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# Impacts of introducing Nile tilapia on the fisheries of a tropical reservoir in North-eastern Brazil

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**Abstract** Nile tilapia, *Oreochromis niloticus* (L.), has been introduced in most tropical and subtropical regions of the world to improve inland fisheries and aquaculture. This species is generally viewed as beneficial where introduced, but the environmental impacts of its widespread introductions are uncertain and not well understood. In this study, a 30-year time series of fisheries records from a tropical reservoir was divided into five equal periods of 6 years and compared. The introduction of Nile tilapia did not increase the total catch-per-unit-of-effort (CPUE), the number of fishers actively fishing or their per capita income. Conversely, a significant reduction in the CPUE of other commercially important species was observed after the introduction of Nile tilapia in the reservoir. Although other factors cannot be rule out as possible explanations of the observed changes in the reservoir fisheries, the results are consistent with the hypothesis that these changes may have been caused, at least partially, by the introduction of the Nile tilapia.

KEYWORDS: biological invasions, exotic species, freshwater fishes, reservoirs, semi-arid tropics.

## Introduction

Tilapias are cichlids native to Africa but have become an important component of inland fisheries and aquaculture in tropical Asia and South America for over half a century. They have been introduced into over 90 countries worldwide, with a global distribution second only to common carp (De Silva *et al*. 2004). The contribution of tilapias to global aquaculture and capture fisheries production has increased dramatically over the past three decades, and Nile tilapia, *Oreochromis niloticus* (L.), is responsible for much of this increase (De Silva *et al*. 2004). Compared with other nin-native fish species, few would make the case that Nile tilapia has had negative socioeconomic effects. On the contrary, it has been reported that Nile tilapia culture and capture fisheries have made a significant contribution to food production in many tropical and subtropical regions of the developing world (Fernando 1991; Gurgel & Fernando 1994; Canonico *et al*. 2005). Therefore, Nile tilapia is generally viewed as beneficial where introduced, but its ecological impacts are uncertain and not well understood (Canonico *et al*. 2005).

Serious impacts on the environment can be anticipated from the introduction of species like tilapias, whose reproductive pattern enables them to form dense populations of stunted individuals (Welcomme 1988; Canonico *et al*. 2005; Vitule *et al*. 2009). The success of tilapias as introduced species (i.e. establishing self-sustaining and/or growing populations) throughout the tropics appears to be a result of: (1) their omnivorous feeding habits; (2) their flexibility in growth rate and maturation size according to the prevailing environmental condition; (3) their aggressiveness, which can outcompete other species when spawning places are limited; and (4) their broad environmental tolerances and flexible habitat requirements (Beveridge & Baird 2000; Lowe-McConnell 2000).

Therefore, the same traits that make the Nile tilapia successful in culture and capture fisheries in the tropics also make this species a successful invader, with the potential to become a pest where introduced (Canonico *et al*. 2005; Zambrano *et al*. 2006). In addition, species with flexible habitat requirements, trophic opportunism and broad environmental tolerances such as tilapias generally have higher competitive abilities in

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habitats already disturbed by other anthropogenic impacts, such as dam construction and pollution (Canonico *et al.* 2005). Therefore, the introduction of tilapias may act synergistically with other human impacts to decrease the stocks or even eliminate indigenous fish species.

In a recent review on the effects of introduced tilapias on native biodiversity, Canonico *et al.* (2005) concluded that '… significantly more research into the environmental impacts of tilapia introductions is needed. In most cases, there is little or no knowledge of baseline ecological conditions prior to the introduction of non-native species to inland aquatic ecosystems'. The major goal of this study was to evaluate the ecological and socioeconomic impact of the Nile tilapia introduction in a tropical reservoir in the semi-arid region of north-eastern Brazil using a 30-year time series of fisheries catch assessment data. The data were analysed to investigate whether there were any changes in the catch-per-unit-of-effort (CPUE) of indigenous and non-indigenous fish species and in the number and income of fishers after the introduction of tilapia in the reservoir.

## Material and methods

Gargalheiras Reservoir is located in Acari city in the semi-arid region of Rio Grande do Norte State, north-eastern Brazil, at 6º26′11″S and 36º36′17″W. The reservoir has a maximum inundated area of 340 ha and a mean depth of about 5 m (at maximum water level). It was built in 1959 by the National Department of Works against Drought (DNOCS). The fisheries in the reservoir started in 1965 and were monitored every month from 1971 to 2000. Therefore, the fisheries records started 12 years after the construction of the reservoir and avoided the transient dynamics in fish composition associated with newly created reservoirs.

