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REPORT

Estimation of Nitrogen and Phosphorus in Effluent from the Striped Catfish Farming Sector in the Mekong Delta, Vietnam

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Abstract In this study an attempt is made to estimate nitrogen and phosphorus discharged to the environment from the striped catfish (*Pangasianodon hypophthalmus*) farming sector in the Mekong Delta (8°33′–10°55′N, 104°30′–106°50′E), South Vietnam. The sector accounted for 687,000 t production in 2007 and 1,094,879 t in 2008, with over 95% of the produce destined for export to over 100 countries. Commercial and farm-made feeds are used in catfish farming, currently the former being more predominant. Nitrogen discharge levels were similar for commercial feeds (median 46.0 kg/t fish) and farm-made feeds (median 46.8 kg/t fish); whilst, phosphorus discharge levels for commercial feeds (median 14.4 kg/t fish) were considerably lower than for farm-made feeds (median 18.4 kg/t fish). Based on the median nutrient discharge levels for commercial feeds, striped catfish production in the Mekong Delta discharged 31,602 t N and 9,893 t P, and 50,364 t N and 15,766 t P in 2007 and 2008, respectively. However, the amount of nutrients returned directly to the Mekong River may be substantially less than this as a significant proportion of the water used for catfish farming as well as the sludge is diverted to other agricultural farming systems. Striped catfish farming in the Mekong Delta compared favourably with other cultured species, irrespective of the type of feed used, when the total amounts of N and P discharged in the production of a tonne of production was estimated.

Keywords Effluent discharge · Mekong Delta · Nitrogen · Nutrient mass balance · Pangasius · Phosphorus · Striped catfish · Tra Catfish · BMPs

INTRODUCTION

Aquaculture or farming of aquatic organisms is a very old tradition, thought to have originated in China over 2500 years back. Over the last few decades aquaculture is seen as the means of meeting the global aquatic food fish needs, consequent to the plateauing (FAO 2008) of the traditional food fish supplies from wild capture fisheries. It is estimated that currently nearly 50% of the food fish consumed is from aquaculture, which is also reputed to be the fastest growing primary food production sector (Subasinghe et al. 2009). Aquaculture being a relatively new food production sector, in global terms, has been subjected to a greater degree of public scrutiny and debate (De Silva and Davy 2009). Consequently, many issues relating to its environmental impacts (Naylor et al. 1998, 2001; World Wild Life Mediterranean Programme 2005; De Silva and Turchini 2008), resource usage (Wijkstrom and New 1989; New 1991, 1997; Naylor et al. 2000, 2009) and indeed human health impacts (Sapkota et al. 2009) have been raised.

It is often alleged that the ecosystem health of most tropical rivers is in a relatively poor state, primarily due to anthropogenic developments in their catchments, damming and untreated effluent discharges (Dudgeon 2000; Sodhi et al. 2004). The Mekong Delta (8°33′–10°55′N, 104°30′–106°50′E), South Vietnam has an area of approximately 3.9×10^6 ha with an estimated population of 17 million and, being the food basket of Vietnam, is heavily impacted by anthropogenic activities. The Mekong River, which divides into two main branches (Tien Giang and Hau Giang) as it enters the Delta, consequently receives a large quantity of effluent.

Over the last decade or so the Mekong Delta has also become the home to the rather explosive farming sector of the native catfish (*Pangasianodon hypophthalmus* Sauvage), locally known as striped, tra and/or sutchi catfish, but with many different trade names around the world (Nguyen and Oanh 2009; Phan et al. 2009). Also this sector has recorded the highest growth rate in volume compared to any other aquaculture commodity globally over the last decade or so. The sector accounted for 687,000 and 1,094,879 t production, in 2007 and 2008, respectively (Department of Aquaculture 2008), the latter amounting to 34.3% of the total aquaculture production in Vietnam, the fifth ranked nation in global aquaculture production (FAO 2008). The sector also provides employment to about 170,000 persons, mostly women (Sub-Institute for Fisheries Economics and Planning in Southern Vietnam 2009). Moreover, the great bulk of the produce is destined for export to over 100 countries (Globefish 2009), and consequently the sector has drawn the attention of many stakeholders, such as importers, environmentalists, entrepreneurs, etc. and is a commodity that standards are being developed for (Corsin 2007; Neubacher 2009).

