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Fishers' knowledge indicates short-term temporal changes in the amount and composition of catches in the southwestern Atlantic

Evelyn G. Lima [a], Alpina Begossi [b,c], Gustavo Hallwass [b,d], Renato A.M. Silvano [a,b,*]

[a] Federal University of Rio Grande do Sul, Dept. of Ecology, Porto Alegre, RS, Brazil
[b] FIFO – Fisheries and Food Institute, ECOMAR/UNISANTA, Santos, SP, Brazil
[c] CAPESCA/NEPA, UNICAMP, Rua Albert Einstein 291, Campinas 13083-852, Brazil
[d] State University of Santa Cruz, Dept. of Zoology, Ilhéus, BA, Brazil

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ABSTRACT

The scarcity of data on fish catches difficult management of small-scale fisheries in developing countries. This study applies fishers' knowledge to investigate temporal changes in the amount (biomass) and composition (major ecological categories) of fishing resources exploited by small-scale coastal fisheries in the southeastern Brazilian coast. Four hypotheses were investigated: (1) The amount of fish caught reported by fishers would decrease over time. (2) Older fishers would report higher fish catches than younger fishers. (3) Recent interviews would mention large-sized predators less often. (4) Recent interviews would mention less high valued fishing resources. Interviews with 421 fishers in 36 communities in the southeastern Brazilian coast were analyzed, covering a time span of 14 years, from 1995 to 2009. The hypothesis 1 was confirmed, 3 was partially confirmed, while 2 and 4 were not confirmed. Fishers' age was unrelated to all variables. The results from fishers' interviews indicated the temporal trends of: (1) a decrease in the biomass of fish caught; (2) an increase in the occurrence of smaller fish and invertebrates in the catch; (3) an increase of high value fishing resources; and (4) maintenance of large predators. The first two indicators suggest excessive fishing, but the later indicators (3 and 4) suggest that the socioecological system of the southeastern Brazilian coast had not yet undergone major ecological shifts.

1. Introduction

Coastal fisheries worldwide have shown declining catches, stock collapses and increasing fishing effort, which claim for scientific assessments of trends in catches to support effective management measures aiming to revert overexploitation [2,56]. Besides negative social and economic consequences, excessive fishing pressure has caused ecological regime shifts in coastal ecosystems, due to severe declines in populations of marine organisms that perform important ecological functions, such as large predators, large herbivores and even small pelagic fish [16,17,26,27,62]. Overfishing may cause a decline in the overall trophic level of coastal ecosystems, thus simplifying food chains, according to the concept of fishing down the food web [55]. This pattern has been challenged by recent studies, according to which overfishing would progressively reduce the abundance of those species with the highest market value, thus shifting the economic revenues from fishing, irrespective of trophic level [63].

Small-scale tropical fisheries are socio-ecological systems, on which healthy coastal ecosystems are required to guarantee food security [13,19]. These small-scale fisheries are particularly challenging to manage in developing countries, due to their heterogeneity (multi-species and distinct fishing gears), widespread landing sites and scarcity of data on fish catches and fishing effort [7,23,47]. Furthermore, conventional top-down management approaches, such as gear restrictions or marine protected areas, have not been always adequate to small-scale fisheries, generating conflicts and lack of compliance by fishers [44,45,58]. These two major problems of scarcity (or lack) of data on fish landings and management strategies poorly designed to local fishing dynamics could be circumvented by the data-less management approach [38]. This approach consists in using any available information on local fishing dynamics (fish catches, fish biology, management options, fishing grounds), including fishers' local ecological knowledge [40,64], besides scattered data on fish ecology or fish catch and effort [6,38] to propose management strategies. Recent studies have successfully applied fishers' knowledge to investigate temporal trends in abundance of fishing resources and changes in ecological conditions in a range of freshwater and coastal

* Correspondence to: Dept. Ecologia and PPG Ecologia UFRGS, CP 15007, 91501-970 Porto Alegre, RS, Brazil.
E-mail address: renato.silvano@ufrgs.br (R.A.M. Silvano).