Gillnets of mesh sizes $>50$ mm were the major fishing method together with prawn traps. Gillnets of mesh sizes $<50$ mm are prohibited to professional fishers. At the beginning of every month, fishers actively fishing in the reservoir were counted and identified and 25% of these fishers were randomly selected to show their catches each day to the reservoir manager for counting and weighting of the fish and prawn species. Total daily catches were assumed to be four times the amount recorded from the random sample of fishers. Total daily catches were summed over each month and then registered in the fishery records as catches per month. A random sample of 25% of the fishers was the most representative sample that could be taken of the fishers′s population for a daily monitoring of the catches by the reservoir manager.

The CPUE of each fish and prawn species was calculated by dividing their respective capture weight by the number of professional fishers actively fishing per month ($kg^{-1}$ $fisher^{-1}$ $month^{-1}$). Total CPUE was calculated as the sum of each fish and prawn species CPUE. The per capita gross income from the fisheries, expressed in Brazilian Reais (R$), was calculated as the sum of the product of each fish and prawn species CPUE and their respective current market price (Table 1).

Nile tilapia was first introduced in the reservoir in 1973 and first appeared in the records by the end of 1976. However, it only started to dominate the fisheries in 1979. Thereafter, it has been stocked in the reservoir to enhance fish yields and support the low income, technically limited, artisanal gillnets fisheries. Fisheries records were divided into five periods of 6 years: before (1971–1976) and after (1977–1982; 1983–1988; 1989–1994; 1995–2000) the establishment of the Nile tilapia in the reservoir to distinguish the short-term and long-term changes following the introduction.

One-way ANOVA on log-transformed data was used to test for differences in the CPUE, number of fishers and their per capita gross income between the five periods. Data were log transformed to equalise variances and normalise the residuals. Confidence intervals were used for all differences between pairs of means to test for differences between the five periods. Confidence intervals that did not include 0 were used as evidence of means that were not equal. These statistical analyses were performed using StatTools 5.5 (Palisade Corporation, Ithaca, NY, USA).

## Results

Fish catches comprised of both indigenous and introduced species. Among the indigenous species, only

**Table 1.** Price (R$ $kg^{-1}$) of fish and prawn in the Gargalheiras reservoir

| Species | Common name | Price (R$) |
|---|---|---|
| *Astronotus ocellatus* | Apaiari | 5.00 |
| *Cichla ocellaris* | Tucunaré | 5.00 |
| *Hoplias malabaricus* | Traíra | 1.75 |
| *Macrobrachium amazonicum* | Prawn (fresh) | 2.00 |
| *Macrobrachium amazonicum* | Prawn (fillet) | 6.00 |
| *Oreochromis niloticus* | Tilapia (fresh) | 3.75 |
| *Oreochromis niloticus* | Tilapia (fillet) | 6.00 |
| *Plagioscion squamosissimus* | Pescada do piauí | 5.00 |
| *Prochilodus brevis* | Curimatã | 2.00 |

Exchange rate R$ 1.80 = US$ 1.00 (July 2010).

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curimatã, *Prochilodus brevis*, (Steindachner), and traíra, *Hoplias malabaricus* (Bloch), were important in the fisheries. The introduced species were pescada, *Plagioscion squamosissimus* (Heckel), tucunaré, *Cichla ocellaris* Bloch & Schneider, apaiari, *Astronotus ocellatus* (Agassiz), and the prawn, *Macrobrachium amazonicum* (Heller), in addition to *O. niloticus*. Introduced species other than *O. niloticus* contributed about 74% to the total fish catch before the introduction of the *O. niloticus*; after the tilapia introduction, about 96% of the fish catch consisted of introduced species.

