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Short communication

Fishing down Brazilian marine food webs, with emphasis on the east Brazil large marine ecosystem

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A B S T R A C T

An analysis of Brazilian marine fisheries catch data covering the years 1978–2000 is conducted with emphasis on testing for the occurrence of the 'fishing down the marine food web' phenomenon in the East Brazil Large Marine Ecosystem (LME). The results show that this phenomenon becomes apparent only after national data are disaggregated into smaller entities, as exemplified here for seven states of Northeastern Brazil (corresponding to the East Brazil LME). Once the disaggregation was performed, the decline of trophic level occurring through most of Northeastern Brazil was shown to occur at a rate of 0.16 trophic level per decade, one of the highest rates of trophic level decline documented in the world. Also, fishing 'through' the food web, proposed as an alternative to fishing down, did not occur. Overall, this indicates that the Marine Trophic Index (i.e., the mean trophic level of the catch) is indeed a robust indicator of biodiversity loss, as envisaged by the Convention of Biological Diversity, and that the marine biodiversity of the East Brazil LME is being eroded.

1. Introduction

Fisheries science has met a number of challenges since 1884, when Huxley suggested that marine stocks are essentially inexhaustible (Hall, 1999), the biggest two being that numerous important stocks have in fact collapsed, and the world fisheries catch is declining (Watson and Pauly, 2001; FAO, 2009). Different indicators of overexploitation have been proposed to track these events: $F > F_{MSY}$, $B < B_{MSY}$, percentage of immature specimens in the catch, and average length, for example (Mace, 2001; Rochet and Trenkel, 2003; Froese, 2004; Garcia and Grainger, 2005). One of these, based on the "fishing down" phenomenon first documented in Pauly et al. (1998), is the Marine Trophic Index (MTI), adopted in 2004 as one of eight indicators for "immediate testing" by the Convention of Biological Diversity (CBD, 2004; Pauly and Watson, 2005).

The MTI, i.e., the mean trophic level of the catch, has been shown to decline throughout the world (Pauly et al., 1998; Pauly and Watson, 2005), suggesting that large, high-trophic level fishes are being removed from the ecosystems faster than they can replenish themselves, leading to an (relative or absolute) increase of low-trophic levels (small fishes and invertebrates) in the ecosystems, and hence in the catches extracted from these (Pauly and Watson, 2005).

Although this phenomenon was shown to occur globally, for marine and freshwater systems (Pauly et al., 1998) and at smaller scale at various locations, e.g., the east and west coasts of Canada (Pauly et al., 2001), the Mediterranean (Pinnegar et al., 2003), the coast of Chile (Arancibia and Neira, 2005), Uruguay–Argentina (Jaureguizar and Milessi, 2008), the Gulf of Thailand (Christensen, 1998), or India (Bhathal and Pauly, 2008), this was challenged by Essington et al. (2006). These authors suggested, instead, that in most ecosystems, the decline in MTI was due to adding to a sustained catch of high-trophic level species catches of low-trophic level species, a process far more benign, which they dubbed "Fishing through the food web". However, note that for 'fishing through' the food web to occur, catches must be increasing, which is not the case on a global basis (FAO, 2009). Whether 'fishing through' occur at local scales can be decided only by local studies, as will be presented below.

In Brazil, the signals of depletion have been very clear for some stocks, notably sardine (*Sardinella brasiliensis*), a low-trophic level species, which represents the most severe case of collapse. Overall, Brazil's catches declined from about 230 000 tonnes in 1973 to 33 000 tonnes in 1990 (Paiva, 1997). In Northeastern Brazil, snapper and lobster fisheries have been overexploited (Paiva, 1997), and recovering plans for lobsters have been put in place. The objective

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Table 1
Structure of the ACCESS database of landing statistics originating from Brazilian marine fisheries.

Variable	Description
1. Year	1978–2000
2. State	Amapá, Pará, Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Espírito Santo, Rio de Janeiro, São Paulo, Paraná, Santa Catarina, and Rio Grande do Sul
3. Fishery	Artisanal or industrial
4. Species	By common name
5. Landings	Tonnes
6. Source	All sources are listed in Table 2

of this study is to describe the general pattern of fisheries resources use in Brazil, with emphasis in the East Brazil Large Marine Ecosystem, and in the process, demonstrate the occurrence of the 'fishing down' in an area from which it had not been reported before.