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ecosystems [18,22,35,39,61]. Nevertheless, most of these studies address particular fish species more susceptible to fishing pressure, such as reef fish or sharks [31,59], while fewer studies investigate temporal changes in the amount and composition of fish catches by comparing distinct data-bases, such as governmental landing statistics and fishers' knowledge [21]. Information on temporal trends in fish catches are required to support management interventions and policy measures better suited to the needs and concerns of Brazilian small-scale coastal fishers [6,7]. In Brazil, previous studies analyzed fishers' knowledge to reconstruct temporal changes in abundance of some target fish species in the tropical northeastern coast [18,21,31], but fewer studies have addressed changes in fish abundances in the more populated and potentially more heavily impacted southeastern coast [42]. Moreover, studies usually concentrate in particular fishing communities and few studies analyze a large amount of interviews with fishers from a broad geographic area [10].

This study aims to apply fishers' knowledge to investigate temporal changes in the amount (biomass) and composition (major ecological categories) of fishing resources exploited by small-scale coastal fisheries in a large geographical area in the southeastern Brazilian coast. Data from interviews with fishers were analyzed to address two main questions. Is the amount of fish caught related with time of the interview or with the age of interviewed fishers? Is the composition of fish caught (number of species and frequency of citations) related with time of the interview or age of interviewed fishers? The observed trend in the abundance of catches reported by fishers was compared with fish landings from official governmental statistics in the same region and studied period. Based on available evidence on temporal trends in coastal fisheries, four hypotheses were investigated: (1) The amount of fish caught reported would decrease over time with less fish caught reported by fishers in recent years. (2) Older fishers would report higher fish catches than younger fishers. (3) Composition of fish landings differ over time: recent interviews would mention less large-sized predators compared with older interviews. (4) Recent interviews would mention less high valued fishing resources compared with older interviews.

2. Material and methods

2.1. Study site

This study was based on data from fishers' interviews conducted in 36 fishing communities in the southeastern Brazilian coast, from the North of São Paulo state to the South of Rio de Janeiro state (Fig. 1). These fishing communities are distributed in four major regions, from North to South (Fig. 1): (1) Angra dos Reis and Ilha Grande Bays (n=17 communities), (2) Paraty Bay (n=11); (3) Ilha Bela (n=4); (4) São Paulo northern coast, including the cities of Ubatuba and Bertioga (n=4). These regions were arbitrarily defined according to the proximity among communities, similar fishing dynamics (gear used, market orientation, tourism influence) and habitat features, such as the presence of bays, estuaries and islands [4,13,46].

2.2. Fishing communities

The studied coastal fishers living along the southeastern Brazilian coast belong to the caiçara cultural group, who descend from indigenous people and Portuguese and practice small-scale agriculture and fishing [3,7]. These artisanal fishers use small to medium sized boats, paddled canoes and various kinds of fishing gear, including gillnets, hand lines and trawling, to catch pelagic and reef fishes, shrimp and squid [3–5,13,42]. More recently, some caiçara fishers have increasingly dedicated to tourism related activities to supplement their income [4,46]. The studied caiçara fishing communities are located along some of the last remnants of the threatened Atlantic Forest ecosystem in southern Brazil, which had caused conflicts between resident fishers and governmental authorities who establish conservation units that restrict traditional agriculture and fishing activities [3–5]. Recently enforced marine protected areas (MPAs) and intense large scale fishing in coastal areas have also raised conflicts with small-scale fishers in the southeastern Brazilian coast [11,12,44,45].

2.3. Interviews with fishers

Data were gathered from standardized interviews with 421 caiçara fishers made during several independent research projects along 14 years, from 1995 to 2009. These interviews are stored in the archives of the non-governmental organization (NGO) Fisheries and Food Institute (FIFO, http://www.fisheriesandfood.org). The fishing communities included in the studies and the interviewed fishers were selected by following defined criteria, such as dedication to fishing as the main economic activity, being older than 18 years age, living in the community for at least 10 years. The researchers interviewed fishers individually through a standardized and structured questionnaire. Although the content of questionnaires differ among studies, these usually addressed issues related to socioeconomic characteristics (age, scholar level, jobs, income), fishing behavior (fishing grounds, gear used) and fishing resources exploited (main species caught, amount of catches). More details on sampling procedures and topics addressed in interviews can be found in the resulting publications of these

