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INPUTS OF NITROGEN AND PHOSPHORUS TO ESTUARIES OF NORTHEASTERN BRAZIL FROM INTENSIVE SHRIMP FARMING

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ABSTRACT

Lacerda, L.D. 2006. Inputs of Nitrogen and Phosphorus to Estuaries of Northeastern Brazil from Intensive Shrimp Farming. Braz. J. Aquat. Sci. Technol. 10(2):13-27. ISSN 1808-7035. Intensive shrimp aquaculture has increased by about 20% per year during the last decade along the semi-arid NE coast of Brazil due to the optimal climate and environmental setting. Emissions of N and P from this activity to 16 estuaries along the coast of Ceará and Rio Grande do Norte states, NE Brazil, where about 80% of the shrimp farming area of the country is located, showed that intensive shrimp farming presents average emission factors for N and P ranging from 6 to 664 $kg.km^{-2}.yr^{-1}$ and from 0.4 to 77 $kg.km^{-2}.yr^{-1}$, respectively. These emission factors resulted in total annual emissions of 9 to 485 $t.yr^{-1}$ and 0.7 to 35 $t.yr^{-1}$, for N and P respectively. Larger loads occurred at the Jaguaribe River (Ceará State) and the Açu River (Rio Grande do Norte State). Intensive shrimp farming is the major relative contributor of N to the Jaguaribe (CE) (41%) and Açu (RN) (63%) basins. Also at the Guamaré basin (RN) it contributes with 26% of the total N load. Contribution of P from intensive shrimp farming is relatively small varying from <5% in most basins to a maximum contribution of 13% at the Açu basin (RN).
Although the contribution of intensive shrimp farming relative to agriculture and husbandry is small in most of the studied areas, the location of farms adjacent to estuaries makes possible direct inputs to waters, while most other emissions go firstly to soils before eventually being transported to surface waters.

Key words*:* Nitrogen, phosphorus, estuaries, shrimp farming, northeastern Brazil.

INTRODUCTION

Many estuaries are submitted to environmental impacts resulting from the excess of nutrient loads from anthropogenic activities installed at their watersheds. These include changes in community structure and food webs, harmful algal blooms, excessive seaweed and epiphyte growth, low oxygen level, and reduced biodiversity (Bricker *et al.*, 1999; 2003). Most of these impacts result from a complex chain of events varying in space and time, but that can be attributable to an ultimate pressure: the accumulation of excess nitrogen and phosphorus in fluvial water in its way to the ocean (NRC, 2000; Tappin, 2002).

Primary production and the eventual onset of the eutrophication process are ultimately related to the ecological response to excess nutrient loads, in particular of nitrogen, in a manner similar to the correlation between the actual nutrient concentrations in water (Rosenberg *et al.*, 1990; Boynton *et al.*, 1995; Brunner, 1998; EPA, 2002; NRC, 2000). Therefore, the use of nutrient loads instead of concentrations, particularly in areas were detailed studies on nutrient concentrations are unavailable, such as in the semi-arid coast of NE Brazil, may turn into a satisfactory approach to evaluate the sensibility of estuarine systems to further introduction of anthropogenic effluents.

Many estuaries of the semi-arid coast of NE Brazil where intensive shrimp farming takes place, also receives nutrients form other anthropogenic sources, among them the disposal of untreated sewage; solid wastes and waste waters, urban runoff, husbandry and the use of fertilizers and other chemicals in agriculture. Industrial effluents are a minor source of nutrients along this part of the Brazilian coast whereas large metropolitan areas lack aquaculture activities. Apart from the anthropogenic sources, natural processes' contributions to the nutrient loads are atmospheric deposition and soil runoff.

Shrimp aquaculture has increased by about 20% per year during the last decade along the NE coast of Brazil due to the optimal climate and environmental setting. Shrimp farms in Brazil occupied less than 100 ha in 1998. By 2003, however, farm area has increased to over 14,000 ha, about 11,500 ha located along the NE coast, about 7,900 ha located along the semi-arid coast of Ceará and Rio Grande do Norte States (ABCC, 2003). Worldwide the activity has been blamed to cause several environmental impacts associated with the emission of large amounts of N and P to estuarine waters (Twilley *et al.*, 1999; Burford *et al.*, 2003). Experimental data from N and P emissions form shrimp farms in Australia varied from 290 and 16 $kg.ha^{-1}.yr^{-1}$, respectively (Jackson *et al.*, 2003; Burford *et al.*, 2003). In the Gulf of California, Mexico, annual input of N and P from shrimp farms reaches 112 and 32 $kg.ha^{-1}$, respectively (Paez-Osuna *et al.*, 1999; 2003). However, few studies have compared shrimp farming N and P emissions with other anthropogenic and natural sources in a given area making difficult the associations between shrimp farm effluents and eutrophication to be revealed (Lacerda *et al.*, 2006).

In the present study a comparison is given, based on an emission factor approach, of the annual emissions of N and P from intensive shrimp farming and other different anthropogenic sources and natural processes to 16 estuaries along the coast of NE Brazil, where about 80% of the shrimp farming area of the country is located.

MATERIAL AND METHODS

Study areas

The Northeastern region is the largest producer of cultivated shrimp in Brazil, with about 11,500 ha of shrimp ponds and average productivity of about 6.2 $t.ha^{-1}.yr^{-1}$ and a total annual production of about 66,000 tons (ABCC, 2003). The activity is developed in estuarine areas of low urban and no industrial development, seeking good environmental conditions, particularly of water quality for its proper development. However, most urban wastes are not treated, while agriculture and husbandry have recently developed fast along the coastal region. Therefore, scattered data already suggest that some of these areas are showing signs of incipient eutrophication, potentially threatening the activity (Guedes, 2003).

