Biogeochemistry (2006) 79: 91–108
DOI 10.1007/s10533-006-9004-z

Assessment of nitrogen flows into the Cuban landscape

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Key words: Atmospheric deposition, Fertilizer, Nitrogen, Nitrogen budgets

Abstract. The alteration of the nitrogen (N) cycle by human activities is widespread and has often resulted in increased flows of nitrogen to the marine environment. In this paper we have attempted to know the changes of N fluxes in Cuba by quantifying the N inputs to the landscape from (1) fertilizer applications, (2) atmospheric deposition, (3) biological nitrogen fixation and (4) net import of food and feeds. N-inputs to the country progressively increased until the end of the 20th century, reaching a peak during the 80s when low cost fertilizer imported from the former Soviet Union led to heavy rates of application. This rapid growth represented more than a 5-fold increase with respect to pristine values; higher than the two-fold global increase of anthropogenic N reported by Vitousek et al. (1997 Human alteration of the global nitrogen cycle: sources and consequences. Ecol. Appl. 7:737–750). Inorganic fertilizer was the largest single source of reactive N, followed by atmospheric deposition, biological fixation, and net imports of foods and feed-stocks. Nitrogen inputs peaked in 1987 and data expressed on an area basis show that N flux to the Cuban landscape, in the 80s, was one of the highest reported in the literature. During the 90s, there was a dramatic drop in nitrogen inputs mainly associated to a decrease in the use of inorganic fertilizer. Other factors reducing nutrient inflows to Cuba, during the same period, were imports of foodstuff and livestock feeds, a decrease of nitrogen oxide emissions, and a decrease in the sugar cane crop area. Using an empirical relationship (Howarth et al. 1996 Regional nitrogen budgets and riverine N & O fluxes for the drainages to the North Atlantic Ocean: Natural and human influences. Biogeochemistry 35:75–139) we present a very preliminary estimate of N-inputs to coastal waters and discuss the consequences of these changes on the coastal zone.

Introduction

Human activities have more than doubled the inputs of reactive nitrogen (Nr) to the terrestrial landscape (Galloway et al. 1995; Howarth et al. 1996; Smil 1997; Vitousek et al. 1997). This increase was originally limited to developed countries, but is now being extended to developing countries (Matson et al. 1999). The accumulation of Nr in ecosystems is one of the most important research questions associated with the impact of humans on the nitrogen cycle (Galloway and Cowling, 2002). The influx of excess nitrogen has caused serious alterations to the natural nutrient cycle and disrupted terrestrial and aquatic ecosystems especially where intensive agriculture and high fossil fuel combustion coincide (WRI 2001).

One of the best-documented consequences of human alteration of the nitrogen cycle is the eutrophication of estuarine and coastal waters (Vitousek et al. 1997). While in moderation, nutrient inputs to oligotrophic coastal waters may increase fish production (Howarth et al. 2000) especially of pelagic species (Caddy 1993), a more intensive input of Nr has serious effects on the fisheries, biodiversity and ecosystem functioning (Boesch 2001).

Due to the location of Cuba in the oligotrophic Caribbean Sea, in absence of significant processes of coastal upwelling and because the very small tidal range; river discharge, delivering terrestrial material in particulate and dissolved form, is the most important source of nutrients supporting Cuban marine coastal fisheries (Baisre 1985). An analysis of the dynamics of its fisheries resources shows that, in 1995, approximately 38.9% were in the senescent phase (with declining catches), 48.7% were in the mature phase at a high exploitation level and only 12.4% were still in the developing phase with some possibility of increased landings. The decline is noteworthy in the cases of some of the most important estuarine species like shrimps, mullets and mangrove oyster. Baisre (2000) has hypothesized that a reduction of nutrients inputs to coastal waters is one of the factors that must be considered when analyzing the causes of this decline.

This paper represent a first step toward more specific studies about the ecological consequences of human alterations on the N-cycle in Cuba and the impact of anthropogenic nutrients in the coastal waters and marine fisheries. By considering the whole Cuban territory as a large watershed, I estimate N-inputs to the landscape from a combination of fertilizer use, atmospheric deposition, biological fixation and net imports of foods and feedstock. A preliminary assessment of the probable fluxes to coastal areas was also attempted by using a model developed for temperate regions.

Material and methods

Study area

The Cuban Archipelago, has a total surface area of 110860 km^2 which includes the Isle of Cuba (104945 km^2), the Isle of Youth (2200 km^2) and more than 1600 small and unpopulated islands and keys (3715 km^2). Approximately two-thirds of Cuba consists of plain or rolling lands with low elevation. The rest of the territory is formed by three groups of mountains where most of the natural forest occurs. The country lies within the northern tropics and has a sub tropical climate moderated by trade wind. Average daily temperatures range from 21 °C in winter to about 27 °C in summer. Annual average rainfall is 1300 mm with a marked difference between the rainy season (May to October) and the dry season (November to April).The combined area of the country is made up of agricultural lands (34.8%), non-cultivated lands (34.1%), and forest (21.5%), with a small fraction of urban land (6.6%) and freshwater aquatic areas (2.9%).

Many watershed runs like a spine along the length of the main island and as a consequence, most of the rivers are of limited length and reduced flow.

Furthermore, many parts of the country are underlined by limestone and some rivers may flow underground for at least parts of their lengths (Cubagua 2004).