Striped catfish culture practice in the Mekong Delta, a modernised version of an old practice (Nguyen and Oanh 2009; Phan et al. 2009), stands out in many respects from other aquaculture systems and practices. Foremost, the average production ranges from 350 to 400 t/ha/crop, with fish being harvested at 1–1.5 kg size for processing into fillets for export (Nguyen and Oanh 2009; Phan et al. 2009). Striped catfish exports worldwide have dramatically grown in recent years because it is seen as an acceptable substitute to other “white fish”, such as Atlantic cod (*Gadus morhua* L.) in Europe and channel catfish (*Ictalurus punctatus*) in the USA, but much less costly (Globefish 2009). Hence, striped catfish farming is one of the most important aquaculture sectors of the current global aquaculture industry. Striped catfish culture is predominantly in deep earthen ponds (average 4–4.5 m), mostly along the two main branches (Tien Giang and Hau Giang) of the Mekong River (Fig. 1), and are densely located (Fig. 2), often of uniform pond size, and with all farms extracting and discharging water from and into the river or connected channels. In aquaculture operations, feed is often regarded as both, the highest recurring monetary cost (Goddard

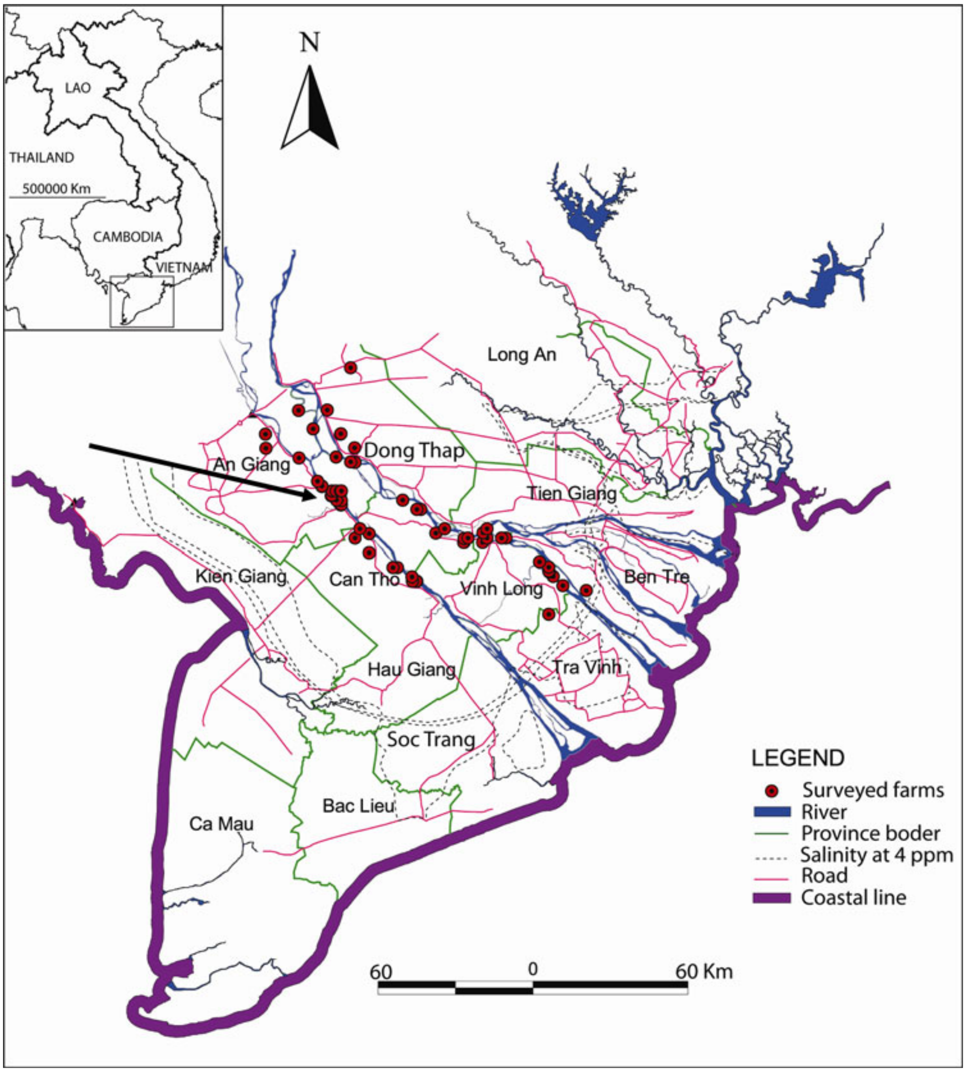

Fig. 1 The location of the main striped catfish farming areas in the Mekong Delta, Vietnam, in relation to the Delta as a whole (adopted from Phan et al. 2009). The *arrow* indicates the area of catfish farms that are shown in Fig. 2

Fig. 2 A Google image showing the concentration of catfish farms. Note the uniformity of pond size. The farm area shown here is indicated by the *arrow* in Fig. 1

1996) and the main factor responsible for potential detrimental impacts on the environment primarily through the discharge of nitrogen and phosphorus as excreta and other metabolic products (De Silva and Anderson 1996).