Figure 1 shows the location of the 16 estuarine areas studied. The lower basins of the 16 rivers are located within the “Tabuleiros Costeiros do Nordeste” formation characterized by Tertiary and Quaternary sediments forming coastal plains constituted by sandy soils closer to the coast and yellow-red latosols (mostly oxisols) inland. Small stretches of alluvial eutrophic soils occur along river valleys (Pedreira, 1971; RADAM-BRASIL, 1981; Silva & Mendonça, 1989; Silva, 1996; Hidroservice, 1998; IDEMA, 1999a,b; Lima *et al.*, 2000). Natural vegetation in most of the area has been converted to subsistence, non-mechanized agriculture and extensive husbandry. Major cultures in the sandy soils are coconut, cashew nut and banana, whereas latosols are used mostly for sugar cane and pasture. Population density is generally low and concentrated in small towns close to the sea. Table 1 shows the major environmental characteristics of the 16 estuaries studied. Rainfall varies from 1,250 $mm.yr^{-1}$ at the Guaraíras basin to 550 $mm.yr^{-1}$ at the Açu Basin. The 16 estuarine systems differ by a factor of 2 to 20 in basin area, from the larger

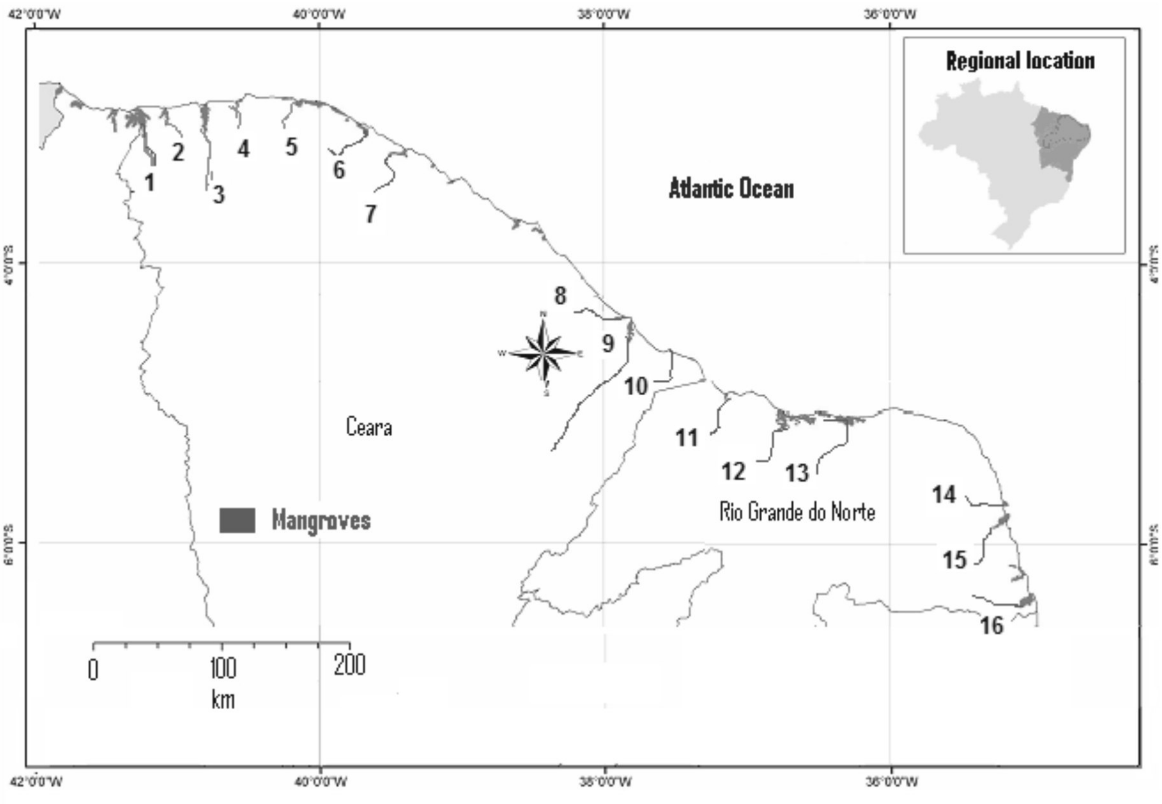

Figure 1 - Map showing the locations of the 16 studied river basins in NE Brazil. 1. Timonha, 2. Coreaú, 3. Acaraú, 4. Aracatiaçu, 5. Aracatimirim, 6. Curu, 7. Mundaú, 8. Pirangi, 9. Jaguarabe, 10. Icapuí, 11. Apodi, 12. Açu, 13. Guamaré, 14. Ceará Mirim, 15. Guaraíras, 16. Curimataú.

Coreaú (4,680 km^2) basin to the smaller Ceará Mirim basin (200 km^2). Shrimp far area also vary largely by a facto of 40 from the Açu basin (1,679 ha) to the smaller Ceará Mirim with only 30 ha of shrimp ponds (Table 1).

Emission factors approach

Nutrient load to non-industrialized coastal watersheds is mostly from diffuse sources and therefore, is a difficult variable to be directly measured, so indirect approaches based on emission factors and inventories of natural processes and anthropogenic activities dimensions are the most applicable strategy for their estimation (Tappin, 2002). Estimates of nutrient loads to a given estuary are achieved by using emission factors based on production/consumption parameters of the different anthropogenic sources and the chemical balance of natural processes (Nriagu & Pacyna, 1988; Howarth *et al.*, 1996; Howarth, 1998). Most necessary variables can be estimated from surveys and inventories of these activities, such as population parameters, urban and rural areas per basin, agriculture production and fertilizer use, among others. Emission factors have been successfully used to estimate nutrient and pollutant load at the local (e.g. Barcellos & Lacerda, 1994; Binner *et al.*, 1996; Marins *et al.*, 1998; 1999); regional (Lacerda *et al.*, 1995; 2006; Howarth *et al.*, 1996; Lacerda & Marins, 1997; Howarth, 1998; NRC, 2000; Vaisman & Lacerda, 2003); and global (Nriagu & Pacyna, 1988; Nriagu, 1989; Pirrone *et al.*, 1996; 1998) levels and have been adopted as standard methodology by various environmental agencies (EEA, 1999; EPA, 2002). In general, emission factors (EF's) used in this study were those available in the literature for each activity or process. However, all EF's were adapted to local conditions whenever necessary. For example, wastewater production per inhabitant is generally calculated based on water consumption parameters typical of urban areas. However, under the semi-arid condition of most of the studied basins, these factors were corrected by the actual water consumption rate of the population of each basin (Döll & Hauschild, 2002). Similarly, fertilizer utilization, shrimp farming technology and other agricultural parameters used in the present study were those of the actual sites. General global

Table 1 - Major environmental characteristics and shrimp production statistics of the studied estuaries along the Northeastern Brazilian coast.