Total catch from the reservoir was on average 6.44 t month$^{-1}$ (Fig. 1), excluding years 1990 and 1991, when a sudden rise in total and tilapia catches was registered. The total CPUE remained about the same over the three decades but greatly increased in 1990 and 1991 because of this sudden rise in tilapia CPUE (Fig. 2). ANOVA found a significant increase in total CPUE in the period from 1989 to 1994 (Fig. 2). This period exhibited the highest mean but also the greatest variance in total CPUE because of the great upsurge of tilapia catches in 1990 and 1991. The time series of the other fish species suggests that they were negatively affected after tilapia first appeared in the fisheries records (Fig. 2). On the other hand, prawn was apparently favoured after the tilapia introduction (Fig. 2). ANOVA confirmed a significant reduction in the CPUE of *P. squamosissimus*, *P. brevis* and *H. malabaricus* but a significant rise in prawn CPUE after the introduction of tilapia (Fig. 3). The CPUEs of *C. ocellaris* and *A. ocellatus* were not affected after the tilapia introduction (Fig. 3).

The mean number of fishers actively fishing in the reservoir each month has remained about the same over the three decades, but in 1979 and 1991, this number increased considerably (Fig. 4). However, no differences were found in the mean number of fishers among the five periods compared (Fig. 5). The per capita gross income has also remained about the same over the decades except for a considerable increase observed in 1990 and 1991 (Fig. 4). ANOVA found the per capita income was significantly higher in the period from 1989 to 1994 than in the other periods before or after the introduction of tilapias (Fig. 5). This sudden increase in the per capita gross income was caused by the sudden increase in tilapia and total catches in 1990 and 1991 (Fig. 1).

## Discussion

A significant reduction in the capture of *P. squamosissimus*, *P. brevis* and *H. malabaric* and a significant increase in prawn catches were found after the introduction of tilapia. The observed increase in the prawn catches was probably caused by the decrease in *P. squamosissimus* abundance because it mainly preys on prawns in these reservoirs (Lazzaro *et al.* 2003). Conversely, the reduction of the other fish species in the catches after the tilapia introduction might have been caused by tilapia alone and/or by other factors such as the impact of reservoir inundation, changes in fishers'