Accordingly, this article attempts to estimate the nitrogen and phosphorus discharge into the Mekong River from the striped catfish farming sector, which occurs along the banks of the river and its channels. This farming sector was chosen in view of the fact that, in the last decade, it has recorded the highest growth rate in volume compared to any other aquaculture commodity globally, and also provides an opportunity to assess the total discharge from an aquatic farming system as a whole. In fact, and interestingly, the production from the striped catfish farming sector is concentrated in a relatively small geographical area (Figs. 1, 2), and characterised by highly homogenous farming practices; both criteria that have been rarely witnessed for any other aquaculture sector.

MATERIALS AND METHODS

In this study a number of data sources were utilised; data on fish feeding practices and the average FCR (amount of food dispensed as fed/increase in biomass of stock in wet weight) obtained by the recent survey of 97 catfish farms in the Mekong Delta implemented by Collaboration for Agriculture and Rural Development (CARD) program between the Governments of Vietnam and Australia, funded through the Australian Agency for International Development (AusAID) (see Phan et al. 2009 for more detailed information), proximate analysis of representative feed samples, both commercial and farm-made feeds, and information from the literature on nitrogen and phosphorus retention in the body. During this survey it was apparent that catfish farmers predominantly use commercial, pellet feeds, and a small percentage make their own feed, referred to as farm-made feeds, using locally available ingredients. Also during the survey details on feeding practices and the type of commercial feeds used at different stages of the growth cycle were obtained. This study did not compare the composition and the efficacies per se of farm-made feeds against the commercially manufactured pellet feeds, which by itself warrant a separate detailed investigation. However, it has been demonstrated that the difference in the proximate composition of the two feed types are marginal, but criteria such as water stability, digestibility, etc. between the two types are unknown (Phan et al. 2009).

Feeds

A total of 12 commercial feed samples, from six manufacturers were chosen randomly for analysis, out of a total of about 20 relatively large feed manufacturers (each producing over 200 t/year) operating in the Mekong Delta, and catering almost exclusively to the catfish farming sector (Nguyen and Oanh 2009; Phan et al. 2009). In addition, four farm-made feeds (FMF) were obtained from different sites. Farm-made feeds use a variety of locally available ingredients, foremost among which dried fish powdered, rice bran and soy bean meal (Phan et al. 2009). On the other hand, the ingredient makes up and the proportions used in commercial feeds are not publicly available. The only information available with regard to the latter is the proximate composition which is clearly presented on the feed bags, usually each of 20–25 kg (Phan et al. 2009). It is estimated that only about 3% of farmers use farm-made feeds, of which about 49% are made on site, the rest being purchased from other farm sites (Phan et al. 2009).

Feed samples were collected from farms, of batches of feed that had been procured most recently and were well within the recommended shelf life period. New feed bags were opened and a sample of 500–800 g, from each feed bag, for three randomly selected bags for each type of commercial feed obtained and transferred into plastic containers and secured air tight. Samples were transported to the laboratory and kept at 4°C until further analysis. The specifications provided in each bag were noted.

The commercial feeds sampled were of three types, recommended for use for grow-out of catfish of three size groups, as specified by different feed manufacturers. The three types recommended for use for different stock sizes were 14–150, 20–200 and over 500 g. For convenience and clarity these feeds are termed small feed (SF), medium feed (MF) and large feed (LF), respectively, in the text and the corresponding tables and figures.

Proximate composition analysis was conducted using standard procedures; moisture content by drying at 80°C to constant weight, protein by Kjeldahl nitrogen method (N × 6.25) using an automated Kjeltech (Model 435 and 323, Buchi, Switzerland), lipid by ether extraction using an automated Soxhlet extraction (Model 810, Buchi, Switzerland), and ash by combustion at 600°C for 3 h in a muffle furnace (Model A-550, Vulcan, USA). Gross energy content was estimated by combusting in an oxygen atmosphere in a Bomb Calorimeter (Model 1261, Parr, USA). Phosphorus content of feeds was determined photometrically by conversion to phosphomolybdovanadate (Model Spectronic, Genesys 2, Milton Roy, USA).