Estuary	Lower basin area (km^2)^{1,2}	Annual average rainfall (mm)^1	Population (inhabitants)^3	Shrimp farm area in 2003 (ha)^4
Timonha (CE)	615	1,120	26,084	147
Acaraú (CE)	3,000	1,000	132,082	743
Coreaú (CE)	4,680	1,100	123,913	439
Aracatiaçú (CE)	1,580	830	32,333	62
Aracatimirim (CE)	740	1,140	30,347	58
Curu (CE)	600	1,240	53,003	110
Mundaú (CE)	2,135	1,590	138,896	42
Pirangi (CE)	1,627	910	42,343	90
Jaguaribe (CE)	1,735	900	79,832	1,260
Icapui (CE)	430	950	16,052	59
Apodi (RN)	975	700	244,600	874
Açu (RN)	950	550	58,900	1,680
Guamaré (RN)	550	600	9,900	414
Ceará Mirim (RN)	200	900	19,600	30
Guaraíras (RN)	325	1,250	59,100	747
Curimataú (RN)	300	1,150	34,800	1,070

1- Hydroservice (1998); IDEMA (1999a; 1999b). 2 - Maia (2004). 3 - IBGE (2003a). 4. ABCC (2003).

emission factors were used when data for the actual site were unavailable.

RESULTS AND DISCUSSION

Natural emissions: Soil runoff

Soil loss and atmospheric deposition are the two major natural processes contributing with N and P to the studied basins. Soil loss is highly increased by agriculture and depends on soil type and climate. Losses from agricultural land can range from 116 to 309 t.km^{-2}.yr^{-1} under temperate climates (Schlesinger, 1997; Gouldie, 1987) to 60 to 760 t.km^{-2}.yr^{-1} in tropical regions and averages about 130 t.km^{-2}.yr^{-1} for low declivity areas with lack of mechanized agriculture (Greenland & Lal, 1977), such as the coastal plains of northeastern Brazil. Based on a review on soil loss rates for soil types and environmental settings similar to those found in our study area, Gouldie (1987) also proposed a similar average soil loss rate of 128 t.km^{-2}.yr^{-1}, which will be then used for the calculations in the present study.

Emissions of N and P through soil loss depend on their concentrations in each soil type. Concentrations of N and P in soils of the region studied are available for many NE Brazilian coastal basins and soil types (Silva, 1996; Ramalho & Sobrinho, 2001; Ramalho *et al.*, 2001) and were used to estimate soil N and P loss to rivers. These concentrations range from 500 to 900 mg.g^{-1} and from 100 to 500 mg.g^{-1} for N and P respectively, depending on soil type. Finally, the estimates of N and P losses were corrected taking into consideration the retention capacity for N and P of the soil, which also considered that part of the N emissions can be directly transferred to the atmosphere through denitrification and dissimilatory reduction of nitrates under sub-oxic conditions in waterlogged soils (Burford *et al.*, 2003). For P, however, most of it can be transferred to rivers associated with the particulate load and eventually to coastal areas (NRC, 2000). Retention rates of N and P for agriculture soils have been reported as 70 % and 65 % for N and P respectively (Malavolta & Dantas, 1980; Silva, 1996). Altogether, table 2 presents the estimates of N and P emissions to surface waters of the 16 basins studied based on the parameters described above. Soil type and basin area were considered the two major factors controlling nutrient emissions. Alluvial and Cambisol are the richer soil units regarding N and P concentrations, followed by latosols, solonetz and quartz sands.

Range of N emissions from soil loss under temperate climate and non-mechanized agriculture are from 75 a 230 kg.km^{-2}.yr^{-1}, with an average of 133 kg.km^{-2}.yr^{-1} (Howarth *et al.*, 1996; Howarth, 1998), whereas P emissions range from 5 to 50 kg.km^{-2}.yr^{-1} (Howarth *et al.*, 1996; Valigura *et al.* 2000) and up to 230 kg.km^{-2}.yr^{-1} in the Amazon Basin (Howarth *et al.*, 1995). Losses of N and P per unit of area vary little among the studied basins and are in general within the lower range reported by the above-mentioned authors for mechanized agriculture (Lacerda *et al.*, 2006). However, total emissions vary widely depending on basin size. Emissions of N vary from 223.4 t.yr^{-1} in the largest Coraú basin to 13.0 t.yr^{-1} in the smallest Ceará Mirim. Emissions of P vary from 201.6 t.yr^{-1} in the Coreaú basin to 2.6 t.yr^{-1} in the Ceará Mirim.

Natural emissions: Atmospheric deposition

Atmospheric deposition is a function of the basin area, the annual rainfall and the concentration of N and P in the bulk deposition (dry and wet). The fraction of the deposition eventually reaching surface waters will also depend on the retention rate of the atmospheric-derived N and P in soils (Golley *et al.*, 1978; Johnson & Lindberg, 1998; Silva Filho *et al.*, 1998). Along the Brazilian coast deposition rates of these nutrients also vary depending on the degree of urbanization and industrialization of the specific sector of the littoral. Along the Brazilian coast, total N and P atmospheric deposition ranges from 80 to 300 mgN.m^{-2}.yr^{-1}, and 4 to 10 mgP.m^{-2}.yr^{-1}, over pristine and heavy industrialized sites, respectively and with an annual rainfall of about 1,000 mm (Silva Filho *et al.*, 1998; Mello, 2001; 2003). These ranges of values are similar to those found for other coastal areas in the world under similar development conditions (Schlesinger *et al.*, 1982; Johnson & Lindberg, 1998; Brunner, 1998; Tan & Wong, 2000). Taking into consideration the local low level of industrialization and urbanization we used as best average estimate 100 and 8 mg.m^{-2}.yr^{-1}, for N and P respectively, which are similar to the averages reported by other authors for natural or low-developed areas (Golley *et al.*, 1978; Burns, 2004). The estimated deposition rates were corrected for the actual annual precipitation of each basin and the average soil retention rates observed for these two nutrients. Burns (2004) estimated an average of 63% atmospheric N retention based on results from eight Mid West USA basins. Golley *et al.* (1978) reported 70% retention of atmospheric P in soils in the Central American coast. In coastal Brazilian soils retention rates of N and P are similar to those (about 65% and 70% for N and P, respectively) (Malavolta & Dantas, 1980; Silva *et al.*, 2000) and these figures are used in the present study. The fraction retained in soils, however, will be included in the calculation of inputs from soil runoff, since atmospheric derived N and P make up part of their soil concentrations.

