento da qualidade da água deve ser realizado nos viveiros de criação de peixes e nos tanques de produção de plâncton, especialmente naqueles próximos aos pontos P3 e P4. Outra recomendação a ser adotada é a remoção do sedimento na lagoa de decantação (P5) devido ao grande acúmulo de fósforo neste local.

Palavras-chave: variáveis físico-químicas, índice trófico, estação de seca e chuva.

Introduction

Since an increase in the number of fish farms in Brazil during recent years has become an important datum, many fish farms have been regarded as research models by government departments. Most fish farms receive water directly from river or reservoirs, with special impact on management employed, and the subsequent discharge in rivers or reservoirs without any previous treatments. Most fish farms are divided into compartments, such as laboratories for larvae culture, fish breeding ponds, plankton (natural feed) production ponds, fish fattening ponds and other equipments. Due to fertilization and fish feeding management the above mentioned compartments may deteriorate directly the water quality. One of the most important ecological issues in water ecosystems is the progressive loss in biodiversity and fishing yields. In fact, several hydroelectric plants establish fish farms to replace the native ichthyofauna of impacted ecosystems. Current study focuses on the FURNAS fish farm which produces fish fry to repopulate large reservoirs built along the river Grande, State of Minas Gerais, Brazil.

Fish farms are maintained by complex physical and chemical factors and by biological interactions which directly depend on water quality. Framing activities can cause important impacts on the environments due to the discharge of waste water into streams, rivers and lakes (KONSOWA, 2007). Physical and chemical oscillations in fish ponds basically depend on energy input, with special emphasis on the frequency and nature of the nutrient discharge added to the system. In general,

the fish farms receive adequate water availability and constant renewal supply but the water is discharged into the river without any treatment (SIPAÚBA-TAVARES et al., 2010). There are two sources which modify water quality in fish farms (1) food supplied to fish; in fact, intake occurs at the rate of 25%, whereas the rest is dejected into the environment as urine (nitrogen) and feces (phosphorus); (2) fertilization is one of the most important problems concerning fish ponds, or rather, the determination of the best fertilizer dose to be added to the pond. Optimal requirements of fertilizers for different types of bottom soil conditions and their interactions with various factors of pond ecosystem are still unknown (FENG et al., 2005). Aquaculture production has increased more than 40 times during the last 50 years and it is expected to have a five-fold rise in the coming 50 years. Consequently, rise in aquaculture production has to be planned within the context of minimizing environment impact and optimizing resource utilization (AVNIMELECH et al., 2008).

The present investigation characterizes the water quality of fish farms with regard to employed management and compares their different trophic states to identify differences related to the dry and rainy seasons.

Material and methods

Study area

Current experiment was carried out at Furnas Hydrobiology and Hatchery Station (20°40' S 46°19' W), Furnas Hydroelectric Plant (São José da Barra, Minas Gerais State, Brazil). The fish farm is located on the left bank of the River Grande, some 2 km from FURNAS reservoir, which provides water to the fish farm. Continuous water flow provides 5% daily exchange rate of the breeding volume. The fish farm with 211 ponds, whose areas range between 60 and 3,000 m^3, produces young fish for breeding. Sampling sites were allocated from the reservoir where the water is harvested (P1) for the fish farm up to the effluent outflow site (P6) of the fish farm to the River Grande. Each fish pond has a separate water inflow system, but the water outflow pipe system of the ponds converges along the fish farm and passes through sites P3, P4, P5 and P6 sampled within the fish farm. The sample sites are boxes that receive and distribute water for many different sections of the fish farm, except for site P5, a decantation lake, and the effluent (P6). Water samples were collected from six sampling sites, as

follows site 1 (P1) close to the impounding of water supply (Furnas Reservoir); site 2 (P2) water distribution center to ponds and breeding ponds of the fish farm; sites 3 (P3) an effluent of the larvae culture ponds; site 4 (P4) receives the effluent of the plankton production ponds; site 5 (P5) in the lake which, besides containing fish, receives water from the entire fish farm; and site 6 (P6) is the effluent of fish farm. Water samples were undertaken every other day, during 20 consecutive days, during the rainy (February, 2002) and dry (August 2002) seasons.