Estimation of Nitrogen and Phosphorus Discharge

Nutrient-balance models have been used to estimate farm nutrient discharge of N and P for several fish species, and are considered to be a more reliable and cost-effective than direct measurement on farm (Cho et al. 1991, 1994; Kelly et al. 1996; Cho and Bureau 1998; d'Orbcastel et al. 2008). In the absence of detailed information on fate on nutrients in the catfish pond environment, and as we were attempting to estimate for the whole sector concentrated in the Mekong Delta, amounts on nutrients lost to sediments or removed by pond cleaning were not taken into account. In this analysis the nutrient-balance model used information on nutrients inputs (feed added) and nutrients removed (harvested fish) to estimate gross nitrogen (N) and phosphorus (P) discharge levels from the striped catfish farming sector in the Mekong Delta. The model utilised published information on N and P content of striped catfish (Yi et al. 2004) combined with FCR data (Phan et al. 2009), and proximate analysis of feeds from the current study to estimate discharge levels. All output variables from the model are presented as kilogram of total N and total P per tonne of fish produced.

Since the proximate composition of commercial feeds varied according to the size of fish being fed, the model used two production phases taking these feeding strategies of the catfish farming practices into consideration; Phase I for diets fed to fish up to 200 g and Phase II for diets fed to fish greater than 200 g. Because information on the fish biomass and the amount of feed used in each phase are not known, three different model simulations were conducted with 40, 50 and 60% of N and P loading being attributed to Phase I, and, accordingly, 60, 50 and 40% of N and P loading being attributed to Phase II. In addition, since N and P content of commercial feeds varied between manufacturers and the N and P content of farm-made feeds were highly variable, model simulations were undertaken using high (95th percentile), median and low (5th percentile) of N and P feed content values, which are detailed in Table 1.

FCR data for commercial feeds and farm-made feeds were obtained from 83 and 12 farms, respectively, during a survey of catfish farms in the Mekong Delta (Phan et al. 2009). FCR values ranged from 1.0 to 3.0 (median 1.69) and 1.3 to 3.0 (median 2.25) for commercial and farm-made feeds, respectively; and, as described above, simulations were then conducted at high (95th percentile), median and low (5th percentile) FCR for each feed type. It has been suggested that in normal aquaculture practices less than 5% to as much as 30% of fish feed, in the form of dust or uneaten pellets, is not consumed by fish (Cho et al. 1991). However, this loss is taken into account in the final FCR values and was not built into the computations.

Published information on N and P content of whole striped catfish is limited. Yi et al. 2004, provided values of 6 and 0.7% (dry matter basis) for N and P, respectively, of farmed striped catfish (1.8 and 0.21% wet weight, respectively). These values were used to estimate nutrient discharge loadings for striped catfish farming.

RESULTS

The commercial pellet feeds for striped catfish grow-out collected and analysed in this study are thought to be representative of the feeds available and commonly used on farms. These feed were recommended by different manufacturers as feeds suitable for fish of 14–150 g (SF), 20–200 g (MF) and over 500 g (LF). However, the first

Table 1 N and P nutrient loadings for different feed types, N and P content of feeds, FCR values and production phases (commercial feeds only) for striped catfish farming in the Mekong Delta (calculations used N and P content of striped catfish from Yi et al. 2004)

N & P content in feed (% wet weight)	Production phase/ structure	Nutrient loading (kg/t fish) at different FCR values					
		N			P		
Commercial feeds		Low FCR (1.53)	Median FCR (1.69)	High FCR (2.0)	Low FCR (1.53)	Median FCR (1.69)	High FCR (2.0)
Low (3.60 N, 0.70 P)	40% Phase I	33.4	38.9	49.4	9.9	11.2	13.6
Median (4.34 N, 0.96 P)	60% Phase II	38.2	44.2	55.6	12.9	14.4	17.5
High (4.86 N, 1.10 P)		45.4	52.1	65.1	14.7	16.4	19.8
Low (3.60 N, 0.70 P)	50% Phase I	34.0	39.5	50.1	9.7	10.9	13.3
Median (4.34 N, 0.96 P)	50% Phase II	39.9	46.0	57.8	12.8	14.4	17.4
High (4.86 N, 1.10 P)		47.2	54.1	67.4	14.7	16.4	19.8
Low (3.60 N, 0.70 P)	60% Phase I	34.5	40.1	50.8	9.5	10.7	13.0
Median (4.34 N, 0.96 P)	40% Phase II	41.5	47.7	59.9	12.7	14.3	17.3
High (4.86 N, 1.10 P)		49.0	56.0	69.7	14.7	16.4	19.8