Inputs to estuaries from the atmosphere per unit of area estimated using the parameters above are 35 and 5.6 mg.m^{-2}.yr^{-1} for N and P, respectively. As expected, total loads from atmospheric deposition resulted highly influenced by the basin area. The largest basin of the Coreaú estuary receives 51.1 t.yr^{-1} and 4.1 t.yr^{-1} of N and P, respectively, whereas the smallest Ceará Mirim basin receives 7 and 0.5 t.yr^{-1} of N and P, respectively (Table 2).

Notwithstanding the differences in N and P concentrations in soil types and in the atmospheric deposition, basin area is the most important parameter controlling the natural loads of N and P to the basins studied. As expected, these loads are much smaller than those reported for more urbanized sites along the Brazilian coast (Mello, 2001; 2003), but are similar to those estimated for pristine environments (Golley *et al.*, 1978; Burns, 2004).

Anthropogenic emissions of N and P to the lower basins of the studied rivers

The most important anthropogenic sources of N and P in the studied areas are agriculture, husbandry and aquaculture, urban wastewaters, disposal of solid wastes and urban runoff. Their relative contribution varies depending on the degree of urbanization, population and extension of agricultural lands. Invariably, none of these effluents receive any treatment before being released into the environment along this area of the Brazilian coast.

Agriculture

Leaching of agricultural soils has caused eutrophication in many water systems, from small catchments under subsistence agriculture to larger basins receiving effluents from mechanized agriculture, such as the Gulf of Mexico Basin receiving Mississippi River inputs (Rabalais, 2002). The fraction of N and P applied as fertilizers lost from agriculture soils range from 10 to 40% and 25 to 80% for clayey and sandy soils respectively (Howarth *et al.*, 1996). Emission factors for N and P from agriculture soils are available but mostly restricted to mechanized, large-scale agriculture and can reach 200 kg.km^{-2}.yr^{-1} (Sharpley & Syers, 1979; Sharpley & Rekolainen, 1997; Sharpley & Tunney, 2000). Unfortunately however, these emission factors cannot be applied to the agriculture practices taking place in our sites.

Table 2 - Estimates of N and P inputs (t.yr^{-1}) from natural sources to the studied estuaries along the Northeastern coast of Brazil.

Estuarine basin	Soil runoff[1, 4]		Atmospheric deposition[2,3]		Total natural input	
	N	**P**	**N**	**P**	**N**	**P**
Timonha (CE)	36.4	34.9	6.9	0.6	43.3	35.5
Acaraú (CE)	189.6	174.8	27.5	2.2	217.1	177
Coreaú (CE)	223.4	201.6	51.1	4.1	274.5	205.7
Aracatiaçú (CE)	103.0	95.4	13.1	1.1	116.1	96.5
Aracatimirim (CE)	48.0	39.1	8.4	0.7	56.4	39.8
Curu (CE)	41.9	26.6	7.6	0.6	49.5	27.2
Mundaú (CE)	147.3	119.8	29.0	2.3	176.3	122.1
Pirangi (CE)	95.4	25.6	14.7	1.2	110.1	26.8
Jaguaribe (CE)	123.6	45.4	19.8	1.6	143.4	47
Icapui (CE)	26.8	7.9	4.1	0.3	30.9	8.2
Apodi (RN)	76.0	55.6	24.0	1.6	100	57.2
Açu (RN)	93.8	29.4	17.0	1.2	110.8	30.6
Guamaré (RN)	29.3	5.9	12.0	0.7	41.3	6.6
Ceará Mirim (RN)	13.0	2.6	7.0	0.5	20	3.1
Guaraíras (RN)	21.2	10.8	14.0	1.2	35.2	12
Curimataú(RN)	28.0	14.0	12.0	1.1	40	15.1

1- From Table 2. 2 - Average N and P bulk atmospheric deposition (100 and 8.0 mg.m^{-2}.yr^{-1}, respectively), based on concentrations in bulk atmospheric deposition from Mello (2001; 2003) and Silva Filho *et al.* (1998). 3 - Basin area and annual rainfall from table 1. 4 - Soil retention rates of 65% and 70% for N and P, respectively, after Malavolta and Dantas (1980) and Silva (1996).

For non-mechanized agriculture average loss rates of P are in general much lower, N losses, however, are similar and are highly dependent on crop type (Silva *et al.*, 2000). Results obtained under this type of agriculture along the Brazilian coast provide loss rates relative to the amount of fertilizer applied varying from 6 to 20 % for P and from 26 to 32 % for N (Malavolta & Dantas, 1980; CFSEMG, 1989; Silva *et al.*, 2000). The crop type also influences the loss rate of nutrients, since different cultures require different amount of fertilizer application. Table 3 summarizes the typical quantities of fertilizers used in agriculture in the northeastern Brazilian coastal region. Demands for N fertilization are particularly high for sugar cane (90 to 275 kg.ha^{-1}), sweet potatoes (40 - 140 kg.ha^{-1}), and citrics (120 - 180 kg.ha^{-1}), for example. Whereas for P, particularly demanding cultures are beans and citrics (30 - 60 kg.ha^{-1}), fruits (12 - 20 kg.ha^{-1}) and corn (40 - 70 kg.ha^{-1}) (Agrobyte, 2003; EMBRAPA, 2003; SEAGRI, 2003; CPAA, 2003). Major N and P losses from these cultures are from sugar cane and citrics (26 - 32 % for N and 6 – 20 % for P), followed by coconut, corn and beans (16 – 25 % for N and 6 – 20 % for P) (Malavolta & Dantas, 1980; FSEMG, 1989). The estimated amount of nutrients loss in each basin is a function of these differences in culture type and their relative area of cultivation. As a result, the relatively small Curimataú basin (300 ha) receives more N from agriculture (749 t.yr^{-1}), due to the dominance of sugar cane, than the larger Açu basin (950 ha), which receives only 45 t.yr^{-1} of N, due to the relatively small cultured area and less-N demanding culture types typical of this basin (Table 4).