2. Materials and methods

Annual landing data from Brazilian commercial marine fisheries were compiled and encoded in Microsoft Access for the period 1978–2000 by State, by fishery type (artisanal and industrial), and by species or group of species (Tables 1 and 2). After encoding the database (called CATCHDAT hereafter), the correspondence between the common names presented in the original source and the scientific name was established, using the decision diagram illustrated in Fig. 1. Also, a database of common and scientific names (I in Fig. 1) was created which includes molluscs, crustaceans, fishes, turtles, and whales. The database of fish names (II in Fig. 1) includes 4172 common names associated with 725 species of marine and estuarine species, and represents an extension of the database presented in Freire and Pauly (2003). After applying the process illustrated in Fig. 1, only seven species associated with small catches remained unidentified, i.e., 'ubaroba' and 'miracú' (State of Rio de Janeiro), 'papa fina' and 'papuda' (Bahia), 'sagra' (Paraná), and 'tapa pomba' (Santa Catarina).

The trophic level of the species i (TL_i) was defined by

$$TL_i = 1 + \sum_{j=1}^{n} DC_{ij} TL_j \tag{1}$$

where DC_{ij} represents its diet composition, j is the prey, and TL_j is its trophic level. Estimates of TL_i were based on information on the diet of each species, as compiled in Freire et al. (2008), complemented with data from FishBase (http://www.fishbase.org/) and Opitz (1996).

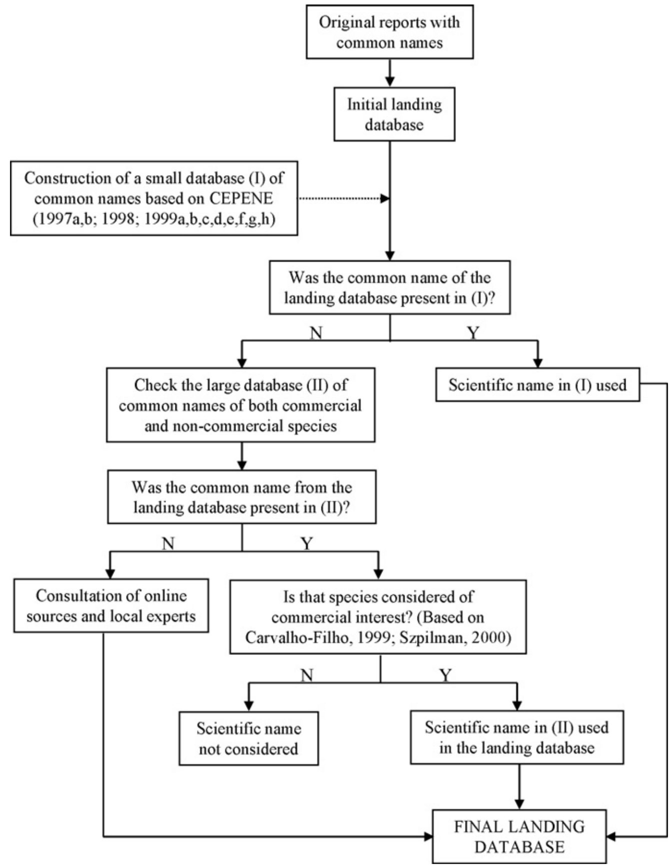

Fig. 1. Decision diagram on the correspondence between common and scientific names for commercial species to obtain the final landing database. The database of common names (II) is available in FishBase (http://www.fishbase.org/) (from Freire, 2003). N = No; Y = Yes.

The mean trophic level ($\overline{TL}$) of the catches was then estimated from:

$$\overline{TL}_k = \frac{\sum_{i=1}^{m} Y_{ik} TL_i}{\sum_{i=1}^{m} Y_{ik}} \tag{2}$$

where Y_{ik} are landings of species i in year k, and m is the number of species or group of species caught in year k (Pauly et al., 2001). Note that categories such as 'outros peixes', 'caíco' and 'mistura', all representing unidentified fishes, were not included in this analysis due to the impossibility of assigning them a precise trophic level.