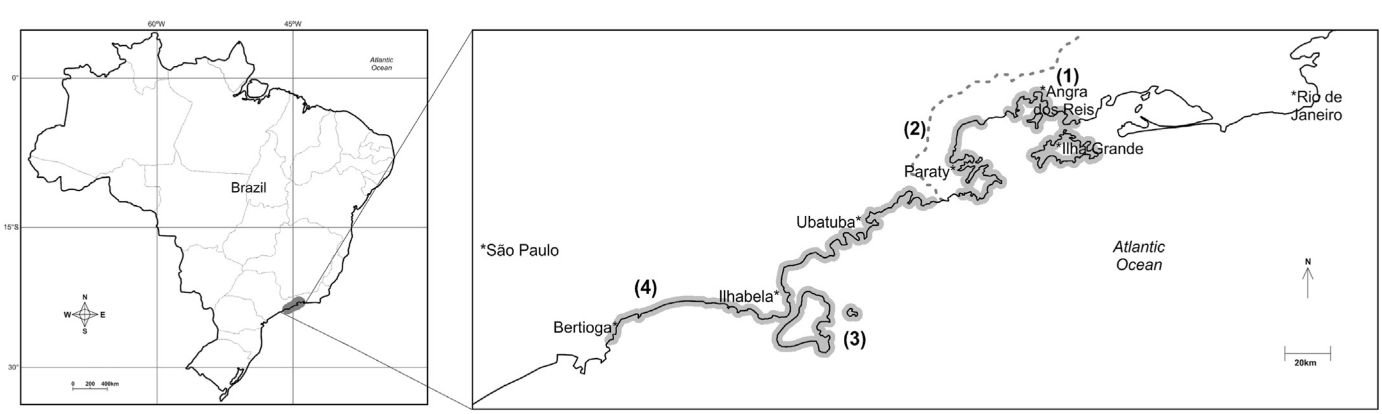

Fig. 1. Location of the studied region in the southeastern Brazilian coast, indicating the four regions: (1) Angra dos Reis and Ilha Grande Bays, (2) Paraty Bay, (3) Ilha Bela, (4) São Paulo northern coast.

research projects [3,4,11,12,13,42,44–46]. This approach has constraints in the sampling design, which mix distinct regions, communities and time periods. Nevertheless, a previous study successfully applied a similar approach of analyzing scattered information from more than 1000 interviews with Brazilian coastal and freshwater fishers to investigate broad scale patterns on preferences and avoidances of fish [10].

2.4. Data analyses

For the purposes of this study, the following information from each interview (fisher's citations) was selected and analyzed: biomass of fishing resources caught during the last fishing trip made by the interviewee, time when this last fishing trip occurred, fishers' age, fishing community and region where the interview was made. The time reported by each interviewee for the last fishing trip was converted in days passed January 1st 2010, which was considered as a starting point, thus providing a quantitative continuous variable for analysis. Nevertheless, because all interviewees were active fishers at the time when interviews were made, fishers interviewed in similar years (or in the same year) reported similar periods of time passed since the last fishing trip, generating clumped data around the years when research projects were made (Fig. 2). The reported biomass of fish caught had many small or zero catches (Fig. 2). Therefore, the continuous variables of 'days since reported fishing' and biomass of fish caught did not show normal distribution and could not be used in parametric statistical tests.

Separate non-parametrical Spearman correlation analyses (rs) were made between the dependent variable biomass of fish and two independent variables: days since reported fishing and fishers' age, to check the hypotheses 1 and 2.

Published data on fish catches of coastal fisheries in the São Paulo state, which includes part of the studied region (Fig. 1) have been collected and organized by a governmental fisheries institute [37]. These official statistics are organized by month, so data were analyzed only from the same period studied (1995–2009), converted to days passed January 1st 2010 by assigning 30 days for each month before 2010. The dependent variable biomass of fish caught and the independent variable days passed 2010 were then compared through a Spearman correlation analysis.