In marine waters, Baisre (1985) described in sequence three fishery ecological complexes in terms of the decreasing influence of land. The three ecological complexes are: estuarine–littoral, seagrasses-coral reef and oceanic. The estuarine–littoral complex is particularly influenced by terrestrial fluxes and is typical of low coast, estuaries and lagoons dominated by terrigenous material and mangroves. Ecologically, they represent highly fluctuating habitats subject to great environmental changes, often accentuated by the unpredictable rainy season. There are elevated levels of primary production and organic detritus, which are the basis of relatively simple food webs. Estimated area of the estuarine–littoral complex is about 8500 km^2, approximately 16% of the total shelf area and it reaches its greatest extent on the southeast coast in the Gulfs of Ana Maria and Guacanayabo into which the largest river systems of the country drain (Baisre 1985).

Changes in the nitrogen cycle in Cuba was determined in this paper by quantifying net new anthropogenic Nr inputs to the country landscape and comparing to baseline inputs. New refers to Nr that is either newly fixed within, or transported into a region (Howarth et al. 2002).

Natural inputs

The estimation of natural biological N fixation in Cuban pristine areas could provide a baseline for further comparison with anthropogenic inputs in human dominated ecosystems. Available data suggest that approximately 60% of Cuba was covered with forest in pre-Columbian times (Smith 1954). This forest was largely deciduous broad-leaf while pine forests probably occupy the same 4% they do today and the tropical rain forest was limited to a small area in the northeastern mountains (Marrero 1950). Considering that 60% of the area of the country was covered by deciduous broad-leaf forest; 26% by tropical dry savanna, while the remaining area is occupied by different types of vegetation (xeromorphic shrubs, wetlands, mangroves, pinelands, (Smith 1954), I calculated N-fixation in Cuban pristine landscape using the area covered by the different types of vegetation and reference values from the literature.

Natural nitrogen fixation rates are difficult to estimate because of ecosystems heterogeneity. Cleveland et al. (1999) reviewed the available published estimates of both symbiotic and non symbiotic components of N fixation for each typed ecosystem, using the ecosystem classification of Schimel et al. (1996). For the dry tropical broad-leaved forest, the most common vegetation type in Cuba, Cleveland et al. (1999) reported a range of values from 9.4 to 34.0 kg N ha^{-1} yr^{-1} with an average of 21.7 kg N ha^{-1} yr^{-1}. Estimates of N-fixation in tropical savannas are higher because of the sparse presence of some legumes, and range from 16.3 to 44.0 kg N ha^{-1} yr^{-1} with a mean estimate of 30.2 kg N ha^{-1} yr^{-1} (Cleveland et al. 1999). In this paper, I used the lower and more conservative values for estimating inputs from N fixation in natural systems, because as pointed by Galloway et al. (2004), ‘‘there are several compelling reasons to believe that an estimate in lower portion of the range is more realistic than higher estimates’’.

Anthropogenic inputs

Besides determining annual N inputs from fertilizer application, atmospheric deposition, biological nitrogen fixation by agricultural crops, and net movement of food and animal feed stocks into or out the country, I also assessed the interannual variability of these inputs. Except for data on nitrate wet-deposition, from 1982 to 1994, the remaining data were available over a longer period of time, between 1961 and 2000.

Data on inorganic-N fertilizer was obtained from the International Industrial Fertilizer Association database (IFA 2004), while atmospheric deposition was estimated with data from a network of 5 monitoring stations operated by the Institute of Meteorology across the country (Figure 1). Atmospheric deposition (wet and dry) in Cuba is mainly associated with industrial and agricultural (biogenic) N emissions. The two major sources of nitrogen pollution to the air are fossil fuel combustion (e.g. vehicle and power plant emissions) and agriculture (e.g. fertilizer and manure emissions). Nitrate (NO_3^-) and ammonium (NH_4^+) are the dominant forms of inorganic N in atmospheric deposition (Centella et al. 2000). I considered only the emissions of oxidized nitrogen compounds to the atmosphere (NO_x), because the emission of ammonia and ammonium (NH_x) supposedly originates from the volatilization of fertilizer and animal wastes, and represents N recycling within the system (Howarth et al. 1996). According to Cuesta et al. (1998), atmospheric wet deposition in Cuba is about 60% and the dry one is 40% while the oxidized nitrogen compounds contribute 40% and the reduced ones 60%. Final values of total atmospheric deposition of NO_x were calculated using these figures. I have not considered the NH_x deposition from oceanic sources although we recognized that this is a potential source of N particularly because Cuba is a small and elongated island. Estimates of inputs of nitrogen in food and feedstocks were based on import and export data from the Food Balance Sheets prepared by FAO for different countries (FAOSTAT 2004), and the N content of the different food items obtained from the Food Composition Table published by the Research Institute for the Food Industry (IIIA 1985).

