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Fish-farming water quality and environmental concerns in Argentina: a regional approach

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Abstract In spite of the steady increase in fish farming in Argentina, studies on water quality are scarce. Eight fish farms from two different regions in the northeast and east of Argentina were studied to explore source and effluent water quality. Ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) levels were measured. High nitrate concentrations in water source were observed in the eastern region farms. An increase in NH_4^+, NO_3^-, and NO_2^- in effluent water was determined in most of the sampled farms. Heavy metals (i.e., cadmium, chromium, copper, iron, manganese, nickel, and zinc) and arsenic concentrations were analyzed. Heavy metal concentrations were below the detection limit in the northern region. However, As was detected in the water source of five farms and was over the recommended limit (100 $\mu g l^{-1}$) for aquaculture in one. An increase in Mn and Zn concentrations in effluent water was observed in two farms. The lack of treatment of the effluent water in these farms leads to an increase of nutrients and heavy metal concentrations in the surrounding areas. Environmental effects of fish-farming practices in Argentina are discussed.

Keywords Argentina · Arsenic · Environment · Heavy metals · Nutrients · Water quality

Introduction

Fish farming in Argentina is increasing every year (FAO 2007) to satisfy the demands of internal and external markets. Four different geographic production regions are considered

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in Argentina for aquaculture: the temperate subtropical northeast region, best suited for tilapia, *Oreochromis sp.*, catfish, *Rhamdia quelen* (Quoy and Gaimard), pacú, P*iaractus mesopotamicus* (Holmberg), carp, C*iprinus carpio* (Linnaeus) among others, the cold temperate west Andean mountain range region suitable for salmonid production, the temperate continental east region considered for pejerrey, *Odontesthes bonariensis* (Valenciennes) production, and the temperate-cold temperate seashore region considered for fluke*, Paralichthys orbignyanus* (Valenciennes), lisa, *Mugil sp.*, mussel organism and algae (Luchini 2004). There are many possible species for aquaculture in each region; however, the main product of aquaculture in Argentina is rainbow trout, *Oncorhynchus mykyss* (Walbaum) in the Andean region followed by pacú in the subtropical northeast region.

Water quality is one of the main concerns in aquaculture. Any change in the chemical or physical parameters can cause a negative effect on the growth of the organisms, their physiological state, or even mortality, causing major losses in production. Many studies describe the quality of the waters (surface and groundwater) in some Argentinean regions (e.g., Pesce and Wunderlin 2000; O'Farrell et al. 2002; Jergentz et al. 2005; Vignolo et al. 2006; Feijoó and Lombardo 2007; Galindo et al. 2007; Schenone et al. 2007; Schenone et al. 2008); however, none of these studies consider water sources in terms of suitability for fish production. There are no water quality guidelines in Argentina for fish production; thus, there are no strict controls over aquaculture water sources or effluents. The main physicochemical factors measured by farmers in small-scale production systems are pH, conductivity, and dissolved oxygen (daily), and nitrite and ammonium (weekly if possible) in the production ponds. Heavy metal presence or ammonium, nitrate, and nitrite concentrations in water sources are not considered in many cases.

It is known that heavy metals are harmful to some fish species (Hetrick et al. 1979; Gómez et al. 1998; Playle 2004; Liao et al. 2008; Lin and Liao 2008; Davidson et al. 2009; Yadav and Trivei 2009) resulting in a decreased production. Low heavy metal concentrations are not always related directly to the production quantity but to product quality if the final destination is human consumption. This is due to the fact that heavy metals have the capacity to bioaccumulate in some fish tissues (Marcovechio et al. 1988; Oliveira Ribeiro et al. 2005; Chi et al. 2007; Carriquiriborde and Ronco 2008; Uysal et al. 2008), leading to higher concentrations in fish compared with farming water. In this way, the fish quality deteriorates, and if concentrations exceed the limits for human consumption, there may be consequences in regard to human health. The adverse human health effects associated with exposures to heavy metals are diverse, and include but are not limited to, neurotoxic and carcinogenic effects (Sapkota et al. 2008).