Farm-made feeds	Low FCR (1.63)	Median FCR (2.25)	High FCR (3.0)	Low FCR (1.63)	Median FCR (2.25)	High FCR (3.0)
Low (1.25 N, 0.51 P)	1.9	9.7	19.0	6.0	9.20	13.0
Median (2.90 N, 0.92 P)	28.8	46.8	68.5	12.7	18.4	25.3
High (3.39 N, 1.28 P)	36.9	57.9	83.4	18.7	26.6	36.2

Low = 5th percentile, median = median, high = 95th percentile

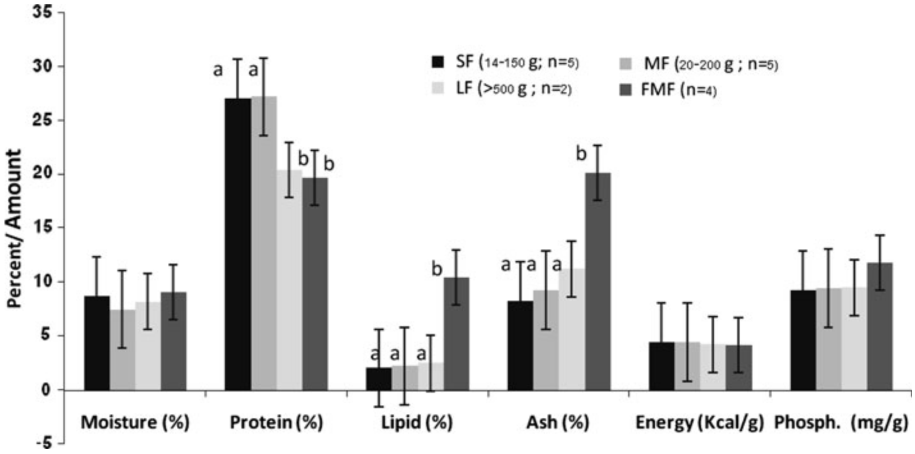

Fig. 3 The proximate composition, energy content and phosphorus content (on as fed basis) of the different feed types, and categories. *Bars* represent mean ± SD. For any one parameter, different superscripts indicate significant differences ($P > 0.05$). The commercial feeds are categorised, based on manufacturers' recommendations on the stock size where for 4–150 g, 20–200 g and over 500 g sized fish are termed small feed (SF), medium feed (MF) and large feed (LF), respectively, and FMF refer to farm-made feeds

two types of feeds (SF and MF) are used mostly for 3–5 months of the culture period, and it is estimated that nearly 60% of the stock by weight is fed on first two feed types, whilst larger fish are commonly fed with the third type (LF). The chemical composition of the different feed types vary to some extent, the most significant being the lower protein content of LF, used for stock over 500 g (Fig. 3), with a protein content comparable to that of farm-made feeds. All commercial feeds had a significantly lower level of lipid content compared to that in farm-made feeds, which exceeded 10%, and similarly the amount of ash was lower in the former type of feeds. The energy content and phosphorus content did not differ significantly between feed types ($P > 0.05$).

The data on feeds in the catfish farming sector collected by Phan et al. (2009) were not utilised in detail previously. However, the above study was linked to the present one and in the latter details pertaining to feed type efficacies were analysed in detail and presented. The FCR for commercial pellets and farm-made feed ranged from 1.0 to 3.0

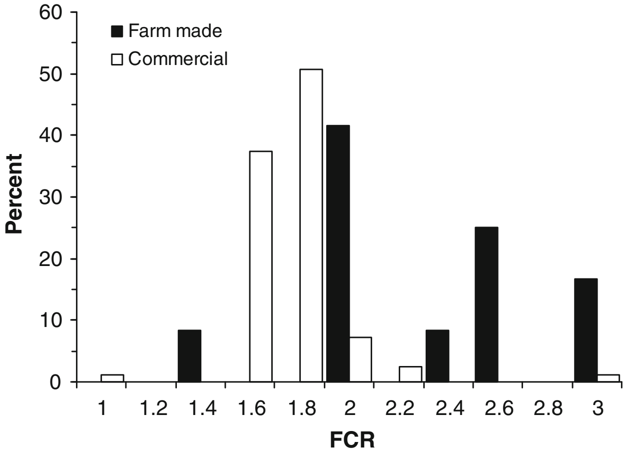

Fig. 4 The distribution of FCR in the two feed types in the 97 surveyed farms (based on data from Phan et al. 2009)