Management

Populations in the ponds comprised 'tilapia' (*Oreochromis niloticus*), 'trairão' (*Hoplias larcedae*), 'pintado' (*Pseudoplastystoma corruscans*), 'pacu' (*Piaractus mesopotamicus*), 'curimba' (*Prochilodus lineatus*), 'piapara' (*Leporinus obtusidens*), 'carpa' (*Ciprinus carpio*), 'dourado' (*Salminus brasiliensis*), 'piau' (*Leporinus friderici*). The estimated total weight of fish reached 3 tons. Continuous water flow comes from water in the Furnas Reservoir. Fish were fed a supplementary diet containing 15% crude protein at the rate of 3% average live weight. Fertilization in the ponds was done by chemical (25.6 kg of simple super phosphate and 48 kg of ammonia sulfate) and organic fertilizers, with the addition of 100 kg pig dung in natura at approximately 7-day intervals only to the plankton ponds (close to P4).

Physical and chemical data

Water samples were collected at a depth of 0.10 m, with the exception of P5 which was 2.5 m deep, using a 5-L Van Dorn bottle. Nitrate, nitrite ammonia and alkalinity were determined according to Mackereth et al. (1978). Total phosphorus, orthophosphate, chlorophyll-a, dissolved oxygen (DO), total suspended solids (TSS), organic and inorganic solids, 5-day biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total Kjeldahal nitrogen (TKN), chloride and silicate were determined according to Murphy and Ryley (1962), Nusch (1980), Golterman et al. (1978) and APHA (1998), respectively. Temperature, pH, electrical conductivity and water flow were taken by probe Horiba U-10 and flow meter, respectively.

Bottom soil

Bottom soil samples were collected every three days in the lake using a 4-cm diameter PVC core only at site P5. Nitrogen and phosphorus analyses were undertaken according to Mackereth et al. (1978) and Murphy and Riley (1962), respectively. All samples were carried to the laboratory in ice boxes.

Trophic State Index

Carlson's trophic state index (TSI) was calculated for variables chlorophyll-a (TSIChl), total phosphorus (TSIP) and Secchi disk (TSISD), according to Carlson (1977).

Evaluation of Environmental Impact

Environmental impact was evaluated by diagnosis of the limnological analyses during the fish farm operation stage according to an evaluation matrix proposed by Pillay (1992).

Statistical analysis

Two-way ANOVA was applied to physical and chemical variables in order to compare sites (P1-P6) and seasons (rainy and dry), and to evaluate the interaction between them (ZAR, 1996). Significance level was $p < 0.05$.

Results

Nitrate and ammonia presented an inverse fluctuation pattern ($p < 0.05$). Nitrate was the dominant nutrient in the supply water (P1 and P2) mainly during the rainy season, varying between 166 and 337 μg L^{-1} (Figure 1). Only nitrate among the nutrients analyzed had high rates in the water supply (P1 and P2). Ammonia greatly increased in the fish farm during the dry season, with highest concentrations at sites P3 (298 μg L^{-1}) and P4 (300 μg L^{-1}). They are sites close to the ponds that receive organic fertilizers (pig dung). Due to such management, site P5 and P6, which are the water outlet of the fish farm, had high rates of these nutrients (Figure 1). Total phosphorus and orthophosphate rates had a similar fluctuation pattern with high concentrations during the dry season and low ones during the dry one. However, rates differed significantly ($p < 0.05$) between seasons. Highest rates of the above nutrients were found in sites close to the ponds which receive pig dung fertilizer (P3 and P4). Low rates of total phosphorus and orthophosphate at the outlet of the fish farm (P6) may be associated to phosphorus retention on the sediment of lake P5 in which phosphorus rates on the bottom soil were above 1 g L^{-1} (Figure 1; Table 1). Nitrogen absorption on the bottom soil at site P5 was not as efficient as that of phosphorus, varying between 1.8 and 3.6% (Table 1). TKN had similar concentrations ($p > 0.05$) in the two seasons, with higher concentrations at P5, featuring 1.7 mg L^{-1} during the rainy season and 1.1 mg L^{-1} during the dry one. Highest TKN

concentrations at P5 coincided with highest rates at P4 (1.1 mg L^{-1}) in both seasons, when pig dung was used as fertilizer (Figure 2).