A Fishing-in-Balance (FiB) index (Pauly et al., 2000) was calculated in order to assess if changes in the mean trophic level were compensated by changes in catches:

$$FiB_k = \log\left(Y_k \left(\frac{1}{TE}\right)^{TL_k}\right) - \log\left(Y_0 \left(\frac{1}{TE}\right)^{TL_0}\right) \tag{3}$$

Table 2
Sources used to compile landing statistics from Brazilian marine fisheries.

Period	Frequency	Format	Sources
1978–1979	Annual	Paper	SUDEPE (1980–1981)
1980	Annual	Paper	IBGE (1980–1989b)
1981–1989	Semi-annual	Paper	IBGE (1980–1989b)
1990–1997	Annual	Paper	CEPENE (1991–1998)
1998	Annual	Electronic	IBAMA (G.C. dos Santos, Pers. comm.)
1999	Annual	Paper	CEPENE, 2000a
2000	Annual	Electronic	IBAMA (S. Bezerra, Pers. comm.)

Table 3
Contributions demonstrating the occurrence of 'fishing down marine food webs' using spatially disaggregated datasets, following the original presentation of this phenomenon by Pauly et al. (1998) based on the global FAO landings dataset.

Country/area	Period	TL/decade	Source and remarks
Gulf of Thailand	1965–1997	0.05–0.09	Christensen (1998); Pauly and Chuenpagdee (2003)
Cuban EEZ	1960–1995	0.10	Baisre (2000), based on reliable national statistics
Eastern Canada	1950–1997	0.10	Pauly et al. (2001), based on data submitted to FAO by Fisheries and Oceans Canada (DFO)
Western Canada	1910–1996	0.03	Pauly et al. (2001), based on comprehensive dataset assembled by Wallace (1999)
Celtic Sea	1946–1998	0.02	Recalculated from Pinnegar et al. (2002), based on trophic levels estimated from stable isotopes of nitrogen
Chinese EEZ	1970–1998	0.20	Pang and Pauly (2001); note that Chinese catch reports to FAO are very unreliable
Iceland	1918–1999	0.06	Valtysson and Pauly (2003), based on comprehensive catch database of Valtysson (2001)
East Coast, USA	1950–2000	0.04	Chuenpagdee et al. (2006), based on data supplied to FAO by NOAA, USA
Chesapeake Bay, USA	1950–2000	0.04	Chuenpagdee et al. (2006), based on NMFS landing data (http://www.st.nmfs.noaa.gov/st1/index.html)
World, all fishes	1950–2000	0.01–0.12	Pauly and Watson (2005), based on spatial disaggregation of landing data supplied to FAO by the world's maritime countries
Northern Gulf of Mexico	1950–2000	0.02	Pauly and Palomares (2005), based on FAO data (Area 41), disaggregated into USA (North) and other countries (South)
West Central Atlantic	1950–2000	0.07	Pauly and Palomares (2005), based on FAO data (Area 41), disaggregated into USA (North) and other countries (South)
Indian States and Union Territories	1950–2000	0.01–0.08	Bhathal and Pauly (2008), based on Bhathal (2005), and pertaining to all Indian States (6) and Union Territories (4)
State of Piauí	1978–2000	0.17	This study
State of Paraíba	1978–2000	0.10	This study
State of Pernambuco	1978–2000	0.16	This study
State of Alagoas	1978–2000	0.16	This study
State of Sergipe	1978–2000	0.16	This study

where k refers to year, 0 = baseline year (1978), Y = catch, TL = mean trophic level in the catch, and TE = transfer efficiency between trophic levels = 0.1, the value of TE being a mean value derived from 48 ecosystem models (based on Pauly and Christensen, 1995).

3. Results and discussion

The MTI of all Brazilian landings originating from marine waters exhibits an upward trend for the period 1978–2000 (Fig. 2a), probably due to (i) the collapse of the Brazilian sardine, a low-trophic level species, and (ii) an increase in the contribution of offshore tuna, i.e., fishes not originating from the neritic (shelf) system from where the other catches originate, but rather from the central Atlantic as in the case of yellowfin and bigeye tunas. However, the same trend was observed when large pelagics were eliminated from the analysis (Fig. 2a). This analysis combines landings from large marine ecosystems (LMEs) as diverse as North, East, and South Brazil, the last strongly affected by the collapse of the Brazilian sardine.