Data on N fixation refers to the sum of symbiotic N fixation by cultivation of legume crops, and non-symbiotic N fixation (Yan 2003). The cultivation of rice and other non-legume crops supply an additional source of biologically fixed N by microorganisms (Watanabe 1986). I estimated agricultural fixation rates of N in Cuba by multiplying the area of the different crops, and pasturelands by N fixation rates from the literature. The fixation rate used for edible beans was 40 kg N ha^{-1} yr^{-1}; which is the average for several types of

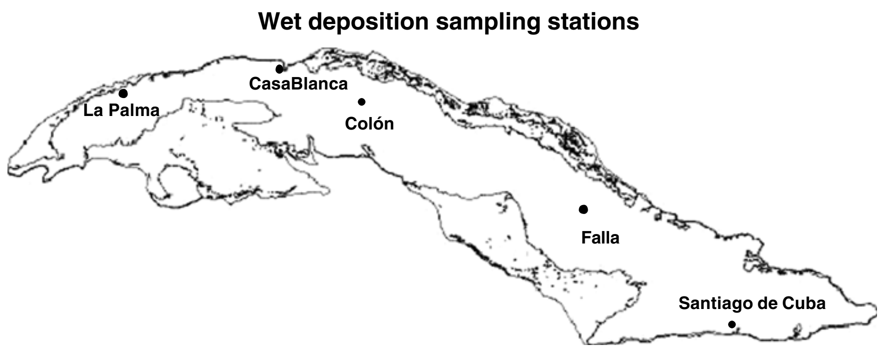

Figure 1. Map of Cuba showing the stations where wet atmospheric deposition have been monitored. This network is operated by the Institute of Meteorology.

beans calculated by Jordan and Weller (1996). Other fixation rates used were 30 kg ha^{-1} yr^{-1} for cyanobacteria associated with rice and 50 kg ha^{-1} yr^{-1} for endophytic diazotrophs associated with sugarcane (Smil 1999). For pasture, a fixation rate of 4 kg ha^{-1} yr^{-1} was used (Jordan and Weller 1996). Data on cultivated areas for all of these crops were also available at the FAO database (FAOSTAT 2004).

Estimates of Nr export to coastal waters were made using a simple linear regression model relating net anthropogenic Nr inputs to total Nr exports in rivers (Howarth et al. 1996). This model proved to be useful for estimating Nr fluxes in 16 major watersheds in the northeastern USA (Boyer et al. 2002) and it seems to be the best choice from several models used to estimate Nr fluxes from those watersheds (Alexander et al. 2002).

All fluxes were expressed as mass per unit area (Gg N km^{-2}) and as mass per unit area, per unit time as kg N km^{-2} yr^{-1} or kg N ha^{-1} yr^{-1}. (1 Gg = 1000 ton; 1 km^2 = 100 ha). When presenting the data on an area basis, I considered the combined area of the Isle of Cuba and Isle of Youth to be 107145 km^2.

Results

Natural inputs

Although electric discharges is one of the two natural sources of Nr, we assumed that this source do not have changed very much and have not been included in the N-budget. Natural biological fixation in Cuban pristine areas in pre Columbian times, accounts for 123 Gg N yr^{-1} and when expressed on an area basis this is equivalent to roughly 1119 kg N ha^{-1} yr^{-1}. This figure is about 6- fold the actual data for biological N fixation in primary and secondary forest which averaged 20 Gg N yr^{-1} from 1961 to 2000.

Anthropogenic inputs

Nr inputs from fertilizers

The most commonly used fertilizers in Cuba were urea (36.2%), ammonium nitrate (34.5%) and ammonium sulphate (24.3%). N-inorganic from fertilizer use from 1961 to 2000 averaged 180 Gg N yr^{-1}, although there were great differences between years (Figure 2). From 1961 to 1989, a progressive increase of nearly 9-fold occurred, from 41 Gg N yr^{-1}; to 367 Gg N yr^{-1}. Fertilizer use then declined drastically to 78 Gg N yr^{-1} (nearly 5-fold) by 2000.

Considering the entire area of the country, the yearly average of fertilizer application is 17 kg N ha^{-1} yr^{-1}, although during the period of intensive use of inorganic fertilizers in Cuban agriculture (1980–1989), the average inputs rose to 28 kg N ha^{-1} yr^{-1}. If only the area of agricultural land is considered, fertilizer application rate in Cuba increases to more than 90 ha^{-1} yr^{-1}, reaching a maximum of 94 ha^{-1} yr^{-1}.

Net atmospheric Nr inputs from fossil-fuel combustion

The principal sources of oxidized N in Cuba are the combustion of fossil fuel, motor vehicles and different industrial processes (Centella et al. 2000). Total atmospheric deposition of NO_x from 1982 to 1994 is presented in Figure 3, ranging from a minimum of 32 Gg N yr^{-1} in 1992 to a maximum of 171 Gg N yr^{-1} in 1987. With the decrease in the use of inorganic fertilizer, atmospheric deposition becomes the most important source of anthropogenic N in the last decade accounting for 34% of all the inputs in 1994.

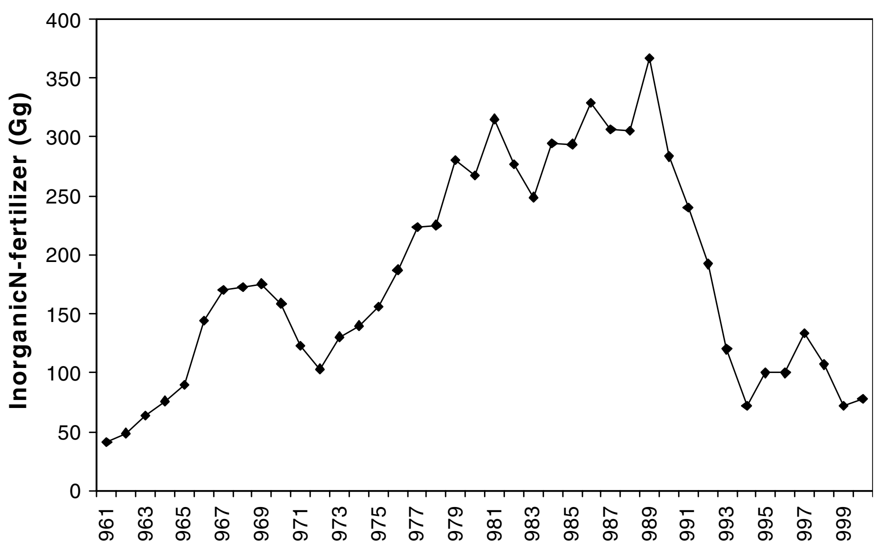

Figure 2. N inputs to Cuba from 1961–2000 from use of inorganic fertilizer (Data from the International Industrial Fertilizer Association).