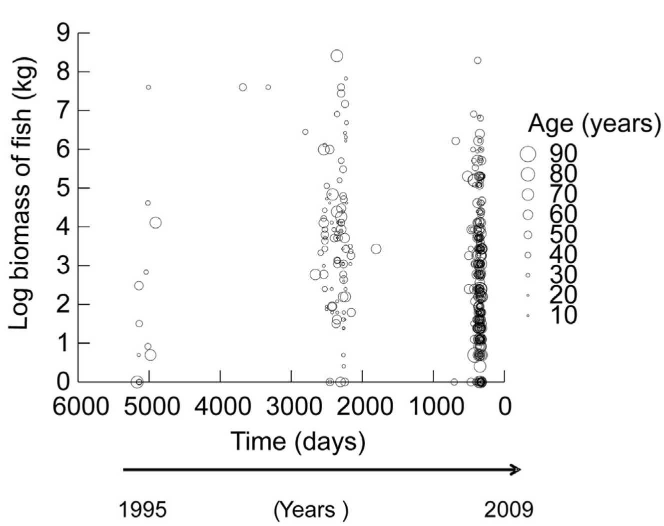

Fig. 2. Relationship between days since reported fishing (as from January 1st 2010, showed as 0 in the x axis) and biomass of fish caught reported by 421 fishers interviewed in 36 fishing communities in the southeastern Brazilian coast. Size of symbols indicates the age of each interviewed fisher. The scale of the x axis was reversed to better show the passage of time from older to more recent reported fishing.

Fishers' interview data were grouped at the level of fishing communities (n=36), to be able to use parametrical statistical analyses and to check for general patterns beyond individual variations in catches. These analyses also tested hypotheses 1 and 2, considering in this case the continuous variables of average biomass of fish caught reported by the interviewed fishers of each community (dependent) and average age (independent). Region was added as an independent categorical variable in this analysis, as some communities would be located closer to each other and may share the same overall ecological characteristics, for example by being situated in an island or in a bay. In these analyses that grouped data by fishing communities, the continuous variable 'days since reported fishing' failed to show a normal distribution even after data transformation. These data were then converted in a categorical variable indicating time since reported fishing with two levels: recent (<5 years ago from 2010) and old (>5 years ago). Although arbitrarily defined, these categories properly reflected the distribution of most reported fish landings before and after 1800 days (5 years) since 2010 (Fig. 2). General Linear Models (GLMs) were made considering the dependent variable as reported average biomass of fish caught (log transformed) and combinations of three independent variables: average fishers' age, region and time since reported fishing. Values of Akaike Information Criteria (AICC) and weight for each model were calculated, to check those models that better explained the variation in the reported biomass (lower values of AICC). The parametric and non-parametric analyses were made using the R software.

Not all the 421 interviewed fishers mentioned the composition of fish catches and information on composition of catches was usually elicited during the same interview, but through distinct questions. A subset of 396 interviews with fishers who mentioned information about the fishing resources exploited were selected to analysis of catch composition. The interviewed fishers provided information on catch composition when answering questions about the last fishing trip (the same question analyzed for biomass caught), fish regularly caught, preferred fish or most consumed fish. Unfortunately, the amount (number of individuals or biomass) caught for each mentioned fishing resource could not be calculated. Two dependent variables were adopted to test the hypotheses 3 and related with catch composition: presence/absence of each fishing resource reported in each interview and the number of species (common names) of fishing resources reported. The independent variables were days since reported fishing and fishers' age.

The 396 interviewed fishers reported 108 fishing resources identified by distinct common names, of which 99 could be identified at the levels of biological species or genus. Identifications followed publications about Brazilian coastal fishes used by fishers [8,14,15,57,65] and the experience of some of the authors (AB and RAMS). The few non-identified fishing resources (n=8) were excluded from analyses, as these were cited by only one interviewee (0.3% of total) and are possible unusual catches, peculiar names or mistakes. To test the hypothesis on ecological changes in the catch (3), each fishing resource was assigned to one of eight ecological categories (number of common names cited for each): (1) invertebrates (small to medium size, n=9), (2) Reef herbivores (medium size, n=1), (3) Demersal herbivores (medium size, n=4), (4) Reef generalists (omnivorous and invertebrate feeders of small to medium size, n=12), (5) Demersal generalists (omnivorous and invertebrate feeders of small to medium size, n=16), (6) Pelagic generalists (omnivorous and invertebrate feeders of small to medium size, n=21), (7) Reef predators (piscivorous with large sizes, n=8), (8) Pelagic predators (piscivorous with large sizes, n=28). Medium size is considered as up to 30 cm total length and large size above this value, for adult fish. Fishing resources were also sorted in three economic categories, considering their market value: (1) high (n=23 common names), (2) average (n=49), (3) low (n=27). These ecological and economic categories were defined on the basis of authors' knowledge of coastal fish in the studied region. Logistic regression analyses were made using as dependent variables the presence or absence of each ecological category and each economic category of fishing resource cited in interviews and as independent variables days since reported fishing and fishers' age. The relative frequency of each of these ecological and economic categories between recent (less than 5 years) and old (more than 5 years) interviews were also visually compared.