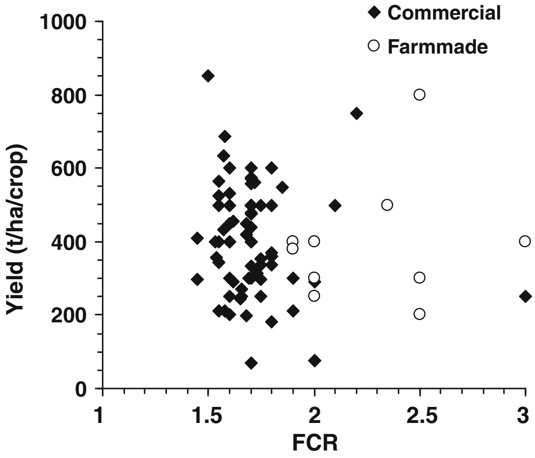

Fig. 5 The scatter diagram of relationship of FCR to yield for the two feed types used (based on data from Phan et al. 2009)

(mean 1.69), and 1.3 to 3.0 (mean 2.25), respectively, which differed significantly ($P < 0.001$) from each other (Figs. 4, 5). The relationship between feed type and yield was insignificant ($P > 0.05$), but the production cycle when using farm-made feed was usually 4–8 weeks longer. There was no discernible statistical relationship between yield and FCR for either type of feed (Fig. 5).

Gross Estimates of Nitrogen and Phosphorus Discharge

Often estimates of nutrient loading in aquaculture practices have been based on laboratory studies of single units of production, barring a few cases (Ackefors and Enell 1990, 1994). To date there has been no detailed study of the nutrient loading in discharge waters from striped catfish farms in the Mekong Delta, and for that matter for a culture practice of the scale of that of catfish, taken as a unit.

Nutrient loadings from catfish farming for different food types and N and P content of diets were estimated for different FCR's (Table 1). Estimated nutrient loadings for farm-made feeds were substantially more variable than for commercial feeds, but median values were similar for N loadings. Nutrient loadings for commercial feeds ranged from 33.4 to 69.7 kg/t (median 46.0 kg/t) and 9.5 to 19.8 kg/t (median 14.4 kg/t), for N and P, respectively, while for farm-made feeds loadings ranged from 1.9 to 83.4 kg/t (median 46.8 kg/t) and 6.0 to 36.2 kg/t (18.4 kg/t) for N and P, respectively (Table 1). An increase in the proportion of contribution from Phase I increased the N loading due to the high protein content of the diet for smaller fish, but decreased in the P loading (Table 1). Decreasing the FCR reduced both the N and P loadings.

The quantum of striped catfish production in the Mekong Delta grown on commercial feed and farm-made feed is not known. Since the vast majority of farms used commercially made feed, though a proportion of these also use farm-made feed (Phan et al. 2009) using the above median nutrient loadings for both commercial and farm-made feeds, in 2007 when 687,000 t of striped catfish was produced in the Mekong Delta, 31,602–32,152 t N and 9,893–18,274 t P were discharged, while in 2008, 50,364–51,240 t N and 15,766–29,124 t P were discharged (Table 2).

DISCUSSION

In this study, we have attempted to estimate nitrogen and phosphorus discharge from an aquatic farming system, which is one of the biggest globally, but concentrated in a relatively small geographic area of approximately 6,000–7,000 ha (Nguyen and Oanh 2009; Phan et al. 2009). To place it in perspective the current production from the sector, in this relatively small area, is equivalent to nearly 70% of total European aquaculture production.

In our attempt to estimate N and P discharge from the striped catfish farming sector in the Mekong Delta we have taken into account the type of feed used, commercial or farm-made, even though the differences in the proximate composition of the two types of feed types are relatively minor, the FCRs, and aspects of feed usage (use of low protein content feed in the second phase of the grow-out cycle) in the different phases of the grow-out cycle. The main difference between the two feed types (commercial and farm-made) was the relatively high level of lipid in farm-made feeds.

FCRs for catfish farming in the Mekong Delta range from 1.0 to 3.0 (mean 1.69), and 1.3 to 3.0 (mean 2.25) for commercial pellets and farm-made feed, respectively (Phan et al. 2009). These values, which appear to be generally

Table 2 N and P nutrients loadings for striped catfish production in the Mekong Delta in 2007 and 2008

Variable	2007		2008	
Production level (×1,000 t):	687		1,094.879	
	N	P	N	P
Commercial feeds				
Feed required (using median FCR of 1.69) (×1,000 t)	1,161		1,850	
Nutrient loading (t) based on nutrient content of catfish carcass	31,602	9,893	50,364	15,766
Farm-made feeds				
Feed required (using median FCR of 2.25) (×1,000 t)	1,546		2,463	
Nutrient loading (t) based on nutrient content of catfish carcass	32,152	12,641	51,240	20,146