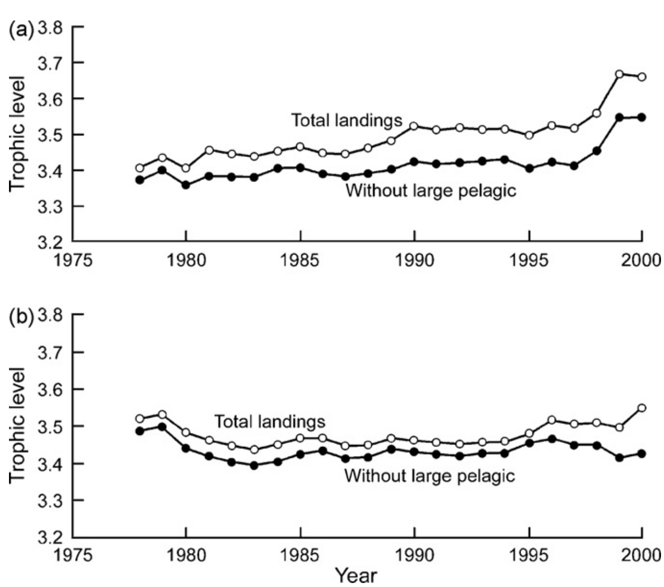

Fig. 2. Mean trophic level of landings for Brazil (a) and Northeastern Brazil (b) for the period 1978–2000. Both total landings and landings excluding large pelagic species are presented.

Landings originating from Northeastern Brazil only (East Brazil LME) showed a steady MTI over most of the period from 1978 to 2000, with an slight upward trend in the last years. However, there was a slight downward trend in the same last years when large pelagics were excluded (Fig. 2b). As occurred in Pauly and Palomares (2005), the downward trend in MTI became stronger when the analysis was performed at a finer spatial scale, here that of States. Fishing down the food web was detected in landings originating from five out of the seven States for which landing data was properly collected using the ESTATPESCA program (Fig. 3). A finer scale is more suitable to analyze changes in the East Brazil LME, as this LME is quite extensive and influenced by different currents in its northern and southern portions (South Equatorial, North Brazil, and Brazil currents). Besides, there are different features throughout the LME such as oceanic banks to the north, and coral reefs in the middle and south areas (Spalding et al., 2001; Haimovici, 2007). Finally, artisanal fisheries are dominant in this area (Paiva, 1997) and are more prone to differently affect (and being affected by) areas with such diverse characteristics due to their limited fishing power.

Compared with values of 0.05–0.10 per decade for most other ecosystems so far studied (see e.g., Bhathal and Pauly, 2008; Table 3), the MTI decline identified here, with value of about 0.16 trophic levels per decade (except for Paraíba State,