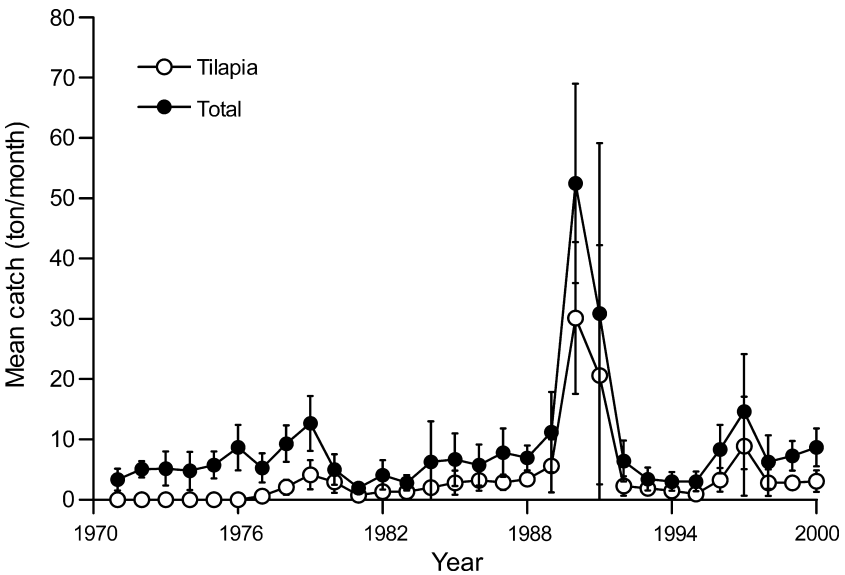


**Figure 1.** Mean (±1 SD) total and tilapia catch (t month$^{-1}$) in Gargalheiras reservoir from 1971 to 2000.

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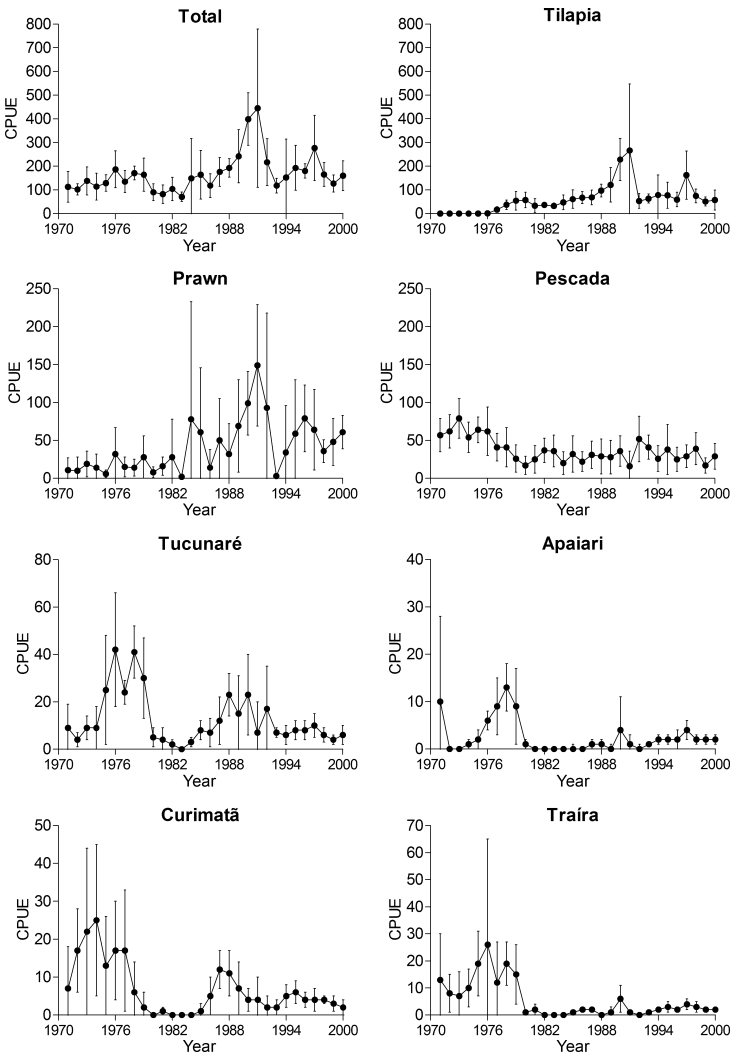


**Figure 2.** Mean (± 1 SD) catch-per-unit-of-effort (kg fishers$^{-1}$) per month in Gargalheiras reservoir from 1971 to 2000.

behaviour, reservoir eutrophication and introduction of other exotic species.

As the fisheries records started 12 years after the construction of the reservoir, it is unlikely the observed changes in the catches reflect an impact of the reservoir inundation. It is also unlikely that the observed changes reflect a change in the behaviour of fishers because the fishing methods employed have remained the same over the study period and is not selective for tilapia or against other species. However, it is possible that the change in the fish composition towards dominance by tilapias was a result of reservoir eutrophication during the study period. Unlike the other species, tilapias are able to filter feed on phytoplankton, which is an abundant food source in eutrophic waters such as Gargalheiras reservoir. However, the reservoir has been classified as eutrophic since the beginning of the 1960s (Okuda 1963), making it unlikely that the changes in fish community composition and abundance were caused by eutrophication alone. Finally, it is possible that the introduction of the other fish species before Nile tilapia accounted for the observed changes in the native species. However, these other non-natives (*P. squamosissimus*, *C. ocellaris* and *A. ocellatus*) were introduced to the reservoir during the 1960s and early 1970s, and CPUE of the two native species (*P. brevis* and *H. malabarica*) did not show any decreasing trend until tilapia started to appear in the catches.

Although other factors cannot be ruled out as possible explanations of the observed changes in the reservoir fisheries, there are reasons to believe that these changes may have been caused, at least partially, by the introduction of the Nile tilapia. Three mechanisms