The eight ecological categories were further grouped in four broader categories (invertebrates, herbivores, generalists, predators) to analyze the number of common names (as an indicator of number of species) cited in each of these categories. This was necessary because some categories had few species (for example, reef herbivores). Spearman correlation analyses were made comparing the number of species from each ecological category and from the three economic categories (high, average, low) and days since reported fishing and fishers' age.

3. Results

3.1. Temporal changes in the biomass of fish caught

Considering data from individual interviews (n=421), the biomass of fish caught was positively correlated with time passed since the last fishing (rs=0.24, n=421, $p<0.001$). Although this result confirmed the hypothesis 1 of decreased catches over time, this correlation was weak (coefficient of 0.24 that explains only 24% of variation in biomass) with large variation among interviews regarding the reported biomass (Fig. 2). Contrarily to the hypothesis 2 a weak (low value of rs) and inverse relationship occurred between fishers' age and biomass of fish caught (rs=−0.16, n=421, $p<0.01$): older fishers tend to report lower catches (Fig. 2). Furthermore, the two independent variables were inversely related: fishers reporting recent catches were older than fishers interviewed long time ago (rs=−0.2; n=421, $p<0.001$, Fig. 2).

Data grouped at community level (n=36), showed an unavoidable interaction between time (more and less than 5 years ago) and region, because some regions had only old interviews (more than 5 years ago) (Fig. 3). Nevertheless, the best six models

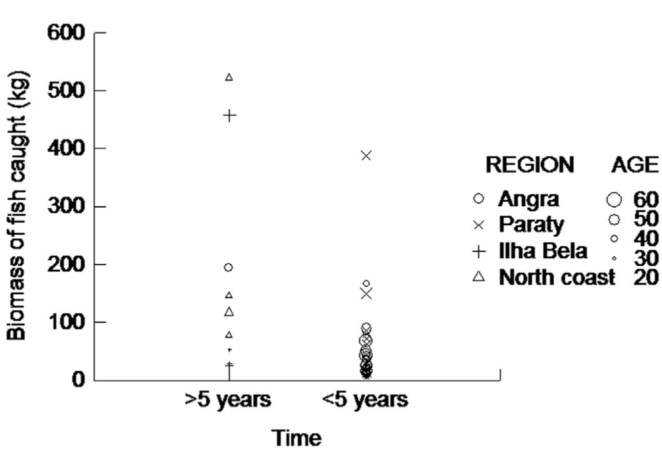

Fig. 3. Biomass of fish caught reported by interviewed fishers before and after 5 years of reported fishing in four regions in the southeastern Brazilian coast (symbols), considering data grouped for fishing communities (n=36), indicating also the average age of interviewed fishers (size of symbols). Angra (n=17 communities), Paraty Bay (n=11), Ilha Bela (n=4), North coast of São Paulo (n=4).

Table 1.
The best six Generalized Linear Models considering fishing communities (n=36) as replicates and biomass of fish caught (log transformed) reported by fishers as dependent variable, for interviews with fishers in the Brazilian southeastern coast. All these models showed AICC values lower than the average AICC (111.5) for all the possible 25 models considering all combinations of the three independent variables (time passed since last fishing, fishers' age and region). Significance of independent variables: * > 0.05; ** > 0.01; *** > 0.001.

Model	Independent variables	AICC	Weight	Adjusted r^2
1	age+time X age **	104.2	0.30	0.22
2	time **	104.8	0.21	0.18
3	time **+age	105.5	0.15	0.20
4	time+age+time X age	106.0	0.12	0.22
5	time+region	108.8	0.03	0.20
6	time+region+region X time	108.8	0.03	0.20

(lower AICC values) out of 25 GLM models included time as a significant explanatory variable (Table 1), indicating that time had a higher relative influence than region on the average reported biomass of fish caught, which was higher for those communities studied more than 5 years ago (Fig. 3). The biomass of fish caught differed also among regions (Table 1), being higher in Ilha Bela and North coast of São Paulo (Fig. 3). There was also an influence of the average age of the interviewees in the biomass of fish caught (Table 1) with interaction between age and time: usually age was higher (older fishers) in communities studied more recently (less than 5 years, Fig. 3).