Chlorophyll-a was very low at P1 and P2 (water supply) due to the reservoir's oligotrophic features. Chlorophyll-a rates in the fish farm were higher; the highest peaks could be encountered at P3 and P4 (fertilized with pig dung) during the rainy season. The highest rates were found in the lake (P5) and in the fish farm outlet (P6) during the dry season. They varied between 14 and 40 μg L^{-1} at P5 and between 19 and 37 μg L^{-1} at P6 (Figure 2).

Further, pH, generally higher than 6, was similar ($p > 0.05$) in the two seasons throughout the fish farm. DO was somewhat higher ($p < 0.05$) during the rainy season with a sharp drop on the fourth day of the experiment at the sites within the fish farm (P3 to P6). However, it normally remained above 3 mg L^{-1}. Fluctuation pattern during the dry season was different ($p < 0.05$) only at P5, which receives total discharge from the fish farm.
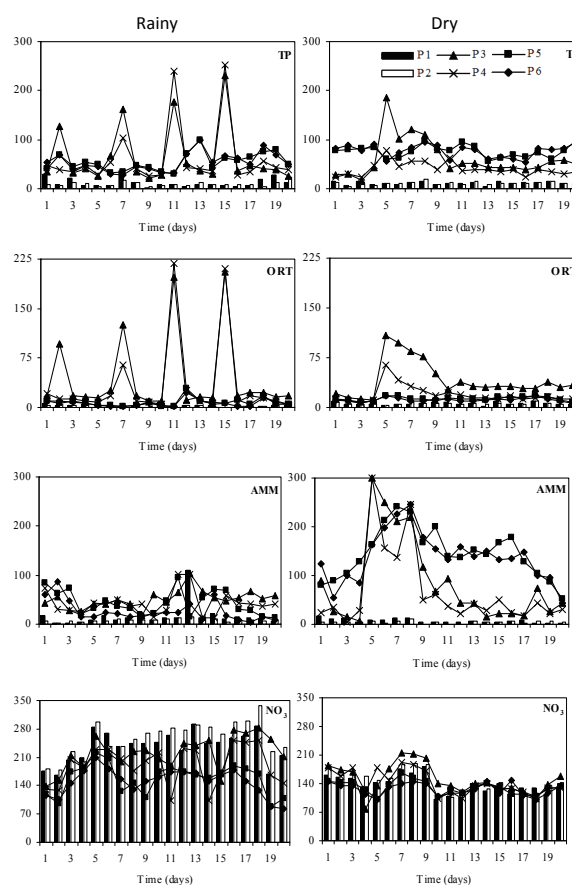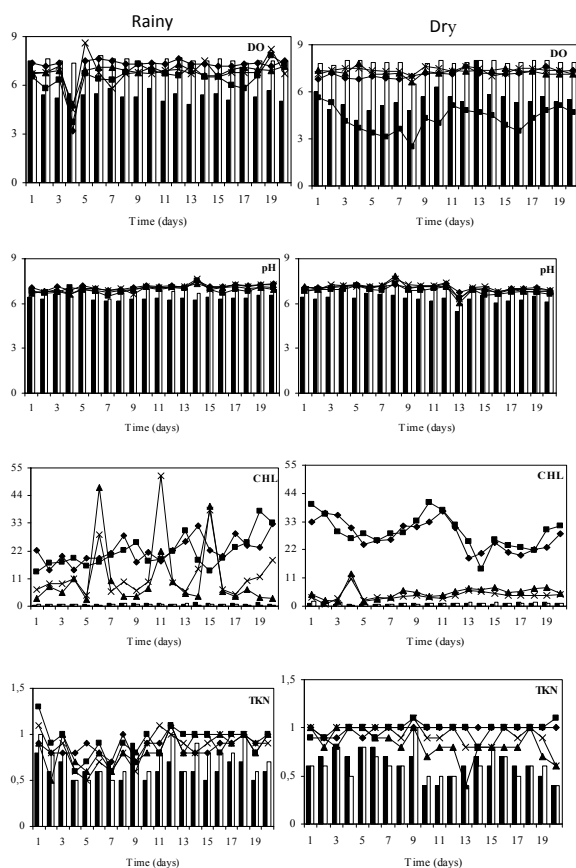