Figure 3. N inputs from total atmospheric deposition of NO_x. The calculations were based on annual average data from wet deposition and the estimates that wet deposition in Cuba represents about 60% while the oxidized nitrogen compounds contribute 40% (from Cuesta et al. 1998).

Nr inputs from N_2 fixation

Nr is also introduced to the Cuban landscape in significant quantities by biological fixation in agricultural systems (Figure 4). Available estimates indicated that biological N fixation in 1961–2000, excluding primary and

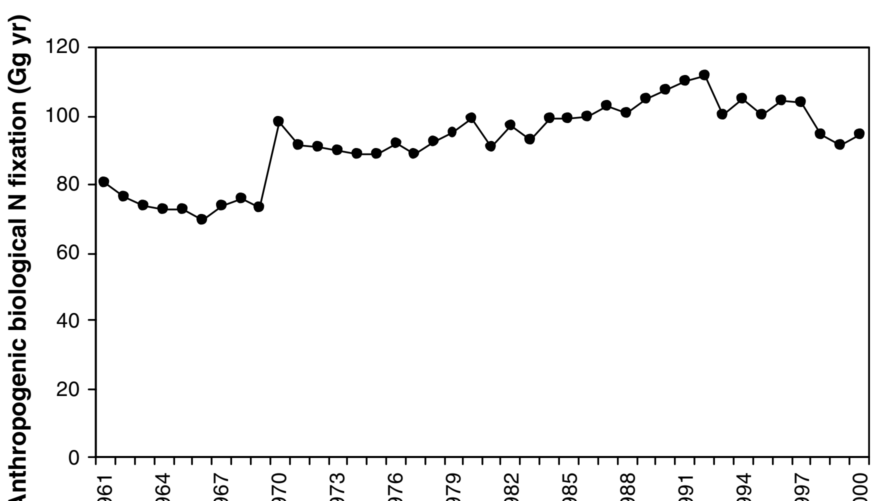

Figure 4. N-inputs from biological fixation in agricultural system from 1961 to 2000. Data on biological N fixation in primary and secondary forest were not included.

secondary forest, averaged approximately 94.5 Gg yr^{-1} and varied from about 72.5 Gg N yr^{-1} in 1965 to some 110 Gg N yr^{-1} in 1991, while it is the most stable of the four sources. Sugar cane crop (66.1%), and pasture (11.1%), were the most important sources of N-biological fixation.

Net Nr import in foods and feeds

The fourth source of nitrogen input in Cuba is from the net movement of food and feedstocks into and out the country. Although Cuba is typically a food exporter, most products, except for sea foods, are nitrogen poor (e.g. sugar and fruits). On the other hand, there are relatively large inputs of nitrogen from imported cereals, fish, chicken meat and milk. Most of the N in imported foods comes from cereals (73.9%), fish (9.7%) and beans (8.8%). The net import of nitrogen from 1961 to 2000 averaged 43.5 Gg N yr^{-1} and there was also a progressive increase on imported N from 1961 to 1980 (Figure 5), which reached more than 66 Gg N.

Summary of Nr inputs

Total N inputs into the country increased progressively from 136 Gg N in 1961 to 640 Gg N in 1987 (Figure 6). Excepting the biological N fixation which do not varies very much, there is a general trend of the other N inputs to increase rapidly until the end of the 1980s and then to decrease even more rapidly after the 1990s (Figure 7). From 1989 onwards, there is a significant decline of imported N in food and feedstock, reaching only 37.1 Gg N in 2000. From 1961 to 1965, biological fixation of N in agricultural systems was the largest source of Nr in Cuba, but since 1966 the use of inorganic fertilizer becomes more important. From 1994 onwards, NO_x deposition

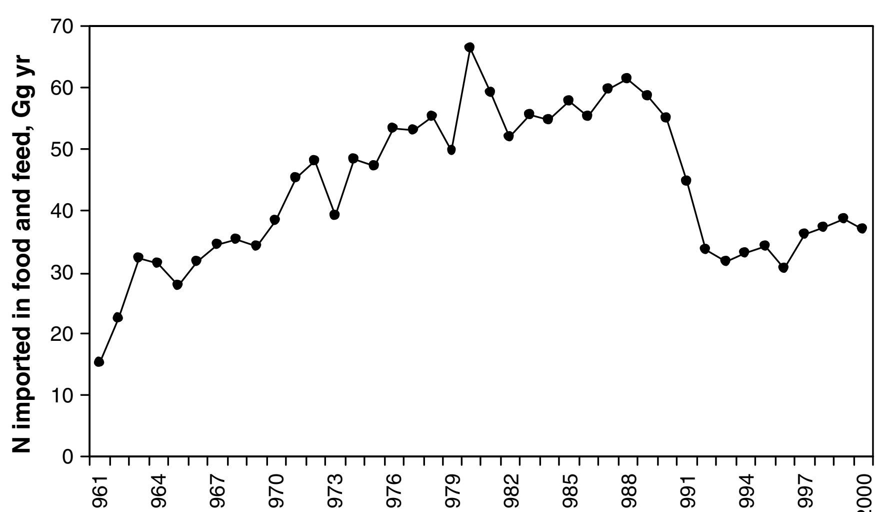

Figure 5. Net import of N to Cuba in foods and feedstocks from 1961–2000.