Nutrient loadings based on median values for fish fed either commercial or farm-made feeds calculated using a nutrient mass balance model (median values from Table 1)

Table 3 N and P nutrient loadings for different farmed species

Species	Culture system	Feed	Discharge (kg/t)		Authority
			N	P	
Rainbow trout (*Oncorhynchus mykiss*)	Cage, raceway	Commercial	47.3–71.1	6.5–24.2	Lanari et al. (1995), Ingram (1999), Bureau et al. (2003)
Silver perch (*Bidyanus bidyanus*)	Pond, cage	Commercial	130	14.4–28.8	Gooley et al. (2000, 2001a, b)
Channel catfish (*Ictalurus punctatus*) and Bluntsnout bream (*Megalobrama amblycephala*)	Pond/cage		120–160	25–35	Guo and Li (2003), Guo et al. (2009)
Areolated grouper (*Epinephelus areolatus*)	Cage	Trash fish	321		Leung et al. (1999)
Bluefin tuna (*Thunnus maccoyii*)	Cage	Fish	260–502		Fernandesa et al. (2007)
Gilthead seabream (*Sparus aurata*)	Cage	Commercial	102.9	17.8	Lupatsch and Kissil (1998)
Common carp (*Cyprinus carpio*)	Pond	Various	30.9–86.0	8.5–26.4	Watanabe et al. (1999), Jahan et al. (2002)
Striped catfish (*Pangasianodon hypophthalmus*)	Pond	Commercial	46.0	14.4	Median values in present study
Striped catfish (*Pangasianodonhypophthalmus*)	Pond	Farm-made	46.8	26.6	Median values in present study

higher than FCR's for other, well established aquaculture finfish where FCRs near or less than 1.0 are often reported (e.g., Dumas et al. 2007). Commercial feeds for catfish analysed in this study may not have been fully optimised for catfish and, as suggested by Phan et al. (2009), their quality being highly variable. Indeed there have been no detailed studies into the nutritional requirements of catfish. Refinement of feed formulations combined with improved feeding strategies (such as to reduce feed wastage) may improve FRC in catfish farming, and thereby reduce nutrient loadings in effluent water, as well enable the practices to be more economically viable (Department of Aquaculture 2008; Sub-Institute for Fisheries Economics and Planning in Southern Vietnam 2009).

Also, a comparison of the amounts of N and P discharged in the production of a tonne of some selected cultured fish species (Table 3) indicates that at present striped catfish farming in the Mekong Delta compares favourably with other cultured species, irrespective of the type of feed used. This may be due to the relatively high feed efficiency of striped catfish, and by generally lower protein and higher carbohydrate content of catfish diets compared to other species (Yi et al. 2004). In comparison to published N and P content values for striped catfish (1.8% N and 0.21% P wet weight) (Yi et al. 2004), values for other species range from 2.2 to 3.4% and 0.39 to 1.20% of wet weight, for N and P, respectively (Lall 1991; Lupatsch and Kissil 1998; Gooley et al. 2001; Schreckenbach et al. 2001; Kiessling 2009). Nevertheless, nutrient loadings presented here for striped catfish farming are to be considered as preliminary estimates only and further, more detailed studies are warranted to refine and validate these values.

From the view point of environmental well being it is also important to consider the total N and P discharges and the actual extent of overall nutrient loading from this rather large aquaculture farming system in the Mekong Delta. Based on values for commercial feeds, the total amount of N and P discharged from catfish farming in the Mekong Delta in 2007 and 2008 were estimated to be 31,602 t N and 9,893 t P, and 50,364 t N and 15,766 t P, respectively (Table 2). On the other hand, if the whole of the Mekong River striped catfish farming sector were to use farm-made feeds the total loading in 2007 and 2008 would be 32,152 and 51,240 t of N, and 12,641 and 20,146 t of P, respectively (Table 2). Thus it seems that the use of commercially compounded feeds is responsible for a very minimal, almost trivial, reduction of N, but greatly reduces the amount of P discharged. However, improved formulation guidelines for farm-made feeds may reduce this value.