Figure 1. Daily variation of nutrients (μg L^{-1}) at the water column of sites P1 to P6, during the rainy and dry seasons, where TP = total phosphorus; ORT = orthophosphate; AMM = ammonia; NO$_3$ = Nitrate.

Table 1. Average, maximum, and minimum (between parentheses) rates of limnological variables at sites P1 to P6, nitrogen (N) and phosphorus (P) in the bottom soil of site P5, during the rainy (R) and dry (D) seasons.

	P1		P2		P3		P4		P5		P6	
VARIABLES	R	D	R	D	R	D	R	D	R	D	R	D
Temperature (0C)	23.3	20.9	23.9	21.8	25.8	22.3	25.8	22.2	26.0	22.8	26.5	23.0
	(23 - 24)	(20 - 22)	(23 - 25)	(21 - 22)	(25 - 27)	(21 - 23)	(25 - 28)	(22 - 24)	(25 - 28)	(22 - 25)	(25 - 29)	(22 - 25)
COD (mg L⁻¹)	0.8	0.7	1.0	0.8	2.1	1.1	2.2	1.3	2.4	3.1	2.5	3.2
	(0.5 - 1.3)	(0.3 - 1.2)	(0.3 - 1.6)	(0.5 - 1.2)	(1.0 - 7.5)	(0.7 - 2.4)	(1.1 - 7.0)	(0.8 - 1.8)	(1.3 - 4.1)	(1.9 - 4.6)	(1.7 - 3.2)	(2.5 - 5.0)
BOD5 (mg L⁻¹)	0.5	0.5	0.4	0.4	1.4	1.1	1.7	0.8	1.9	2.7	2.2	3.0
	(0.2 - 4.0)	(0.1 - 1.3)	(0.2 - 2.9)	(0.1 - 3.7)	(0.3 - 4.9)	(0.1 - 6.0)	(0.7 - 4.5)	(0.4 - 2.5)	(0.7 - 3.9)	(1.3 - 4.6)	(1.2 - 5.0)	(1.3 - 5.4)
Water Flow (L s⁻¹)	*	*	*	*	1,151	717	1,462	753	*	*	*	*
					(737 - 1,343)	(355 - 1,047)	(815 - 2,237)	(224 - 1,517)				
Chloride (mg L⁻¹)	0.8	0.9	0.8	0.9	2.3	1.5	2.4	1.1	2.3	1.3	2.2	1.2
	(0.6 - 1.3)	(0.3 - 1.8)	(0.3 - 0.9)	(0.3 - 1.7)	(0.9 - 4.7)	(0.3 - 4.4)	(0.6 - 4.8)	(0.3 - 2.2)	(0.7 - 6.9)	(0.4 - 3.0)	(0.5 - 3.8)	(0.3 - 2.4)
Silicate (mg L⁻¹)	4.1	4.6	4.9	5.4	4.5	4.8	4.0	5.4	4.2	4.5	4.4	5.2
	(1.8 - 6.3)	(0.7 - 6.7)	(3.5 - 6.2)	(2.7 - 7.2)	(2.2 - 5.7)	(1.0 - 7.2)	(2.7 - 5.3)	(2.4 - 6.8)	(1.7 - 5.1)	(1.9 - 7.2)	(2.3 - 5.4)	(1.8 - 6.8)
Alkalinity (mg L⁻¹)	16.2	16.3	14.5	16.6	17.2	18.0	16.5	17.5	17.5	18.4	17.1	18.2
	(9 - 19)	(15 - 18)	(10 - 18)	(15 - 18)	(15 - 21)	(15 - 27)	(14 - 21)	(13 - 21)	(16 - 24)	(17 - 19)	(13 - 25)	(14 - 20)
N soil (%)	*	*	*	*	*	*	*	*	2.4	2.7	*	*
									(1.1 - 3.1)	(1.8 - 3.6)		
P soil (g L⁻¹)	*	*	*	*	*	*	*	*	1.8	1.9	*	*
									(1.1 - 2.7)	(0.8 - 2.2)		