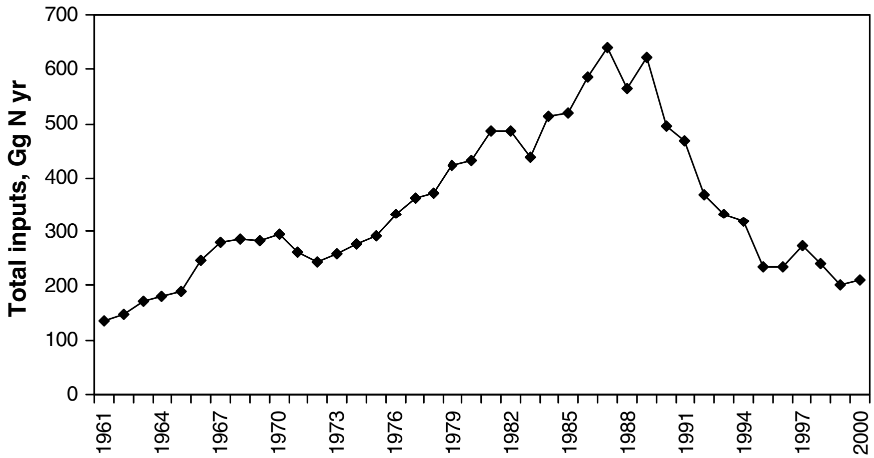

Figure 6. Total N-input to Cuba from 1961–2000. Data on atmospheric deposition was available only from 1983 to 1994 and refers only to deposition of NO_x.

becomes the most important anthropogenic source of Nr in the country budget.

The total inputs in 1987 practically represent more than a 5-fold increase with respect to the pristine values before the Spanish settlement (Figure 8).

In order to compare our data with those previously reported in the literature (Howarth et al. 1996; Yan et al. 2003), total Nr input is presented for three different years (Table 1), which are representative of three different periods of N inputs in the country. The first year (1961) represents an early stage of Cuban agricultural development and the first year when the statistical database

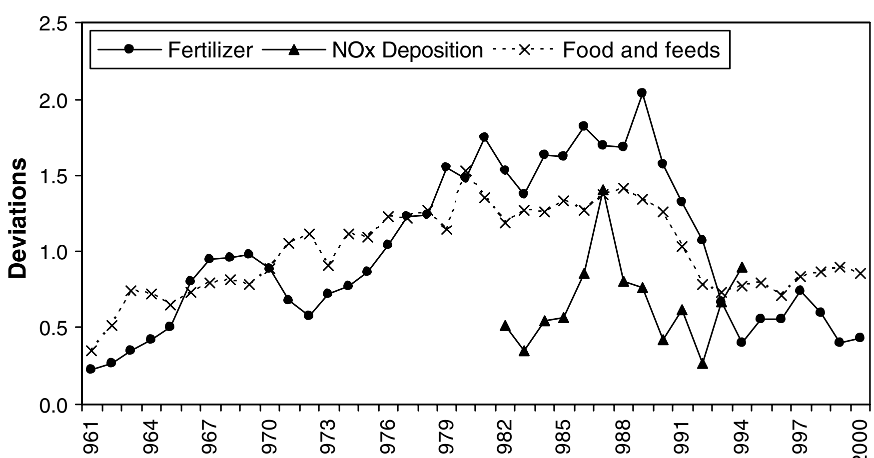

Figure 7. Trends of the inputs from fertilizer, atmospheric deposition and net imports of food and feeds based on standardized data expressed as deviations of the average value.

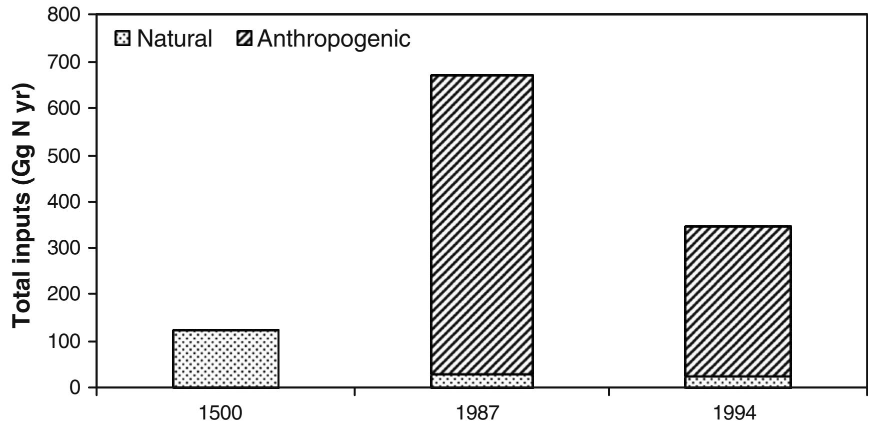

Figure 8. Comparison of N inputs to the Cuban terrestrial landscape from natural and anthropogenic sources, in selected years. 1500 (During the Spanish settlement), 1987 (the year of the highest N-input) and 1994 (representative of the actual conditions).

was more or less complete. The year of maximum input of Nr (1987) occurred after a relatively continuous development and was typical of a period of accelerated use of Nr. This peak was reached one a few years before the partial collapse of the Cuban economy due to the loss of imports from the Soviet Union, which rapidly led to a drastic reduction of imported fuel, fertilizer and food and feedstock.