Besides source waters, the quality of the effluent water is very important when considering environmental aspects of fish production. Aquaculture has become large enough to have significant impacts on the environment and natural resources. This has led to the expression of numerous concerns by both environmental activists and scientists (Dierberg and Kiattisimukul 1996; Goldburg and Triplett 1997; Naylor et al. 1998; Naylor et al. 2000). Some concerns include: water pollution resulting from pond effluents (i.e., salinization of land and water by effluents, seepage, and sediment from brackish water ponds), excessive use of ground water, and other freshwater supplies for filling ponds, spread of aquatic animal diseases from cultured organisms to native populations, negative effects on biodiversity caused by escape of non-native species introduced for aquaculture, destruction of birds and other predators, and entrainment of aquatic organisms in pumps (Boyd 2003) among others. In Argentina, there are no regulations regarding the discharge of aquaculture effluent. The concentration of nutrients and other pollutants, such as heavy metals released to the environment, may cause a negative impact in the surrounding areas. The impact on the environment depends on the total amount or concentration released and also the assimilative capacity of the environment for that particular contaminant (Piedrahita 2003). In contrast, the nutrients contained in aquaculture wastes can be reused through integration of aquaculture–aquaculture and aquaculture–agriculture systems (Lin and Yi 2003). Due to the lack of information about the growing aquaculture activity in Argentina, it is important to take the first steps in regulating water quality for production and wastewater disposal as it has become an important issue. The aim of this study is to evaluate the source and effluent water quality from fish farms in two different regions in Argentina, considering both fish production quality and environmental aspects.

Materials and methods

Eight fish farms from two different regions were sampled. Farms 1, 2, 3, 4, and 5 correspond to the temperate subtropical northeast region, and farms 6, 7, and 8 are located in the temperate continental east region. Within the sampled farms, different production systems were observed for different fish species and production scale (Table 1). In addition, the final purpose is not the same in each farm. For example, the production from farms 1, 2, 3, 4, and 8 productions is destined for human consumption; while, farm 5 production is for aquariums, and the production of farms 6 and 7 is oriented toward the repopulation of lagoons for recreational purposes, such as sport fishing.

The farms with extensive production use large-scale lagoons (over 20,000 m^2). One of the advantages of this type of system is low water maintenance due to natural biochemical processes. Also, the natural food web in these lagoons decreases costs for the farmers. Large-scale production and management are another advantage. In this production system, there are few controls over water quality. The main disadvantage of extensive production is the lack of water during the dry season if the water source is superficial. Natural predators or point contamination may have a negative effect on production. In farms with semi-intensive production, water quality controls are more intense due to the higher density in

Table 1 Production type, species, and final destination of fish in the sampled farms

	Production type	Species	Final destination
Farm 1	Extensive	Tilapia (*Oreochromis sp.*)	Human consumption
Farm 2	Semi-intensive	Pacú (*Piaractus mesopotamicus*)	Human consumption
Farm 3	Semi-intensive	Pacú (*Piaractus mesopotamicus*)	Human consumption
		Tilapia (*Oreochromis sp.*)	
		Carpa (*Cyprinus carpio*)	
Farm 4	Semi-intensive	Tilapia (*Oreochromis sp.*)	Investigation and human consumption
		Pacú (*Piaractus mesopotamicus*)	
		Red Claw (*Cherax quadricarinatus*)	
		Catfish (*Rhamdia quelen*)	
Farm 5	Semi-intensive	Goldfish (*Carassius sp.*)	Aquariums
Farm 6	Intensive	Pejerrey (*Odontesthes bonariensis*)	Investigation and repopulation
Farm 7	Intensive	Pejerrey (*Odontesthes bonariensis*)	Investigation and repopulation
Farm 8	Intensive	Tilapia (*Oreochromis sp.*)	Human consumption

earthen ponds (5,000 m^2). In order to control dissolved oxygen concentrations, many farmers use mechanical aerators. Farms with intensive production farms have more stringent controls over the water quality in their fish ponds due to the high fish density. However, effluent water quality is not monitored in any of the production systems listed above.