*not measured.

Figure 2. Daily variation of dissolved oxygen (DO - mg L⁻¹), pH, chlorophyll-a (CHL - μg L⁻¹) and total Kjeldahal nitrogen (TKN - mg L⁻¹) at the water column of sites P1 to P6, during the rainy (R) and dry (D) seasons.

Since it is deeper (5 m) than the fish ponds (1.5 m), water flow during this period was less intense, with greater decomposition and, consequently, low DO rates. The latter varied between 2.5 and 5.6 mg L⁻¹. The opposite occurred for BOD5 and COD at P5, with highest rates varying between 1.3 and 4.6 mg L⁻¹ and between 1.9 and 4.6 mg L⁻¹, respectively (Figure 2; Table 1).

Rates of suspended, organic and inorganic solids were higher at sites within the fish farm due to feeding and organic fertilization management, featuring a similar fluctuation pattern ($p > 0.05$) among themselves (Figure 3). Nevertheless, highest rates occurred during the rainy season mainly at P3 and P4; highest rates in the dry season occurred at P5 and P6, the water outlet of the fish farm (Figure 3). Conductitivy was below 65 μS cm⁻¹ during the rainy season and 90 μS cm⁻¹ during the dry one. In both seasons the sites with the higest rates were P3 and P4, although highest rate occurred at P3 (93 μS cm⁻¹) (Figure 3).

Alkalinity was low with high mean rates only during the dry season. Temperature was higher ($p < 0.05$) during the rainy season which is the hottest period (summer), albeit not over 28°C (Table 1). Chloride in water increased in the fish farm ($p < 0.05$) with highest rates at P6 in both seasons, varying between 1.2 and 5.0 mg L⁻¹ and between 1.3 and 5.4 mg L⁻¹ during the rainy and dry seasons, respectively (Table 1). No great variations occurred in the silicate ($p > 0.05$) at the sites analyzed. Its mean rates varied between 4.1 and 5.4 mg L⁻¹ in both seasons (Table 1).

Carlson's Index for the determination of the trophic state showed that sites P1 and P2 were oligotrophic, whereas P3 had a mesotrophic environment going on to eutrophic; P4 was eutrophic only for phosphorus during the rainy period. However, P5 and P6 were eutrophic for all variables analyzed during both seasons (Table 2).
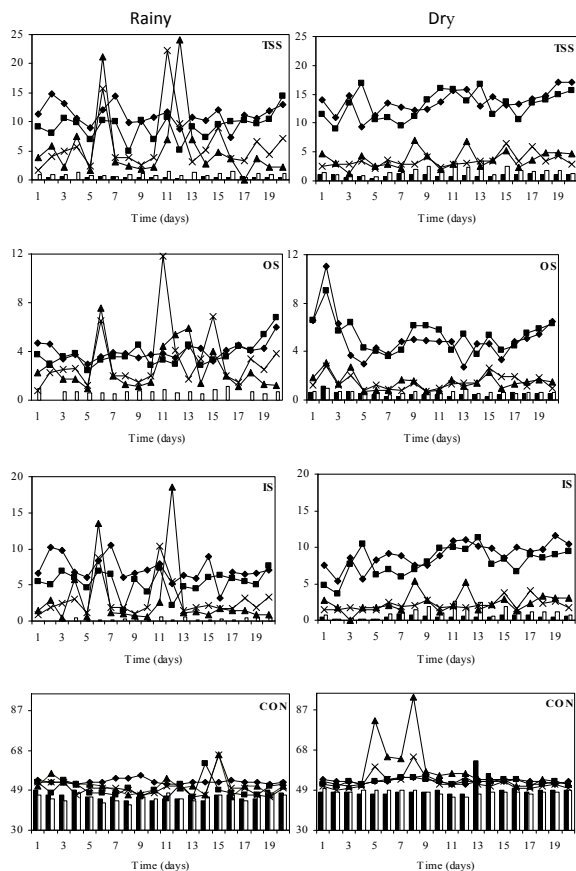
Figure 3. Daily variation of total suspended solids (TSS - mg L^{-1}), organic solids (OS - mg L^{-1}), inorganic solids (IS - mg L^{-1}) and conductivity (CON - μS cm^{-1}) at the water column of sites P1 to P6, during the rainy and dry seasons.