Table 1. N-inputs to the Cuban landscape for three different years. Results from Cuba are compared with data from 10 temperate regions surrounding the North Atlantic (Howarth et al. 1996) and with data from the Chianjtse River watershed (Yan et al. 2003). Fluxes are in N km^{-2} yr^{-1}. Country area used in the calculation was 107.145 km^{-2}.

	NO_y deposition	Fertilizer	Fixation by crops	Net import in foods	Total
North Canada rivers	70	160	30	−50	210
St. Lawrence basin	610	330	260	−30	1170
NE coasts of US	1200	600	750	1000	3550
SE coasts of US	1020	1170	370	450	3010
Eastern Gulf of Mexico	760	1260	250	580	2850
Mississippi River basin	620	1840	1060	−1300	2220
Baltic Sea drainages	480	1730	30	20	2220
North Sea drainages	1090	5960	5	−5	7050
NW European coast	1090	2870	50	−320	3700
SW European coast	460	3370	15	−65	3780
Chiangtse River	(NA)	3510	1070	(NA)	4580
Cuba 1961	(NA)	383	860	143	1386
Cuba 1987	1707	2860	984	558	6109
Cuba 2000	(NA)	728	822	346	1896

(NA) Not available.

Finally, the year 2000 is representative of present conditions. This phase, began in 1990, and shows the results of a drastic decrease of Nr inputs due to a reduction in the use of inorganic fertilizers concomitantly with similar reductions in nitrogen oxides emission, sugar cane area and imported foods and feedstuff. Table 1 also shows that in the 80s, nitrogen input into the Cuban landscape was one of the highest in the literature, only below that of the North Sea.

It is also interesting to express Nr creation and use on a per capita basis to illustrate the average amount of Nr mobilized per person. North Americans for example, mobilize about 100 kg N person^{-1} yr^{-1} (Howarth, et al. 2002). At the other extreme, people in Africa mobilize about an order of magnitude less, about 7 kg N person^{-1} yr^{-1}. The world average is about 24 kg person^{-1} yr^{-1} (Galloway and Cowling 2002). In 1987, when all N inputs peaked as 640 Gg, the Cuban population mobilized 62 kg person^{-1} yr^{-1} while in 2000 this figure dropped dramatically to 19 kg person^{-1} yr^{-1}.

Nr export to coastal waters

Average estimates of Nr export in rivers using the empirical model presented by Howarth et al. (1996) was 926 kg N km^{-2} yr^{-1} and values ranged from 379 kg N km^{-2} yr^{-1} in 1961 to 1461 kg N km^{-2} yr^{-1} in 1987.

Discussion

Human activity has roughly doubled the availability of nitrogen to terrestrial ecosystems of the planet (Vitousek et al. 1997). This nitrogen fixation increased by some two- to three- fold over the three decades between 1960 and 1990, and continues to grow (Galloway et al. 1995). The effects of N cycling in temperate and tropical ecosystem can be better understood if we can compare N dynamics in pristine or minimally disturbed ecosystems and highly modified ecosystems.

In the pristine biosphere, it is generally believed that N-biological fixation was the dominant source of newly fixed N to the landscape (Cleveland et al. 1999). Before the Spanish settlement in Cuba, we can assume that the small number of persons living in the region, their diet based on marine foods, and subsistence agriculture (Tabío and Rey 1985; Dacal Moure and Rivero de la Calle 1986), caused negligible human impacts on N-cycle. Our estimate of N-biological fixation represents then, a baseline for further assessment of the Nr mobilized by human activities.

It has been emphasized (Downing et al. 1999) that, with the progressive intensification of human development, vast areas of forest have been commonly cleared and replaced by agricultural crops or urban areas. The real extent of the destruction of Cuban forest during the Spanish rule is unknown but all the evidences suggest that this impact has been overemphasized. Although some of the so-called India's Chroniclers calculated the number of Indians who occupied Cuba to have been 200,000 or 300,000, this figures seems to overestimate the true population. Evidences supporting it come from the first census carried out in 1774 (ONE 2002), almost 300 years after the colonization. In this Census, the whole population of Cuba was calculated in only 171,620 inhabitants of all races. A rapid development of the population took place since that time and by 1899 the census reported that about 50% of the country was still forested even when the population reached 1.6 millions inhabitants. Then, although deforestation obviously took place since first Spanish settlement, do not reach disastrous proportions until the first half of the XX century. According to Smith (1954), the trend in the destruction and removal of Cuba's forest date from the treaty of 1903 between Cuba and the United States. This treaty gave sugar a place on the preferred list of imports into the USA. For that reason, land was rapidly cleaned for cane planting, and the forest were extensively cut and burned. In 1950, the forest covered only 18% of the landscape (Levi Marrero 1950; Smith 1954). Since then, anthropogenic N inputs have increased significantly until it reached one of the highest values reported in the literature in the 1980s. As mentioned earlier, the Cuban population in 1987 mobilized 62 kg N person^{-1} yr^{-1}, some 3-fold the global average. The increase of N availability between 1961 and the end of the 80s was mainly associated with the intensification of agriculture and livestock production, supplemented by an increase of the use of fossil fuel consumption and imports of feeds and foodstuff.