Husbandry

Nutrients emitted from husbandry practices are released to soils as animal excretes and their concentrations will depend on the concentrations found in animal feed and on the different animal types grown in a given region. According to Boyd (1971) and Esteves (1988), average amounts of excrete ranges from 10 kg.animal^{-1}.day^{-1}, for cows and horses, to 2.5 and 1.0 and 0.18 kg.animal^{-1}.day^{-1}, for pigs and sheep, and poultry, respectively. Nitrogen and P concentrations in animal excrete vary little from 0.6 % for cows and horses and 0.5 % for pigs and sheep for N; and 0.35 %, 0.3 % and 0.5 % of P for cows and horses, pigs and sheep

Table 3 - Amount of N and P as fertilizer for the different cultures in the studied region and their respective loss rates.

Crop	Fertilizer (kg.ha^{-1})		Loss (%)	
	N	P	N	P
Sugar cane	90-275[1.2]	20-40[1.2]	26-32[8]	6-20[8]
Cashew	20[1]	30[1]	20[8]	25[8]
Cotton	22[1,2]	12[1,2]	16[8]	6[8]
Beans	0-20[5.6]	60[3]	16-25[11]	0.7-1.4[11]
Coconut	40[5]	20[5]	25[12]	20[12]
Cassava	0-40[3.4]	15-60[3.4]	25[12]	20[12]
Corn	20-60[6.7.8]	40-70[7.8]	26-32[8]	6-20[8]
Banana	22[2]	12[2]	16[13]	6[13]
Mango	40[9]	20[9]	16[13]	6[13]
Melon	100[9]	30[9]	20[12]	10[12]
Sweet potatoes	40-140[10]	20[10]	16-25[11]	0.7-1.4[11]
Citrics	120-180[9]	30-60[9]	16-25[11]	0.7-1.4[11]
Pineapple	40[9]	20[9]	25[12]	20[12]
Tomato	100[9]	30[9]	20[12]	10[12]

1- Agrobyte (2003). 2 - EMBRAPA (2003). 3 - Abreu *et al.* (2003). 4 - CPAA (2003). 5 - Ferreira (2003). 6 - Silva *et al.* (2000). 7 - CFSEMG (1989). 8. Malavolta and Dantas (1980). 9 - SEAGRI (2003). 10 - DGPC (2003). 11- Vollenweider (1968). 12 - Average limit for sandy soils after Howarth *et al.* (1996). 13 - Average limit for clay soils after Howarth *et al.* (1996).

respectively. For poultry, N and P contents are about 1.2 % and 1.3 %. Once deposited in soils, rates of nutrient retention and uptake by plants will determine the fraction eventually released to waters, which are similar to those described for N and P retention of the natural inputs (NRC, 1993; Bouwman *et al.* 1997; Bouwman & Booij, 1998; NRC, 2000). Although some livestock are reared in closed premises the large majority of the region's husbandry is extensive and dominated by bovine. Therefore, we considered that nutrients emitted from this practice will always pass through soils prior to reaching rivers.

Emissions of N and P to the studied estuaries from the region's husbandry are independent of basin area and ranged from 19 and 20 t.yr^{-1}, for the Ceará Mirim basin, to 701 and 526 t.yr^{-1}, for the Mundaú basin, for N and P respectively, being dominated by bovine cattle due to its larger number and amount of manure produced per capita. Nitrogen load is relatively smaller than the P load mostly due to ammonium loss to the atmosphere. It is important to note that manure is frequently used as fertilizers, which eventually may result in some export of nutrients in farm products out of the basins. This loss, however, is probably very small since this practice is typical of subsistence, familiar agriculture and is not estimated here.

Wastewaters

Wastewaters are one of the major sources of nutrients to coastal areas, particularly in urbanized estuaries. When no treatment plants exist, nutrient load from this source is directly proportional to population and the amount of water used per inhabitant (Smith *et al.*, 1997), since N and P concentrations in wastewater vary within a narrow range (I.C. Consultants, 2001). Therefore emission factors can be easily derived from population parameters to estimate inputs from wastewater released to estuaries (Smith *et al.*, 1997; Howarth, 1998; Bidone, 2000; Bidone & Lacerda, 2002; Martinelli *et al.*, 2002). The estimates presented here

Table 4 - Estimated emissions (t.yr^{-1}) from agriculture and husbandry to the studied estuaries along the Northeastern coast of Brazil.

Basin	Agriculture[1]		Husbandry[2]		Total	
	N	**P**	**N**	**P**	**N**	**P**
Timonha (CE)	191	39	81	49	272	88
Acaraú (CE)	471	611	595	368	1066	979
Coreaú (CE)	133	101	530	324	663	425
Aracatiaçú (CE)	71	72	146	92	217	164
Aracatimirim (CE)	159	161	97	60	256	221
Curu (CE)	520	115	215	159	735	274
Mundaú (CE)	411	373	701	526	1112	899
Pirangi (CE)	159	251	320	257	479	508
Jaguaribe (CE)	146	168	145	90	291	258
Icapui (CE)	88	131	55	32	143	163
Apodi (RN)	224	543	314	389	538	932
Açu (RN)	45	111	88	90	133	201
Guamaré (RN)	30	70	170	176	200	246
Ceará Mirim (RN)	38	24	19	20	57	44
Guaraíras (RN)	864	147	426	561	1290	708
Curimataú(RN)	749	67	190	244	939	311