Table 2. Trophic state index of total phosphorus, chlorophyll-a and Secchi disk during the rainy and dry seasons at sites P1 to P6.

Variables	Seasons	Sites					
		P$_1$	P$_2$	P$_3$	P$_4$	P$_5$	P$_6$
Total	Rainy	33.2	29.4	63.0	63.6	54.3	54.2
Phosphorus	Dry	31.7	31.1	57.0	50.0	59.3	59.3
Chlorophyll-*a*	Rainy	33.9	31.0	45.8	53.5	57.9	56.1
	Dry	31.0	31.9	45.5	43.9	62.0	61.6
Secchi disk	Rainy	27.1	★	★	★	27.7	★
	Dry	26.1	★	★	★	27.0	★

★not measured.

Data analyzed established an environmental impact matrix and took into consideration average concentration reported at each site. Greater impact

was registered (3C) in the fish farm under analysis for variables COD, ammonia, total phosphorus and TSS, in water quality and in the discharge period or rather, when ponds were emptied. TSS was also an impacting variable during the food supply period. Nitrogen and phosphorus in the bottom soil showed average effective importance (2B) during the hauling period (Table 3).

Discussion

Management pattern in the employment of organic fertilizer associated with feed greatly impacted water quality, especially with regard to nitrogen, phosphorus, TSS, organic and inorganic solids, COD, BOD5 and conductivity, with direct effects in the lake (P5) and with medium impact on phosphorus and nitrogen rates. When the latter are placed in the effluent (P6) of fish farm they will surely affect the river Grande's limnological conditions.

Suspended solids, phosphorus and nitrogen are of great concern for their potential impacts on pond effluents and on the environment. Only less than 30% of the feed or fertilizer nitrogen and phosphorus added to ponds are recovered during fish harvest (RAHMAN; VERRETH, 2008). In the fish farm under analysis feed (ration) was added approximately at the rate of 3 kg three times a day in the fish ponds and at the rate of 25 kg three times a week for P5. Above-mentioned rates show an excess in organic load and needs re-evaluation of feed management to decrease and minimize the impact. Current study shows that the effluent's characteristics brought about by fish farm are characterized by great concentrations of suspended solids and by nitrogen and phosphorus compounds.

The nutrients accessed to pond water from fertilizer, unconsumed feed, fish feces and fish metabolites contribute to the pond's eutrophication. Sites P1 and P2 (water supply) are oligotrophic and do not receive any ration, whereas the sites within the fish farm are mesotrophic and eutrophic.

Table 3. Evaluation matrix comprising environmental impact for the operation phase of fish farm during the rainy and dry seasons, with system's factors size (1- small; 2- medium; 3- high); importance (A- small; B- medium; C- high), during the study period; where CON = conductivity and ORT = orthophosphate.

Phases of Activities	Alterations Environment	Water									Bottom soil	
		DO	pH	CON	BOD$_5$	COD	NH$_4$	TP	ORT	TSS	N	P
Use	Water Quality	3B	1B	1C	2C	3C	3C	3C	2B	3C	★	★
of intakes	Bottom Soil	★	★	★	★	★	★	★	★	★	1B	1B
(ration, manure)	Water Flow	1B	★	★	2B	2B	3B	1B	2B	2B	★	★
Fishponds	Hauling	★	★	★	★	★	1B	1B	★	★	2B	2B
Management	Discharge	★	★	★	★	3C	3C	3C	★	3C	★	★
	Food Supply	1A	★	2A	2B	2B	2B	2B	★	3C	★	★

★not detected.