Nr inputs from fertilizers

The relative importance of different sources of nutrients varies greatly among different coastal regions of Cuba, depending on the characteristics of the drainage basin, their human populations, the intensity of agricultural activities, and the amount of atmospheric deposition. But overall, fertilizer applications have been the most important source of Nr inputs to the Cuban territory.

In order to sustain economic levels of production, fertilizer use on tropical lands may eventually exceed rates of application in temperate systems (Downing et al. 1999). Special problems arise with crops as sugar cane and rice, which receive large applications of N, but also lose large amount of N by denitrification and volatilization (Peoples et al. 1995). Sugar cane dominates agriculture in Cuba, accounting for approximately half of the cultivated area and has historically consumed most of the fertilizers (FAO 2003).

Agricultural N inputs by fertilizer application (per total area, including non agricultural lands) in the major drainage basin of the United States ranged from 0.9 kg N ha^{-1} yr^{-1} in the Great Basin, to 40 kg N ha^{-1} yr^{-1} in the Upper Mississippi region (Jordan and Weller 1996). When averaged over the entire area of the country, the rate of inorganic fertilizer use in the USA is approximately 13 kg N ha^{-1} yr^{-1} or some 2.2 fold greater than the global average (Howarth et al. 2002). In Cuba, considering the entire area of the country, the yearly average from 1961 to 2000 was 16.8 kg N ha^{-1} yr^{-1}, a 29% higher than the average in USA. Furthermore, in the period of intensive use of inorganic fertilizers in Cuban agriculture, from 1980 to 1989, the average was 28 kg N ha^{-1} yr^{-1}, or 2.1 fold greater than in the USA. Only in the Upper Mississippi region, where a high proportion of the land is devoted to intensive corn and soybean farming (Jordan and Weller 1996), rates of fertilizer use were higher than those in Cuba. Consequently, a large area of anoxia now exists offshore of the Mississippi estuary (Howarth et al. 2000).

Presently, crops and pasture lands cover approximately 53% of the landscape in Cuba, so inorganic fertilizer input to agricultural land was less concentrated than in the USA where this area covers only about 20% of the landscape (Howarth et al. 2002). Nevertheless, by considering only agricultural crops, the rate of application in Cuba, in 1981 and 1989, increased to more than 90 kg N ha^{-1} yr^{-1}, reaching the highest value in 1981 (94 kg N ha^{-1} yr^{-1}). This average is relatively similar to those rates seen in lands intensively farmed with corn in the American mid-west, where approximately 100 kg N ha^{-1} yr^{-1} are applied (Galloway et al. 2004). This figure is likely to be higher if we consider inputs to a particular river basin. This trend has been changing over the last years and nitrogen inputs are now quite reduced due to the drastic shortage in funds for purchase of inorganic fertilizer since 1990 (FAO 2003).

Nr inputs from atmospheric deposition

Total (wet and dry) atmospheric deposition of NO_x averaged 81 Gg N yr^{-1} from 1982 to 1994, with a peak 171 Gg N yr^{-1} in 1987. The figure for 1990 was 51 Gg N yr^{-1} which do not seem to be very high when we compare it with the 142 Gg N yr^{-1} released as NO_x emissions (Centella et al. 2000) in the same year.

Previous studies on atmospheric deposition in Cuba during a 6-year period (Cuesta Santos et al. 1998) reported total deposition values ranging from a minimum of 7.1 kg ha^{-1} yr^{-1} to a maximum of 33.2 kg ha^{-1} yr^{-1}, measured in an urban station. These authors also reported that the maximum values coincides with the growing of the Cuban economy up to 1989, as well as with the increasing generation of pollutants caused by the industry and transportation. They also stated that the higher values are similar to those reported in most of Europe. These values represent a total annual deposition of atmospheric N ranging from 76 to 355 Gg N yr, while the values for oxidized nitrogen compounds ranged from 30 to 1420 Gg N yr. Although this values seems to be relatively high, atmospheric deposition is a strong function of emissions. Once emitted to the atmosphere, nitrogen compounds, particularly NO_x, can travel great distances (~600 to 800 km or farther) from the point of emission to the point of deposition (Dennis 1997). Considering that Cuba is a long island, and also that northeast trade winds are predominant, it is also probable that some of the NO_x emitted from anthropogenic activities in the southeastern United States might be redeposited on the Cuba's land surface, increasing the estimated amount of Nr deposition.

Nr inputs to coastal waters

Once it has been introduced into a terrestrial system, nitrogen has three fates: (1) storage within the system, (2) transferred to another system (discharged to the water or emitted to the atmosphere), or (3) denitrified. Nitrogen inputs can be exported in many forms and through different pathways to the soil, atmosphere, groundwater and rivers. The extent to which agriculture and other human activities contributed to the nitrogen fluxes are very variable and depend on how intense the y are (Howarth et al. 2002). In the United States and Europe, discharges of nitrogen from rivers are highly correlated with increasing human generated nitrogen inputs into the watersheds, particularly from fertilizers and atmospheric deposition (Howarth et al. 1996; Jordan and Weller 1996).

Boyer et al. (2002) examined the relationships between N inputs and riverine N export for 16 catchments basin in the northeast USA using the empirical model from Howarth et al. (1996) for the large regions that drain to the North Atlantic Ocean. These basins encompass a range of climatic variability and are major drainages to the coast of the North Atlantic Ocean along a latitudinal profile from Maine to Virginia. In spite of the possible limitations of this model for tropical regions, we used it in order to have a first approximation of the magnitude of terrestrial N export to Cuban coastal waters. In any case, the drastic reduction experienced by the N inputs during the 1990s, must have also impacted significantly, the receiving marine waters.