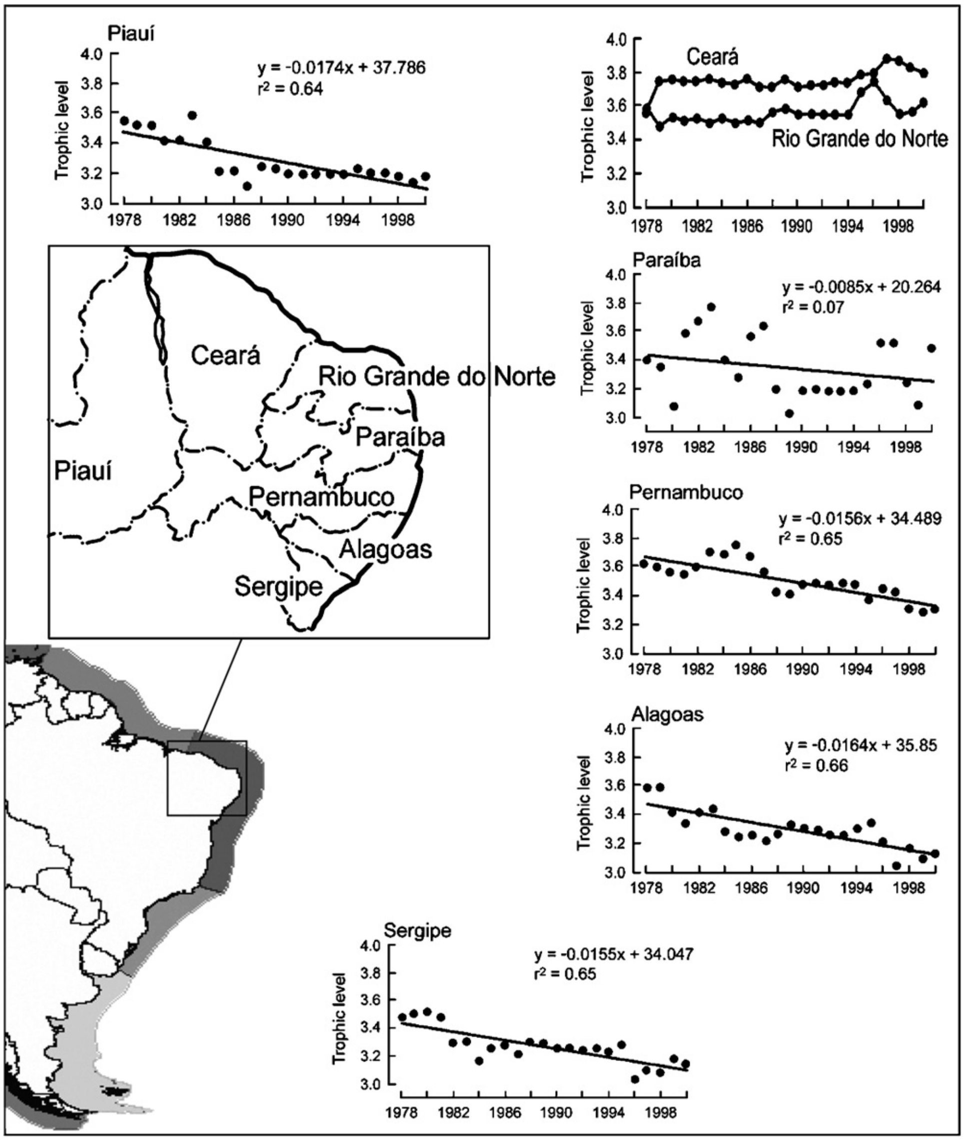

Fig. 3. Changes in mean trophic level for landings from Northeastern Brazil in 1978–2000. PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco, AL = Alagoas, and SE = Sergipe. The States of Maranhão and Bahia are not shown due to the lack of a proper system of data collection. Large Marine Ecosystem 16 (East Brazil) is shown in dark gray.

which had a lower rate) is in fact one of the strongest so far reported.

The decreasing trend in mean trophic level was not compensated by increasing catches for most States. Compensation would have justified a deliberate choice of moving down the food web, towards the more productive, lower components of the trophic web. But this did not occur and, in fact, the FiB index declined during the period analyzed here (Fig. 4).

Only Ceará and Rio Grande do Norte States had steady MTI throughout the period (Fig. 3). These areas had similar catches (Fig. 5) and may have been affected by the high mobility of the industrial fleet from Ceará, which operates in the coast of other states, mainly Rio Grande do Norte (CEPENE, 2000b). Thus, landings originating from other States would mask any trends in the local ecosystem. Finally, the future inclusion of categories such as 'outros peixes', 'caíco', and 'mistura', all representing 'other fishes', may change the results of this analysis, as they reach high proportions in some States (up to 15% of total catch), particularly in the beginning and in the end of the period studied (Fig. 6). However, at this stage, there is no detailed information that allows us to include these categories.

Overall, this analysis confirms Pauly and Palomares (2005) observation that spatial overaggregation can mask the 'fishing down' effect. Thus analysis conducted at national level (at least for large countries such as Brazil) will fail to detect fishing down, as was the case with the study of Vasconcellos and Gasalla (2001), and as shown in Fig. 2a. On the other hand, catch data disaggregated by State, as done here (and in Bhathal and Pauly, 2008), show fishing down to be very strong. Moreover, landings failed to increase during the study period, i.e., the decline of MTI of the States of Northeastern Brazil States was not due to an absolute increase in catches of low-trophic level species. Hence, we have in this region, as we had in India (Bhathal and Pauly, 2008), a clear case of fishing *down* the food web, and not *through* it. This suggests that the distinction of Essington et al. (2006) lacks generality.