1 - Amount of N and P applied for each culture (see table 3). Agriculture area and culture type (IBGE, 2003b; IDEMA, 1999a;b). Average loss rates of applied N (30%) and P (15%) from Malavolta and Dantas (1980); CFSEMG (1989) and Silva *et al.* (2000). 2 - Animal stock from IBGE (2003b). Manure volume in kg.animal^{-1}.day^{-1} are: 10, 2.5, 1.0 and 0.18 for cows and horses, pigs, sheep and chicken, respectively (Boyd, 1971). Manure N and P concentrations in % of animal excrete are: N = 0.6, 0.5, 0.5 and 1.2; and P= 0.35, 0.3, 0.5 and 1.3 for cows and horses, pigs, sheep and chicken, respectively (Boyd, 1971; Esteves, 1998). Soil nutrient retention: N = 65% and P = 70% (NRC, 1993; 2000; Bouwman and Booij, 1998; Bouwman *et al.*, 1997).

are based on the latest population census available for the year 2003 and on a detailed inventory of water use by the local population published by Döll & Hauschild (2002). This survey showed water consumption varying from 82 to 125 (average of 85) L.inhab^{-1}.day^{-1}, in rural areas along the coast, to 100 to 150 (average of 115) L.inhab^{-1}.day^{-1} in urban areas among the 16 studied basins' population. Nutrient concentrations in wastewater were those suggested by von Sperling (1996) based on Brazilian conditions. Finally, the assumption of no-treatment prior to release was used, since the availability of sewage treatment in non-metropolitan areas of the northeastern region of Brazil reaches only 10% of its population.

The estimates presented in table 5 shows N inputs varying from 17 to 400.5 t.yr^{-1} and P inputs varying from 4.5 to 112.5 t.yr^{-1}, with maximum values at the Apodi basin and minimum in the low populated Guamaré basin. Comparisons of the emission factors calculated for this study (4 - 8 g.inhab^{-1}.day^{-1} and 0.6 - 2.9 g.inhab^{-1}.day^{-1}, for N and P respectively) with others from the literature show our values in the lower range of reported factors, since emissions are much lower than those reported for urbanized metropolitan areas. (Howarth, 1998; Bidone, 2000; Bidone & Lacerda, 2002; Martinelli *et al.,* 2002).

Urban runoff and solid waste disposal

Major parameters controlling nutrient loss by runoff from urban areas are the area of impermeable surfaces, the number and dimensions of habitations and annual rainfall. For solid wastes disposal, the main parameters controlling contaminant emissions are population size and per capita production of solid wastes and their disposal method (Davis *et al*., 2001), as well as the average concentrations of N and P in runoff waters from landfill sites and the local rainfall levels (NRC, 2000). In the studied basins, large urbanized areas are absent. Also, most villages and cities present low levels of soil impermeability. Solid waste disposal is mostly restricted to solids present in wastewaters, already mentioned. Therefore, N and P emissions from this source are relatively small, ranging from 0.1 kg.yr^{-1} (for both nutrients) in the Ceará Mirim basin to 76 and 11 kg.yr^{-1}, in the Guamaré basin, for N and P respectively (Table 5), representing less than 10 % of the emissions from wastewaters.

Aquaculture

Shrimp farms are large exporters of nutrients to the coastal environments (Burford *et al*., 2003). The activity uses large amounts of fertilizers and feed to maintain one of the highest productivity rates reported (about 6.2 t.ha.yr^{-1}) (ABCC, 2003). Typical fertilizers application reaches 40 and 10 kg.ha^{-1}.production cycle^{-1} (100 and 25 kg.ha^{-1}.yr^{-1}) of urea and superphosphate, respectively, assuming food conversion rates of 1.5 to 1.8 (Nunes, 2001). Notwithstanding the economic importance of intensive shrimp farming in a global scale, there are only a few studies estimating the emission factors of nutrients from this activity. However, since there is a tendency to uniform shrimp farming technology worldwide, it is reasonable to use emission factors estimated for any area in the world.

At the Jaguaribe River Estuary, for example, Abreu *et al*. (2003) reported total excess P concentrations in outgoing waters during a monitoring year period in a typical farm varying from 0.06 to 0.18 mg.L^{-1}. Considering the water renewal time of the farm, which generally varies from 5 % to 10 % per day, the estimated average emission factor for P was 0.05 kg.ha^{-1}.day^{-1} (about 12 kg.ha^{-1}.yr^{-1}), considering 2.3 production cycles per year, the typical number of production cycles of shrimp farms of NE Brazil. Measured excess N concentrations in effluent waters (including NO_3^-, NO_2^- and NH_3 + NH_4^+ only) varied from 0.16 to 0.39 mg.L^{-1}, resulting in total N concentrations, when corrected to include particulate organic N, since up to 70% of the N present in the effluent is organic particulate N (Burford *et al*., 2003), of 0.52 to 1.29 mg.L^{-1}. this resulted in an average emission factor for N of about 0.47 kg.ha^{-1}.day^{-1}, about 110 kg.ha^{-1}.yr^{-1}. In another farm in the same river Figueiredo *et al*. (2005) estimated annual P input of 9.2 kg.ha^{-1}.yr^{-1}.

Experimental data from Australian farms reported total N and P concentrations in effluent waters of 0.98 mg.L^{-1} and 0.13 mg.L^{-1} respectively (Burford *et al*., 2003), resulting in emission factors of 0.99 - 1.18 kg.ha^{-1}.day^{-1} and 0.06 kg.ha^{-1}.day^{-1}, and annual emissions of 290 and 16 kg.ha^{-1}, for N and P respectively (Jackson *et al*., 2003; Burford *et al*., 2003). In the Gulf of California, Mexico, Paez-Osuna *et al*. (1999; 2003) estimated N and P export from the local shrimp farms of about 112 and 32 kg.ha^{-1}.yr^{-1}, respectively. A comparison of existing N and P emission factors for intensive shrimp farming worldwide is presented in table 6. This comparison suggests a good consistency of the estimated emission factors of N and, in particular for P, for shrimp farms in different parts of the world, an expected result due to the similarity of the technology used.

Estimates of the total N and P contribution from shrimp farming to the different basins studied, based on the range of emission factors displayed in table 6 are presented in table 7. Nitrogen and P emissions vary from the smaller contribution to the Ceará Mirim basin (9 tN.yr^{-1} and 0.7 tP.yr^{-1}), with only 30 ha of ponds, to 485 tN.yr^{-1} and 35 tP.yr^{-1} at the larger Açu basin, with 1,679 ha of pond area. Considerable emissions from shrimp farms also occur in the Jaguaribe, Mundaú and Apodi basins.