One of the best documented and understood consequences of human alterations of the nitrogen cycle is the eutrophication of estuaries and coastal waters (Vitousek et al. 1997). The impact of anthropogenic N in coastal waters have been widely documented in the literature (Ryther and Dunstan 1971; Pearl 1985; Nixon 1995; Caraco and Cole 1999; Cloern 2001; Rabalais 2002); but the dramatic decline of nutrients that occurred in Cuba in the past decade, seems to follow the opposite trend of that seen for other regions of the world and therefore must be seriously considered in future ecological studies.

Some studies suggest (Caddy 2000) that drastic reductions in nutrient inputs to terrestrial landscapes might introduce a rapid change in coastal ecosystems. A good example comes from the dramatic decline of application of fertilizers by some of the countries of Eastern Europe. Discharges of phosphorus and subsequently nitrogen rapidly declined at the beginning of the 90s and by 1996; there was no hypoxic zone on the shelf of the Black Sea for the first time in 23 years (Boesch 2001). According to Kideys (2002), the decrease in nutrient inputs to the Black Sea were immediately reflected in measurements of nutrient from coastal waters.

It is recognized that there are three main categories of nutrient enrichment processes in the coastal zone: (1) coastal upwelling, (2) tidal mixing and (3) land-based runoff and major river outflow (Caddy and Bakun 1994). There is strong circumstantial evidence worldwide that nutrient-enriched riverine discharges enhance fishery production in adjacent shelves (Grimes 2001). It has been also hypothesized (Baisre 2000; Caddy per.com.), that there is a relationship between the drastic decrease of fertilizer applications in agricultural crops in the 1990s in Cuba, and a drop in coastal fisheries during the same period.

The reduction of the extent of brackish areas and wetlands by excessive freshwater extraction upstream will also have adverse impacts on marine species which are dependent on brackish habitat for part of their life history (Aleem 1972; Deegan et al. 1986; Caddy and Bakun 1995). A reduction of freshwater flow might concomitantly reduce the extent of the brackish water area and to provoke the salt-water invasions to the estuary and lower river system that may have severe impacts on estuarine dependent species (Deegan et al. 1986). The building of dams on rivers increases water retention and rates of degradation and sedimentation of particulate organic matter with the new impoundment and reservoirs become effective nutrient sinks (Stockner et al. 2000). In Cuba, the main rivers have been regulated and water volume in artificial reservoirs now represents 24.9% of the nation's internal renewable natural water resources (Cubagua 2004). The effects of river damming in Cuba and the concomitant reduction of nutrient inputs to the coastal zone are reflected in the dramatic decrease of the landings of the more typical estuarine species like mullets (Mugilidae), shrimps (Penaeidae), gerrids (Gerridae) and mangrove oyster (*Crassostrea rhizophorae*) (Figure 9).

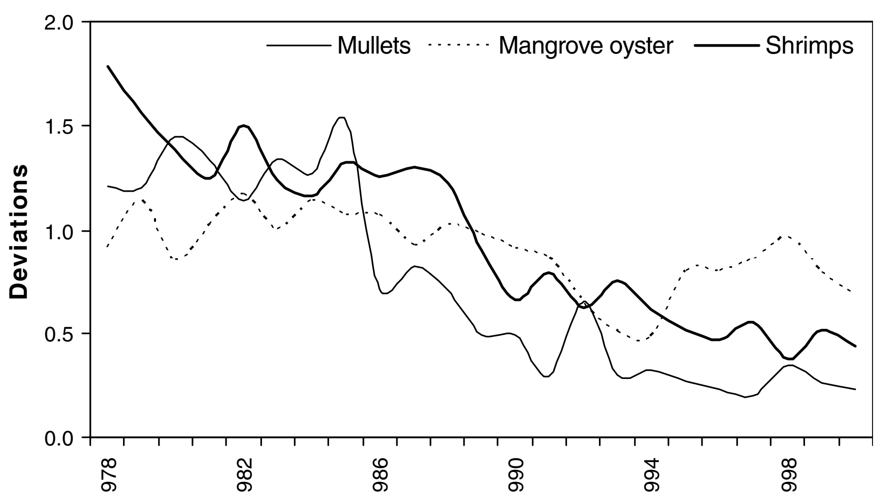

Figure 9. Trends of the catches of typical estuarine species showing a common and progressive decline (Expressed as deviations of the average value for each species).

Synchronous anthropogenic effects on marine coastal systems make it difficult to separate effects of fishing from terrestrial inputs, especially of those caused by nutrient runoff because as far as the different fisheries are close or beyond the top of the yield curve, the effects of environmental changes, natural or anthropogenic, are likely to predominate (Caddy 2000). In Cuba, it seems to be possible that river damming, acting synergistically with the drastic nutrient reduction previously discussed, provide a more comprehensive explanations for the decline of marine coastal fisheries (Baisre 2000) experienced since 1990.

Acknowledgments

Drs. Robert Howarth, Solange Filoso and Luiz Martinelli, not only stimulated my interest in this problem but also provided considerable help during the preparation of this paper as well as reviewing the first draft. I also thank to Dr. Carlos López who kindly provide the information on atmospheric deposition and to Dr. John F. Caddy who reviewed the manuscript and called my attention to the fishery implications of reduction in the fertilizer use in Cuba. I also thank to two anonymous reviewer whose comments improved very much the manuscript.

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