In an earlier pioneering study of two decades back, of Ackefors and Enell (1990), a comparable estimation was done for the entire Swedish salmonid industry (salmons and trouts). It was reported that the total yearly loading of N and P from the Swedish salmonid industry equated to 307 and 38 t, respectively, for a total production of 3,945 t of cultured fish (equating to 78 kg of N and 10 kg P, per tonne of produced fish). However, the authors also estimated the so called "self purification" derived by denitrification, biological uptake and sedimentation, reporting a final estimate of a total load of 264 t of N and 35 t of P (hence, a reduction of roughly 14% of N and 8% of P). In a follow-up study (Ackefors and Enell 1994) by the same authors it was reported that these values were progressively decreasing with the optimisation of feed and feeding practices. Accordingly, and more recently (Kiessling 2009) it was clearly shown that, resulting from continuous improvement in feed regimes and feed composition, the average load of N and P (as kg/t of production) from Swedish fish farming has been significantly reduced to values of approximating 55 and 7 kg/t for N and P, respectively. Comparing these data on the Swedish salmonid industry with those presented in this study for the stripped catfish it is interesting to note that, in general, N load is lower, whilst P load is higher for the current Vietnamese catfish industry. Furthermore, the latter being a relatively younger development there is a lot of scope for improvement and gains in nutrient discharge levels through the adoption of improved feeds and feed management practices, in conjunction with planned water intake and discharge into the environment especially through the adoption of Better Management Practices and a cluster approach.

Admittedly, not all of the N and P are discharged directly into the Mekong River. Some catfish farms in the Mekong Delta (approximately 35%) discharge water directly onto rice fields or gardens (Phan et al. 2009), and some nutrients will be retained in the sludge of ponds or taken up by other biota in the environment. Phan et al. (2009) estimated that in 2007, when 683,000 t of catfish was produced in the whole of the Mekong Delta, 6.4 ML of water was used per t of production, which is about 10% higher than the estimates made previously (Bosma et al. 2009). On the above grounds it can be concluded that the total discharge of nutrients directly into the Mekong Delta from catfish farming is substantially less than the total N and P loads estimated in this study, and the need for more accurate estimations taking into consideration the many variable factors in use and discharge of water from catfish farming practices will enable to obtain more refined estimates. The development of Better Management Practices (BMPs) and the application thereof through a cluster approach (NACA 2009), as had been successfully done in the case of shrimp farming in India (Umesh et al. 2009) will lead to further betterment in feed efficacies and water management regimes, such as through the introduction of "water calendars" in the catfish farming sector leading to significant reductions in N and P discharge levels and thereby contribute to the sustainability of the sector and to improved environmental integrity.

More detailed studies on the nutrient dynamics within the Mekong Delta, incorporating catfish farming and its interactions with other primary production sectors (especially rice farming), are required. In particular, in a similar fashion to the assessment of "self purification" of nutrient loads previously computed for salmonid (Ackefors and Enell 1990), studies on the fate of N and P from catfish farming, such as determining retention rates of N and P in the pond sediments and amounts captured by other farming practices (e.g., rice farming), will enable further refinement of such estimates. These in turn will be useful for overall development planning of the sector as well as provide useful information to a holistic approach to assessing the river well being.

Further more, available information suggests that this quantity of potential discharge from the striped catfish farming sector is relatively small compared to the potential run-off of N and P from fertilizers used in rice farming in the Mekong Delta. In fact, rice cultivation in the Mekong Delta used 170–182 kg of fertilizer per sown acre of paddy, totalling 7.48 million kilogram in 2000 (Truong 2003). Further, it has been suggested that the water quality in the Mekong River between 2005 and 2008 has hardly changed compared to the period prior to the expansion of the catfish farming sector (Bosma et al. 2009). However, as pointed out by Phan et al. (2009), all this is not a matter for complacency, nor does it preclude the fact that further improvements in the manner that effluent is discharged are envisaged to be essential, such as through the adoption of BMPs (NACA 2009). Within this context, an appropriate and promising example is derived by the noteworthy progress of nutrient load reduction recorded for the salmonid industry (Kiessling 2009); an industry roughly 40 years older than the striped catfish farming in Vietnam.

The striped catfish farming along the Mekong Delta and its tributaries occur upstream of 50–60 km of the sea mouth. The Mekong River has the 10th highest flushing rate of all rivers in the world (van Zalinge et al. 2004). It is therefore, conceivable the nutrients discharged are carried to the South China sea rather rapidly, enriching the immediate waters. In the wake of climate change and mitigating measure of carbon sequestration, studies on the Amazon have demonstrated that nutrient discharge from rivers through increased diazotrophy could enhance carbon sequestration (Cooley et al. 2007; Subramanium et al. 2008). As such the striped catfish farming system in the Mekong Delta not only is of enormous socio-economic importance to the region, it is also currently responsible for relatively minor environmental impacts in term of N and P discharge, but also in the long run could help in sequester carbon in significant quantities.

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