Water samples were taken, in triplicate, from the water source, and from continuous effluent, or from ponds, when effluent was not significant. Conductivity (mS cm^{-1}), pH, temperature (°C), and dissolved oxygen (mgl^{-1}) were measured in situ using Hanna field instruments (models HI 9033, HI 9025, and HI 9142, respectively). Water samples were collected in 500-ml polyethylene containers, previously soaked with 10% nitric acid and deionized water, adding 0.2% *v*/*v* nitric acid, and conserved at 4°C. The nitrate (NO_3^-) determination was made according to APHA 4500-NO3 E method, nitrite (NO_2^-) according to EPA 354.1 method, and ammonium (NH_4^+) according to APHA 4500-NH3 D method. For colorimetric determinations, a Jasco 7850 spectrophotometer was used. The presence of As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn was analyzed. Samples for metal determination were conditioned following APHA (1993) techniques. Concentrations were determined by atomic emission spectrophotometry with inductive coupling plasma (ICP-OES), using a PERKIN ELMER Optima 2000 DV device.

Results and discussion

Physicochemical properties of water sources are shown in Table 2. pH values were close to 7 in most of the farms except in farms 1, 2, and 8 which are slightly alkaline. The lowest conductivity was registered in farm 3, which has excellent water quality due to the geological characteristics of this area. Highest conductivities were found in farms 6 and 7. These two farms are in the proximity of high salinity lagoons (INTECH, personal communication). Nitrate values were between 0.1 and 5.2 mgl^{-1}. The highest values correspond to Buenos Aires province farms (6, 7, and 8). These high values are the consequence of intensive agriculture and subsequent non-point source pollution from fertilizers. Nitrite values were below the detection limit in most of the farms with the exception of farms 7 and 8. Low ammonium values were observed (<0.01 and 0.03 mgl^{-1}) in every farm.

Table 2 Physicochemical parameters from water source of farms and source type

	Water source					
	Type	pH	Conductivity μScm^{-1}	NO_3^- mgl^{-1}	NO_2^- mgl^{-1}	NH_4^+ mgl^{-1}
Farm 1	Superficial water	8.0	384	0.8	<0.1*	0.01
Farm 2	Ground and superficial water	8.1	1,986	<0.1*	<0.1*	0.03
Farm 3	Ground water	7.2	42	0.7	<0.1*	0.01
Farm 4	Ground and superficial water	6.9	835	2.1	<0.1*	<0.01*
Farm 5	Ground water	7.0	862	1.3	<0.1*	<0.01*
Farm 6	Ground water	7.3	16,160	5.0	<0.1*	0.02
Farm 7	Ground water	7.3	15,740	5.2	0.3	0.02
Farm 8	Ground water	7.9	1,020	2.8	2	0.01

* Below detection limit

Table 3 Heavy metal and As concentration (μgl^{-1}) from the water source in the different farms

	Water source							
	As	Cd	Cr	Cu	Fe	Mn	Ni	Zn
Farm 1	<10*	<5*	<5*	<5*	<10*	<4*	<5*	<8*
Farm 2	<10*	<5*	<5*	<5*	<10*	<4*	<5*	<8*
Farm 3	<10*	<5*	<5*	<5*	<10*	<4*	<5*	<8*
Farm 4	36	<5*	<5*	<5*	233	<4*	<5*	<8*
Farm 5	40	<5*	<5*	<5*	nd[a]	<4*	<5*	<8*
Farm 6	54	<5*	<5*	<5*	<10	1,337	nd[a]	<8*
Farm 7	19	<5*	<5*	<5*	31	215	nd[a]	<8*
Farm 8	151	7	<5*	<5*	<10*	<4*	<5*	<8*
Detection limit	<10	<5*	<5*	<5*	<10*	<4*	<5*	<8*