The average biomass of fish caught was positively related with number of interviewed fishers for those communities interviewed less than five years ago ($r^2=0.18$, df=25, $p<0.05$), while biomass and number of interviewees were not significantly related for communities interviewed longer than five years ago ($r^2=0.38$, df=7, p=0.08). Nevertheless, the mean number of interviewed fishers did not differ (t=−0.5, df=34, p=0.6) between communities interviewed less than five years ago (n=27, mean=11.4, SD ±4.4) and longer than five years ago (n=9, mean=12.4, SD ±6.8). Therefore, differences in sample size should not influence the aimed temporal comparison of biomass of fish caught.

According to the monthly official statistics of fish landings of the São Paulo state coast [37] the total biomass of fish lands was not related with time passed since 2010 (rs=0.07, n=156, p=0.4) and there was no trend of decreasing catches over time (Fig. 4).

3.2. Temporal changes in the composition of the catch

The hypothesis 3 regarding ecological changes in catches over time was only partially confirmed. The logistic regressions indicated that the probability occurrence of invertebrates, reef generalists and reef predators increased in more recent catches, while the others were unrelated with time measured as days since reported fishing (Table 2). Fishers' age was unrelated to the presence of any of the ecological categories (Table 2). The proportion of interviewed fishers (n=396) who mentioned the major ecological categories of fish caught were similar between interviews from before and after 5 years, except for invertebrates, reef generalists and reef predators that showed higher proportions in more recent interviews (Fig. 5). Occasions when no fish were caught (zero catches) were relatively rare, being mentioned by only 29 fishers (7.3% of total interviewed). The occurrence of zero catches was not related to time neither to fishers' age (Table 2).

The number of fish species (common names) of major ecological categories (invertebrates, herbivores, generalists and predators) mentioned by fishers were all inversely related with time since last fishing, but not to fishers' age (Table 3). Overall, the number of species of all ecological categories increased in interviews made in recent years (Fig. 6).

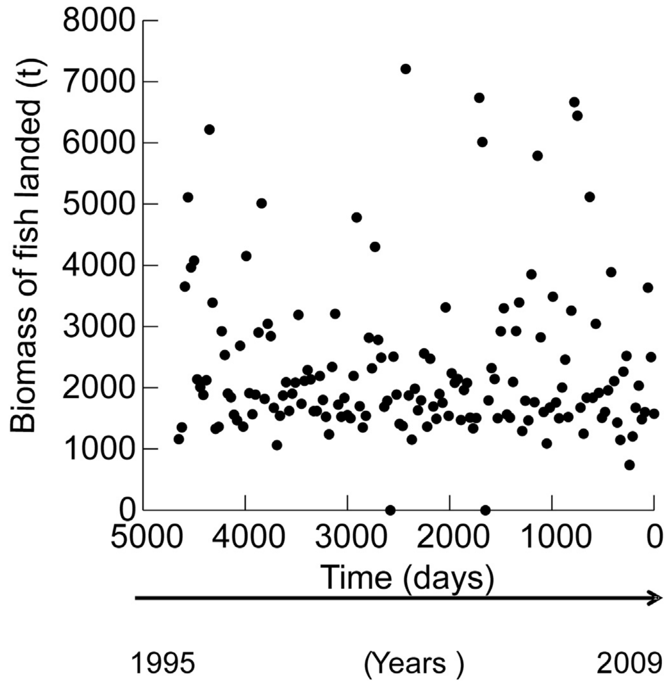

Fig. 4. Relationship between the days passed since January 1st 2010 and biomass of fish landed reported in governmental fisheries statistics of the São Paulo state coast [37], in southeastern Brazil. The scale of the x axis was reversed to better show the passage of time from older to more recent reported fishing.

Contrarily to the hypothesis 4, the time (days since reported fishing) was unrelated to the occurrence of fish with average or low economic value (Table 2). The occurrence of species with high value was inversely related with time, which was unexpected (Table 2). The proportions of interviewed fishers (n=396) who mentioned these economic categories were similar between interviews from before and after 5 years, except for high value fishing resources, which were mentioned by a higher proportion of fishers in recent interviews (Fig. 7).