Care should be taken in the evaluation of P5 and P6 owing to the large organic load they receive. In fact, the place should be used as a depuration lake without any ration or fish and will also improve the effluent water of the fish farm. An evaluation of the environmental impact of the fish farm showed the great importance and high rates of limnological variables, with special emphasis on the impact caused by the additional organic charge placed on the fish ponds with high TKN rates in the water and phosphorus in the bottom soil at P5. This site is the fish farm's decantation lake with inadequate water conditions directly discharged into the river Grande.

It should be emphasized that, in the case of fish farm management, the nature and frequency of foraging and manuring of ponds affect directly the system's water quality. Further, the discharge system of culture ponds is frequently deployed in the fish farm in which, in a short period of time, great quantities of organic load are released and directly affect the site that receives the discharge (P5 and P6). Chloride is also an increasingly high rate element in the fish farm. It is thus mandatory that salt use in controlling fish disease should be managed more adequately so that when it reaches the river it does not have doubled the rate the original quantity had in the water supply (P5 and P6 P1 and P2). Maximum BOD levels reported during the intensive pond failed to reach the critical level of 30 mg L^{-1} (SUMAGAYSAY-CHAVOSO; DIEGO-McGLONE, 2003). Current study shows that BOD5 and COD rates were lower than 6 mg L^{-1}, although this did not occur with TSS, organic and inorganic solids. According to Boyd (1990), TSS is also a good indicator of pollution because of the direct relationship with biomass feed input. As expected, TSS was higher within the fish farm when compared with rate in water supply (P1 and P2). This is due to high organic loading of the fish ponds.

Low ammonia concentrations during the rainy season were associated with high concentrations of nitrate. In fact, they are the most stable form of dissolved inorganic nitrogen for the buildup of nitrogen at high biomass (SUMAGAYSAY-CHAVOSO; DIEGO-McGLONE, 2003). Low alkalinity found in current experiment at the analyzed sites in the fish farm has been associated with pH rates which were mainly below 6.8. CO_2 is released during decomposition and thus lowers pH and alkalinity (RAHMAN; VERRETH, 2008).

Actually there are no clear rules for aquaculture activities with regard to warrants and system management that would guarantee the equilibrium of the environment. One suggestion for sustainable aquaculture is the diffusion of production technology that aims at increasing production, decreasing costs and promoting fish survival (HISHAMUNDA; RIDLER, 2002). Whereas effective practices in environmental protection should be established, incorrect management risks should be lessened through a holistically-approach aquaculture. Lack of information on monitoring and management causes high risks in environmental impact. The establishment of management practices proper to the system's local conditions should be undertaken to prevent or at least to minimize the impacts that may be caused. Evaluation may be undertaken for each system, for each fish species and for the region since different factors may require other conditions and production methods.

Conclusion

According to our results, the following recommendations may be applied in this fish farm

Feed formulations should eliminate high levels of phosphorus and non-digestible compounds, testing the minimum needs of fish species to be cultured.

Frequent monitoring of water quality and fish breeding and plankton ponds, especially those close to P3 and P4, should be mandatory.

Removal of sediment in P5 to decrease nutrient concentrations, especially phosphorus, accumulated on the bottom of the lake.

Greater oxygenation at site P5 (decantation lake) will benefit nitrification and the reduction of ammonia and nitrite in the system; the lake should be used solely as a depuration system for organic and inorganic loads from the fish farm; the water may thus be discharged into the river Grande with the least load of material from fish culture.

Installation of water treatment (wetland) at the effluent of the fish farm so that the impact may be lessened.

Current study also recommends the use of the best available method and manipulation techniques for fish farm monitoring.

Acknowledgements

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