[a] Not determined

* Below detection limit

Heavy metal and Arsenic analysis values in water sources are shown in Table 3. Farms 1, 2, and 3 have concentrations below the detection limits. According to these results, there should be no important effect of heavy metals on production quality if water quality is considered as the only exposure pathway. High source water quality is used for aquaculture in these farms. Arsenic was detected in farms 4, 5, 6, 7, and 8. In this area, As is naturally present and affects groundwater (Farías et al. 2003), and depending on the river flows, may also affect superficial waters. The As levels in farms 4, 5, 6, and 7 were over the recommended limit for human consumption (10 μgl^{-1}) according to the Subsecretaria de Recursos Hidricos de la Nación (National Sub Secretary of Hydric Resources); however, there is no recommended As level for aquatic animal production. If the maximum permitted limit for aquaculture production in Taiwan (50 μgl^{-1}) (Lin and Liao 2008) is considered, farms 6 and 8 could be classified as compromised farms. However, Feldlite et al. (2008) suggest that concentrations of As = 0.1 mgl^{-1}, Cd = 0.01 mgl^{-1}, Pb = 0.1 mgl^{-1}, Hg = 0.002 mgl^{-1} are safe regarding the consumption of flesh from fish reared in reclaimed water, even if the growing season is long (up to 2 years). These requirements are not equally safe if liver or other viscera instead of flesh are consumed. Considering these values, farm 8 As concentration is over the proposed standards. High Mn concentrations were observed in farms 6 and 7, probably because both are in the same area. Cd, Cr, Cu, Zn, and Ni concentrations were below the detection limit in all farms.

Effluent water physicochemical parameters are shown in Table 4. Farms 1, 2, 3, 4, and 5 use earthen ponds for aquaculture production with no continuous effluent flow. Continuous flow systems are used by farms 6 and 7 for pejerrey breeding, generating continuous effluent. Farm 8 uses a recirculating aquaculture system with biological filters and a sediment trap to optimize the use of water.

A pH increase in effluent water (2.7–11.3%) was evident in all farms, except for farm 2, when compared with the water source. Conductivity values increased in every farm with the addition of fish food. An increase in nitrate concentration in effluent waters was observed in all farms, particularly in farms 6, 7, and 8. High protein–containing diets are used; thus, high nitrogen inputs to these systems generate high concentrations of nitrogenated wastes. Nitrite concentrations in effluent waters were below detection limits in farms 1, 2, 3, 4, and 5, but farms 6, 7, and 8 showed an increase compared to the water source. Ammonium

Table 4 Physicochemical parameters from water effluents and ponds in fish farms

	Effluent water					
	Type	pH	Conductivity μScm^{-1}	NO_3^- mgl^{-1}	NO_2^- mgl^{-1}	NH_4^+ mgl^{-1}
Farm 1	Pond	8.9	703	4.1	<0.1	0.45
Farm 2	Pond	7.9	2,220	4.0	<0.1	0.32
Farm 3	Pond	7.6	249	1.2	<0.1	0.01
Farm 4	Pond	7.4	931	3.8	nd*	0.22
Farm 5	Pond	7.2	904	nd*	nd*	nd*
Farm 6	Continuous effluent	7.5	16,250	15.7	1	0.18
Farm 7	Continuous effluent	7.6	16,143	10.2	1	0.05
Farm 8	RAS**	8.11	1,097	6.88	3	2.30

* Not determined

** Recirculating aquaculture system

concentration values were higher in the effluent water compared with the source water in all farms. The highest value was observed in farm 8, which uses a recirculating aquaculture system (RAS). The ammonium level in this farm was maintained at the biological limit to reduce pumping cost without affecting the animals.

Heavy metal and As concentration also varied in the effluent with respect to the water source (Table 5). An increase in As concentration was observed in farms 1, 4, 5, 6, 7, and 8; however, these values are below the suggested limits for fish production (Feldlite et al. 2008), except in farm 8, and the increase is not high enough to be considered an environmental issue. An increase in micronutrients (i.e., Fe, Mn, and Zn) was observed in some farms (Table 5); however, farms 6 and 7 showed a high initial concentration of Mn which decreased in effluent. High Mn concentration may affect fish production (Partridge and Lymbery 2009). Nevertheless, controls over the effluents should be obligatory in every farm and considered in aquaculture projects.