Table 5 - Estimated emissions from wastewaters and urban runoff. including leaching of solid wastes disposal sites for the sixteen basins studied (t.yr^{-1}).

Basin	Waste waters[1]		Urban runoff [2]		Total[3]	
	N	P	N	P	N	P
Timonha (CE)	50.1	14.0	3.1	0.1	53	14
Acaraú (CE)	238.9	66.9	15.5	0.5	254	67
Coreaú (CE)	233.0	65.2	14.7	0.5	248	66
Aracatiaçú (CE)	56.6	15.9	3.6	0.1	60	16
Aracatimirim (CE)	52.5	14.7	3.6	0.1	56	15
Curu (CE)	98.3	27.5	6.5	0.2	105	28
Mundaú (CE)	250	70	17	0.6	267	71
Pirangi (CE)	76.5	21.4	4.9	0.2	81	22
Jaguaribe (CE)	152.0	42.6	9.4	0.3	161	43
Icapui (CE)	27.5	7.7	1.9	0.1	29	8
Apodi (RN)	400.5	112.5	48	7	449	120
Açu (RN)	96	27	7	1	103	28
Guamaré (RN)	17	4.5	76	11	93	16
Ceará Mirim (RN)	32	9	<1	<1	33	10
Guaraíras (RN)	96.5	27	10	2	107	29
Curimataú (RN)	57	16	7	1	64	17

1. Nutrient concentrations in waste waters: N= 35-70 mg.L^{-1}; P = 5-25 mg.L^{-1} (von Sperling. 1996). Population data from IBGE (2003a). Water consumption: 85 L.inhab^{-1}.day^{-1}. in rural areas and 115 L.inhab^{-1}.day^{-1} in urban areas of NE Brazilian coastal area (Döll and Hauschild. 2002). 2 - Population parameters from IBGE (2003a). Annual rainfall from Hydroservice (1998). Includes leaching of solid wastes disposal sites. Solid waste production per inhabitant from ABES (1983). Average constructed housing unit of 50 m^2. Average N and P concentrations in runoff from NRC (2000) and Binner *et al.* (1996). 3 - Totals are rounded to unit.

Table 6 - Comparison of average emission factors (kg.ha^{-1}.day^{-1}) of N and P from shrimp farms based on instantaneous data on nutrient concentrations in effluent waters.

Location	N	P
Ceará State. Brazil[1,2]	0.47[3]	0.05[4]
Australia[5]	1.08[6]	0.06
Gulf of California. Mexico[7]	0.58	0.12
Upper Jaguaribe Basin, Brazil[8]	-	0.03
Range of emission factors	0.27 – 1.08	0.03 – 0.12

1 - This study and Abreu *et al.* (2003). 2 - Water renewal rate 5% to 10%.dia^{-1}. Pond depth of 1.0 m, volume exchanged of 5 x 10^5 L.ha^{-1}.day^{-1} (Nunes. 2001; Abreu *et al.*, 2003). 3 - N estimates based on approximate speciation given in Burford *et al.* (2003), i.e. 70% of the total N being particulate organic N and actual concentrations of NO_3, NO_2 and NH_4 (Abreu *et al.*, 2003). 4 - Based on actual nutrient concentrations in effluent waters monitored during one year (Abreu *et al.*, 2003). 5 - Jackson *et al.* (2003). 6 - Denitrification rate of about 5% (Burford *et al.*, 2003). 7 - Paez-Osuna *et al.* (1999; 2003). 8 - Estimated from original data in Figueiredo *et al.* (2005).

Table 8 compares the emission yields, standardized to kg.km^{-2}.yr^{-1}, of the different natural and anthropogenic sources of N and P obtained under the specific conditions of the 16 basins studied. Average yields for urban runoff and solid waste disposal and waste waters are in general lower than those from other sources. Natural sources of N and P are still a significant contribution to the nutrient loads in these estuaries. An expected result since most basins lack significant urbanized areas. Intensive shrimp farming presents the largest average yield for N (201 kg.km^{-2}.yr^{-1}), followed by agriculture (191 kg.km^{-2}.yr^{-1}) and husbandry (164

Table 7 - Estimates for N and P emissions from shrimp farms[1] to the studied estuaries in NE Brazil (t.yr^{-1}).

Basin	Pond area[2] (ha)	N emission[3.4]	P emission[4]
Timonha (CE)	147	44	3.1
Acaraú (CE)	743	222	16
Coreaú (CE)	439	131	9.3
Aracatiaçú (CE)	62	19	1.3
Aracatimirim (CE)	58	18	1.2
Curu (CE)	110	33	2.3
Mundaú (CE)	42	13	0.9
Pirangi (CE)	90	28	1.9
Jaguaribe (CE)	1,259	375	27
Icapui (CE)	59	18	1.3
Apodi (RN)	874	253	18
Açu (RN)	1,679	485	35
Guamaré (RN)	414	120	8.7
Ceará Mirim (RN)	30	9	0.7
Guaraíras (RN)	747	216	16
Curimataú (RN)	1,070	293	23

1 - From emission factors presented in table 5 and average production cycle per year of 2.3 and 30 initial days without water exchange and further exchange volume of 5% per day, from ABCC (2003) and Nunes *et al.* (2003). 2 - From ABCC (2003). 3 - Assuming 70% of the total N in the effluent discharge being particulate organic N (Burford *et al.*, 2003). 4 - From emission factors presented in table 6.

Table 8 - Range and average (in parenthesis) of emission factors from the different anthropogenic sources of Nitrogen and Phosphorus, standardized to kg.km^{-2}.yr^{-1}, for the specific conditions existing in the estuarine basins studied along the coast northeastern Brazil.