The number of fish species (common names) of the three economic categories (high, average, low) mentioned by fishers were not related to fishers' age (Table 3). However, the number of species of average and low economic categories were inversely related to time passed since reported fishing (Table 3). Although the observed increase in the number of species mentioned of these less valued fish in more recent fisheries (Fig. 8) agreed with hypothesis 4, the number of species with high value was unrelated with time.

4. Discussion

4.1. Temporal trends in catch abundance and composition

The hypothesis 1 of decreasing catches over time was confirmed by the interview data: larger catches were reported, on average, by those fishers interviewed more than 5 years ago and time was the variable that influenced most the reported biomass of fish caught according to the logistic regression models. This agrees with previous studies indicating decreases in catches over time and even local extinctions, according to fishers' knowledge [18,22,31,35,39,59,67]. Nevertheless, a recent study has not evidenced a decline in the biomass of fish caught in the northeastern Brazilian coast during the last 10 years [21]. The observed decrease in the biomass of fish caught also agree with concerns of coastal fishers regarding intense fishing pressure by large scale fishers [3,15,65]. A comparison of sampled fish catches between two time periods (1992 and 2002) in a fishing community of the southeastern Brazilian coast also indicated decreased catches over time [42]. Therefore, the decrease in fish catches inferred from fishers' interviews seems to indicate a real trend of decreasing fishing yields in the heavily populated Brazilian southeastern coast. Other possibility would be that the fishing effort (amount of gear, time

Table 2.
Logistic regressions of interviews with fishers (n=396) who mentioned names of fishing resources, considering as independent variables time (days since reported fishing as from January 1st 2010) and fishers' age and as dependent variables the ecological and economic categories of the catch, besides the occurrence of zero catches, in the form of presence or absence data. For significant regressions (in bold) we provide the regression model and the probability of occurrence of the respective category of the catch in interviews made 349 days ago (those most recent) and 4874 days ago (oldest), calculated from the regression equation.

Independent (x)	Dependent (y)	p	Model	Probability (%): 349 days	Probability (%): 4874 days
Time (days)	**Invertebrates**	**0.001**	**Y=0.57−(0.X)**	**60.5**	**20**
	Reef herbivores	0.8			
	Reef generalists	**0.001**	**Y=−0.92−(0.001 X)**	**21.4**	**0.2**
	Reef predators	**0.026**	**Y=−0.1368−(0.X)**	**44**	**16.8**
	Demersal herbivores	0.12			
	Demersal generalists	0.77			
	Pelagic generalists	0.81			
	Pelagic predators	0.26			
	High value	**0.002**	**Y=2−(0.001 X)**	**86.3**	**39.6**
	Average value	0.67			
	Low value	0.18			
	Zero catches	0.28			
Age (years)	Invertebrates	0.57			
	Reef herbivores	0.75			
	Reef generalists	0.71			
	Reef predators	0.49			
	Demersal herbivores	0.22			
	Demersal generalists	0.27			
	Pelagic generalists	0.16			
	Pelagic predators	0.55			
	High value	0.27			
	Average value	0.38			
	Low value	0.58			
	Zero catches	0.68			