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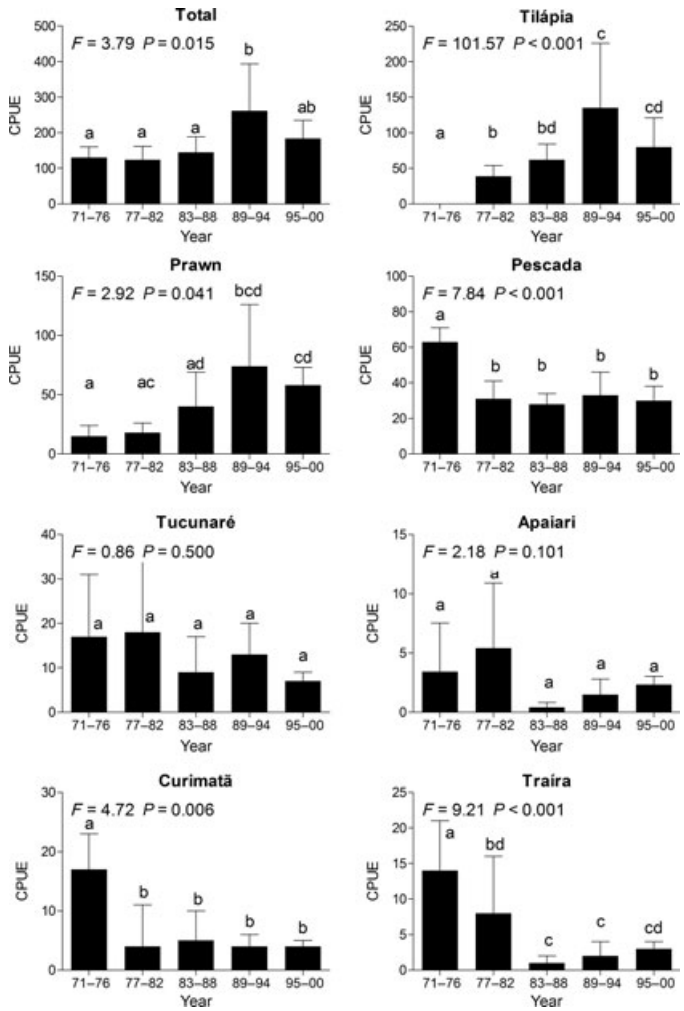


**Figure 3.** Mean (±1 SD) of the mean catch-per-unit-of-effort (kg fishers$^{-1}$) per month in Gargalheiras reservoir in the five periods: before (1971–1976) and after (1977–1982; 1983–1988; 1989–1994; 1995–2000) the establishment of Nile tilapia in the reservoir. Results of the one-way ANOVA on log-transformed data and *post hoc* tests based on confidence intervals of differences between pairs of means. Homogeneous groups are indicated by the same letter.

might account for the impact of Nile tilapia on other fish species: (1) competition for zooplankton with juveniles of other species; (2) fish-mediated changes in the water quality; and (3) competition for space and spawning places.

The fish species that have decreased in abundance after the introduction of the Nile tilapia belong to different trophic guilds. For example, *H. malabarica* is mainly a piscivorous fish, *P. squamosissimus* eats prawn, insects and fish, and *P. brevis* is a detritivore that also feeds on periphyton (Lazzaro *et al.* 2003). However, all these species feed on zooplankton in their juvenile stages and might compete with the Nile tilapia for zooplankton resources. Also, these species might have been negatively affected by changes in water quality mediated by tilapia through sediment bioturbation and nutrient excretion (Drenner *et al.* 1996; Starling *et al.* 2002; Lazzaro *et al.* 2003). Moreover, as tilapia defend territory and provide parental care for their offspring, it might have negatively affected other fish species through competition for spawning sites in the littoral zone, which is also the preferred spawning habitat of most fish species in the reservoir.

In addition to the Nile tilapia traits mentioned in the introduction, the great success of this species in establishing self-sustaining and growing populations in the reservoirs of north-east Brazil can also be attributed to the stocking efforts of DNOCS in the reservoirs. This effort towards increasing tilapia production is not only because of the acceptance of this species in the consumer market but also to the ease and efficiency in producing tilapia fingerlings hatcheries

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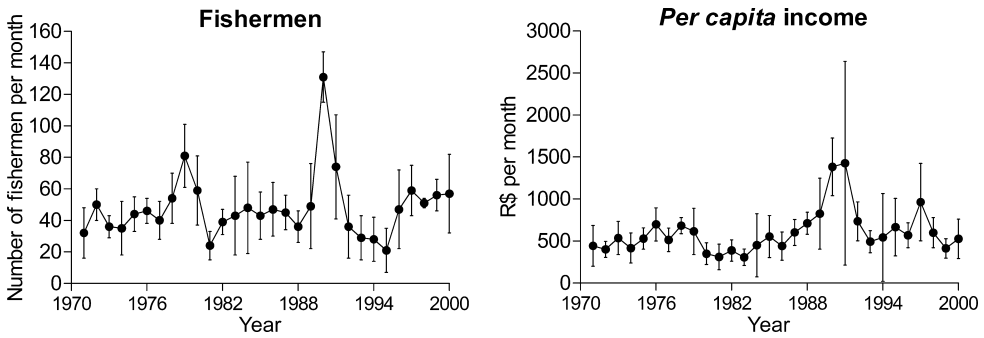


**Figure 4.** Mean (± 1 SD) number of fishers actively fishing per month in Gargalheiras reservoir and their per capita monthly income (R$) from 1971 to 2000.