Source	N	P
Natural sources	59 -133 (79)	12 - 61 (45)
Waste water	31 – 410 (85)	9 – 115 (24)
Husbandry	84 – 1,311 (164)	52 – 1,726 (111)
Agriculture	28 – 2,658 (191)	22 – 557 (151)
Urban runoff	2 – 138 (5)	0.1 – 20 (0.3)
Aquaculture	6 – 664 (201)	0.4 – 77 (15)

kg.km^{-2}.yr^{-1}). For P, largest average yields are from agriculture (151 kg.km^{-2}.yr^{-1}) and husbandry (111 kg.km^{-2}.yr^{-1}). Although shrimp farming also presents a relatively high yield (15 kg.km^{-2}.yr^{-1}), all other natural and anthropogenic sources with the exception of urban runoff presents higher P yields.

The total loads of N and P for each studied basin from anthropogenic sources are presented in table 9. Notwithstanding the high emission factors and yields from shrimp farming, the larger loads of nutrients are due to agriculture and husbandry, which occupy much larger areas. Urban runoff is a negligible source of N

Table 9 - Average estimates of N and P emissions (t.yr^{-1}) from anthropogenic sources in the studied basin along the NE Brazil. The relative contribution (%) of each individual source appears in parenthesis.

Basin		**Source**				
	Wastewaters	Husbandry	Agriculture	Urban runoff	Aquaculture	**Total**
Timonha (CE)						
N	50 (14)	81 (22)	191 (53)	3 (1)	37 (10)	**362**
P	14 (13)	49 (47)	39 (37)	<1 (<1)	3 (3)	**105**
Acaraú (CE)						
N	239 (16)	595 (39)	471 (31)	16 (1)	188 (12)	**1509**
P	67 (6)	368 (35)	611 (58)	1 (<1)	16 (2)	**1063**
Coreaú (CE)						
N	233 (23)	530 (52)	133 (13)	15 (1)	111 (11)	**1022**
P	65 (13)	324 (65)	101 (20)	1 (<1)	9 (2)	**500**
Aracatiaçú (CE)						
N	57 (19)	146 (50)	71 (24)	4 (1)	16 (5)	**294**
P	16 (9)	92 (51)	72 (40)	<1 (<1)	1 (1)	**181**
Aracatimirim (CE)						
N	53 (16)	97 (30)	159 (49)	4 (1)	15 (5)	**328**
P	15 (6)	60 (25)	161 (68)	<1 (<1)	1 (1)	**237**
Curu (CE)						
N	98 (11)	215 (25)	520 (60)	7 (1)	28 (3)	**868**
P	28 (9)	159 (52)	115 (38)	<1 (<1)	2 (1)	**305**
Mundaú (CE)						
N	250 (18)	701 (50)	411 (30)	17 (1)	11 (1)	**1390**
P	70 (7)	526 (54)	373 (38)	1 (<1)	1 (0)	**971**
Pirangi (CE)						
N	77 (13)	320 (55)	159 (27)	5 (1)	24 (4)	**585**
P	21 (5)	257 (58)	161 (36)	<1 (<1)	2 (0)	**441**
Jaguaribe (CE)						
N	152 (20)	145 (19)	146 (19)	9 (1)	318 (41)	**770**
P	43 (13)	90 (27)	168 (51)	<1 (<1)	27 (8)	**328**
Icapui (CE)						
N	28 (15)	55 (29)	88 (47)	2 (1)	15 (8)	**188**
P	8 (5)	32 (19)	131 (76)	<1 (<1)	1 (1)	**172**
Apodi (RN)						
N	400 (33)	314 (26)	224 (19)	48 (4)	214 (18)	**1200**
P	112 (12)	289 (30)	543 (56)	7 (1)	18 (2)	**969**
Açu (RN)						
N	97 (15)	88 (14)	45 (7)	7 (1)	411 (63)	**648**
P	27 (10)	90 (34)	111 (42)	1 (<1)	35 (13)	**264**
Guamaré (RN)						
N	17 (4)	170 (43)	30 (8)	76 (19)	102 (26)	**395**
P	5 (2)	176 (65)	70 (26)	11 (4)	9 (3)	**271**
Ceará-Mirim (RN)						
N	32 (33)	19 (20)	38 (39)	1 (1)	7 (8)	**97**
P	9 (16)	20 (37)	24 (44)	1 (2)	1 (1)	**55**
Guaraíras (RN)						
N	97 (6)	426 (27)	864 (55)	10 (1)	183 (12)	**1580**
P	27 (4)	561 (75)	147 (20)	2 (<1)	16 (2)	**753**
Curimataú (RN)						
N	57 (5)	190 (15)	749 (60)	7 (1)	248 (20)	**1251**
P	17 (5)	244 (69)	67 (19)	1 (<1)	23 (7)	**352**

and P in all basins, representing less than 2% of the total emission, with the exception of the Guamaré basin where 19% of the N emission come from this source. Wastewaters contribute with significant loads of N and P to the more populated basin (Apodi) which harbors over 240.000 inhabitants (33% and 12%, for N and P respectively). Intensive shrimp farming is, however, the major contributor of N in the Jaguaribe (41%) and Açu (63%) basins. Also at the Guamaré basin it contributes with 26% of the total N load. Contribution of P from intensive shrimp farming is relatively small varying from <5% in most basins to a maximum contribution of 13% at the Açu basin.

Although the relative contribution of intensive shrimp farming is small in most of the studied area, except at the Jaguaribe and Açu basins, the location of farms adjacent to estuaries makes possible direct inputs to waters, while most other emissions go firstly to soils before eventually being transported to surface waters.

CONCLUSIONS

The results presented here show that even in areas of low human occupation such as the NE semi-arid coast of Brazil, anthropogenic emissions of N and P are significant sources of these nutrients to estuaries. Although all studied basins present low population densities, inputs from agriculture, husbandry and shrimp farming are considerable and can alter the water quality of the receiving estuaries. Intensive shrimp farming presents the largest yields for N among the studied basins. However, only in two estuary (Jaguaribe and Açu), where pond area reaches 1,260 ha and 1,680 ha respectively, it is the most important source of N. Shrimp farm contribution to the total P emission is relatively small in all estuaries. However, since emissions from this source are directly disposed to estuarine waters the response of coastal ecosystem metabolism to shrimp farm effluents may be more rapid than from other sources and control of these emissions are critical to control the eventual onset of eutrophication.

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