Table 5 Heavy metal and As concentration (μgl^{-1}) from the effluent water in the different farms

	Effluent water							
	As	Cd	Cr	Cu	Fe	Mn	Ni	Zn
Farm 1	21	<5*	<5*	<5*	nd[a]	8	nd[a]	<8*
Farm 2	<10*	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]
Farm 3	<10*	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]	nd[a]
Farm 4	63	<5*	<5*	<5*	554	4454	<5*	<8*
Farm 5	46	<5*	<5*	<5*	nd[a]	nd[a]	nd[a]	nd[a]
Farm 6	58	<5*	<5*	6	52	1092	nd[a]	45
Farm 7	21	<5*	<5*	6	17	89	nd[a]	6
Farm 8	163	6	<5*	<5*	<10*	<4*	<5*	<4*

[a] Not determined

* Below detection limit

Conclusions

Results obtained in this study showed high quality source water, considering the cultured species in each farm. However, high nitrate concentrations were registered in farms 6, 7, and 8. Pejerrey growth would not be affected within these values, due to the high nitrate tolerance for this species (Gómez et al. 1998). High ammonium values were also detected in the effluent of these farms. In intensive aquaculture systems, the ammonium produced from food is generally the second limiting factor after dissolved oxygen (Ebeling et al. 2006).

The arsenic concentrations were over the suggested limit according to the Taiwan regulatory authority (50 μgl^{-1}) in farms 6 and 8 water source and effluent and in farm 4 effluent. The highest As concentration was measured in farm 8. It is known that arsenic consumption may cause poisoning affecting the skin and internal organs such as liver and kidneys, and it is also known to be carcinogenic (Choong et al. 2007). Liao et al. (2008) estimated in tilapia a reference inorganic arsenic guideline value 84 μgg^{-1} dry wt based on the suggested daily consumption rate of 120 gd^{-1} and proposed a bioaccumulation model to describe the arsenic concentration in tilapia exposed to arsenic in an aquaculture pond. Assuming this model, a maximum of 0.31 μgg^{-1} dry wt and a minimum of 0.11 μgg^{-1} dry wt were calculated for farm 8. These values are below the proposed guideline value. However, further investigation on As concentration in fish is necessary to evaluate the potential risk to product quality. Heavy metal concentrations in the other farms were low and are not considered as a risk to the fish. The increase of heavy metals in effluent water could originate from fish food.

Physicochemical parameters reveal the effect of fish production on the environment. Most farms effluents showed an increase in pH, conductivity, nitrate, nitrite, and ammonium due to the fish food added to the ponds. Elevated nitrogenated compound concentrations in effluents were found in farms 6, 7, and 8 possibly due to high protein levels in diets. To prevent higher concentrations in the tanks, a constant water source flow is used. This implies there is a constant supply of nutrients enriching the effluent, generating both a loss for producers and for the environment as a negative impact promoting eutrophication. At farms 1, 3, and 4, there are also ammonium and nitrate concentration increases, but there is no continuous effluent, and at the end of the production cycle, ponds are drained to the environment with no treatment. Current global trends in environmental regulation limit the amount of water which may be consumed or discharged, thus reducing the need for large volumes of water to remove excess nitrates (Hamlin 2006). The use of green technologies such as macrophytes or periphyton to recycle aquaculture water and simultaneously produce fish feed is a low cost alternative and at the same time useful to the producers. The periphyton treatment technique is a double-purpose technique, which is applicable to extensive systems and the proteinaceous bio-flocs technology can be used in extensive as well as in intensive systems. In addition to maintenance of good water quality, both techniques provide an inexpensive feed source and a higher efficiency of nutrient conversion of feed (Crab et al. 2007).There are also many studies about nutrient uptake by macrophytes (Redding et al. 1997; Saha and Jana 2003; Oron et al. 2004; Sooknaha and Wilkie 2004; Maine et al. 2006); however, there are few studies that consider a direct application in aquaculture systems. *Lemna minor* is a free floating macrophyte, which could be an important source of proteins, vitamins, and minerals suitable for incorporation into fish diets (Kalita et al. 2007). Many involved in aquaculture believe that the application of best management practices (BMPs) could be a reasonable and affordable way to improve the quality and reduce the volume of pond effluents (Boyd 2003). Sustainable and economically viable aquaculture may be possible while minimizing environmental impacts if BMPs are implemented.

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