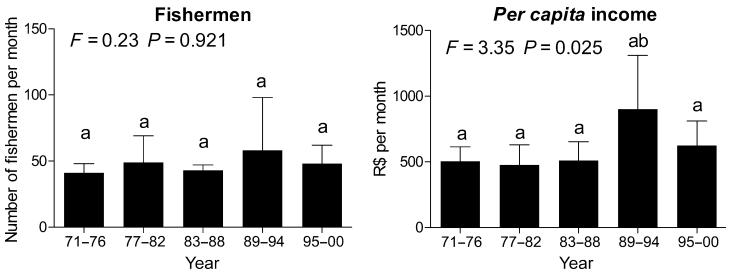


**Figure 5.** Mean (± 1 SD) of the mean number of fishers actively fishing in Gargalheiras reservoir and their per capita income per month in the five periods compared: before (1971–1976) and after (1977–1982; 1983–1988; 1989–1994; 1995–2000) the establishment of the Nile tilapia in the reservoir. Results of the one-way ANOVA on log-transformed data and *post hoc* tests based on confidence intervals of differences between pairs of means. Homogeneous groups are indicated by the same letter.

compared with other species. Nile tilapia represented 66% of the total number of fingerlings stocked in 336 public reservoirs in the region between 1997 and 2002 (Silva 2003). Therefore, the DNOCS stocking programme probably favoured Nile tilapia against the other fish species and might also explain the observed changes in the reservoir fisheries.

The results suggest that the introduction of the Nile tilapia did not bring socioeconomic benefits to the fishers of Gargalheiras reservoir. It did not increase the number of fishers or their gross per capita income, except in 1990 and 1991 when exceptionally high tilapia catches were recorded. Coincidentally, these were the 2 years of president Collor's government, a period of great political and economic instability that negatively affected DNOCs and fisheries monitoring in the reservoir. Therefore, it is possible that the great upsurge of tilapia catches was an artefact of poor monitoring during this period of institutional crisis.

However, it cannot be stated for certain that fishing in the Gargalheiras reservoir would have maintained the same production level or that the number of fishers would not have declined, were it not for the contribution of the tilapia. Moreover, the ANOVA results might have been biased towards accepting the null hypothesis because the current prices of the species were applied to estimate the value of catches and have not considered the value of tilapia and prawn sold as fillet. If they had been considered, the socioeconomic impacts of tilapia introduction may have been positive.

Current prices of the species were applied to estimate the values of catches each year in the data set assuming that the relative price has remained the same. This assumption is not justified if the demand for a given species increases as it become less abundant in the catches. It is not known how fish and prawn prices have changed over time but the native fish species that are now rare in the catches are those with lower current market values (Table 1). Therefore, although the abundances of certain species have decreased after the introduction of tilapia, it seems that the demand for these species has not increased making it unlikely that their relative prices have increased after the introduction of tilapias.

Although the catches of tilapia and prawn from Gargalheiras reservoir can be processed and sold as fillets to add value, they are most often sold fresh at

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this and other reservoirs in the region. Therefore, to attain a more representative assessment of the socioeconomic benefits of the fishing activity in the region, calculations of per capita income were made by taking into account only the price of fresh tilapia and prawn. However, the socioeconomic benefits attributed to the tilapia and prawn catches in Gargalheiras reservoir must be seen as somewhat higher than the ones presented because of the value added by tilapia and prawn sold as fillet.

Nile tilapia has been the fish species of greatest commercial importance in Gargalheiras reservoir because it substituted other fishes in the catches. However, the socioeconomic benefits used to justify the introduction of the Nile tilapia in the reservoir have been overestimated, while the environmental impacts of its introduction have been largely neglected. Although other factors cannot be ruled out as possible explanations of the observed changes in the reservoir fisheries, the results suggest that these changes may have been caused, at least partially, by the introduction of the Nile tilapia.

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