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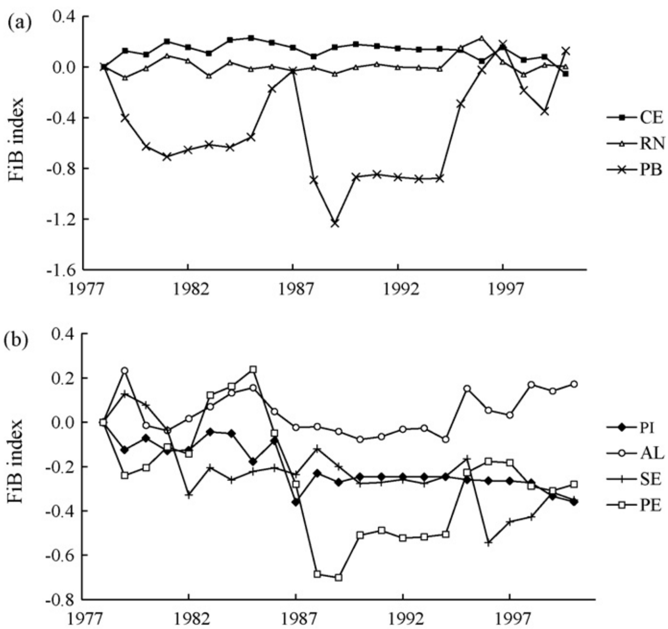

Fig. 4. Fishing-in-balance (FiB) index for Northeastern Brazil during 1978–2000. (a) CE = Ceará, RN = Rio Grande do Norte, and PB = Paraíba; (b) PI = Piauí, AL = Alagoas, SE = Sergipe, and PE = Pernambuco.

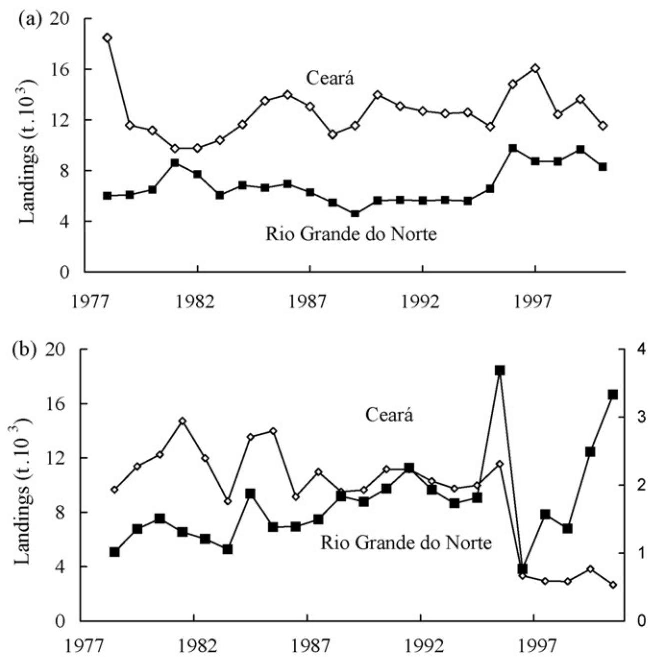

Fig. 5. Landings originating with marine fisheries off the States of Ceará (left axis) and Rio Grande do Norte (right axis): (a) artisanal and (b) industrial (1978–2000).

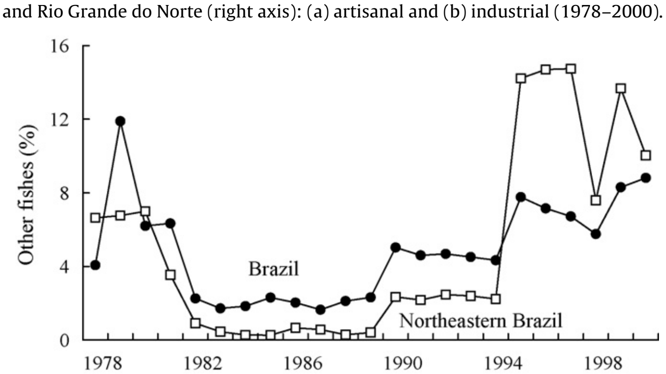

Fig. 6. Proportion of other fishes in relation to total landings in Brazil and Northeastern Brazil.

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