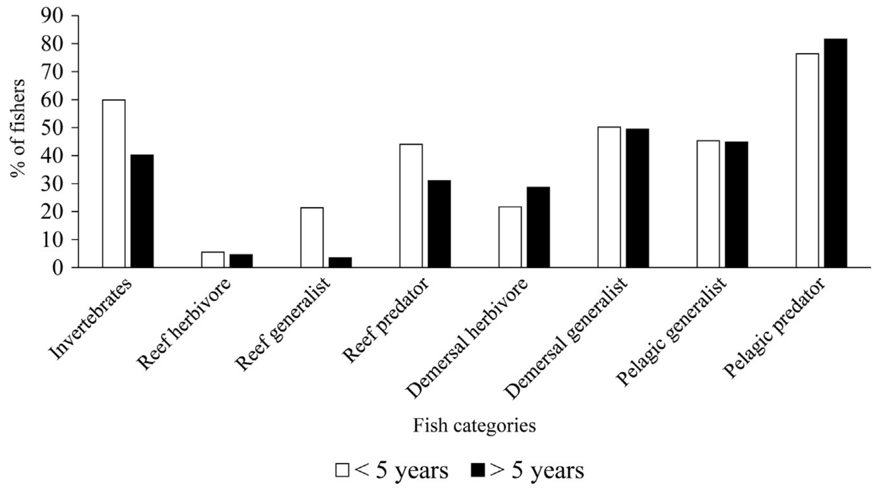

Fig. 5. Proportion of interviewed fishers before (n=309) and after (n=87) 5 years since 2010 who mentioned each ecological category of fish landings in the southeastern Brazilian coast. The sum of the percentages may be more than 100% because some fishers mentioned more than one category.

Table 3.
Correlations (non-parametric Spearman) between time (days since reported fishing as from January 1st 2010) and fishers' age and the ecological and economic categories of the catch, considering the number of species (common names) of fishing resources mentioned by interviewed fishers (n=396) in the southeastern Brazilian coast. Significant correlations are in bold.

Variable 1	Variable 2	rs	p
Time (days)	**Invertebrates**	**−0.13**	**0.01**
	Herbivores	**0.18**	**0.00**
	Generalists	**−0.11**	**0.03**
	Predators	**−0.18**	**0.00**
	All species	**−0.16**	**0.00**
	High value	−0.06	0.24
	Average value	**−0.14**	**0.01**
	Low value	**−0.14**	**0.01**
Age (years)	Invertebrates	−0.03	0.55
	Herbivores	0.08	0.13
	Generalists	0.06	0.20
	Predators	0.03	0.60
	All species	0.08	0.12
	High value	0.07	0.19
	Average value	0.06	0.21
	Low value	0.01	0.88

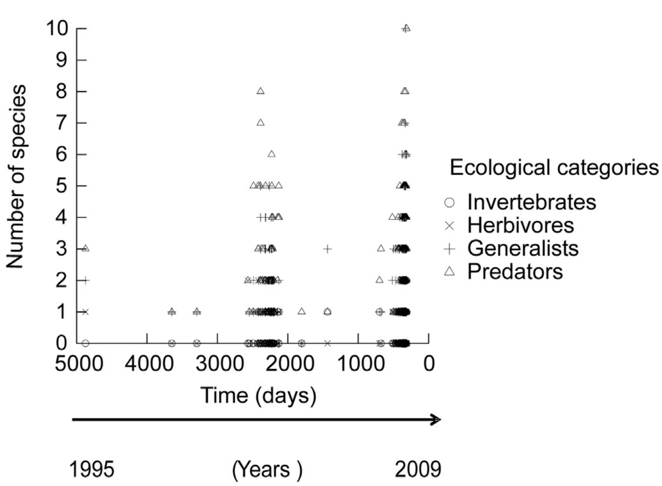

Fig. 6. Relationship between time (days since reported fishing as from January 1st 2010) and number of species of four major ecological categories of fishing resources mentioned by interviewed fishers (n=396) in the Brazilian southeastern coast. The scale of the x axis was reversed to better show the passage of time from older to more recent reported fishing.

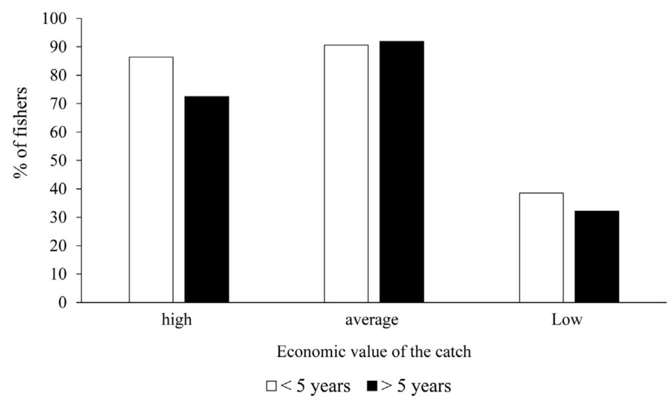

Fig. 7. Proportion of interviewed fishers before (n=309) and after (n=87) 5 years since 2010 who mentioned each economic category of fish landings in the southeastern Brazilian coast. The sum of the percentages may be more than 100% because some fishers mentioned more than one category.

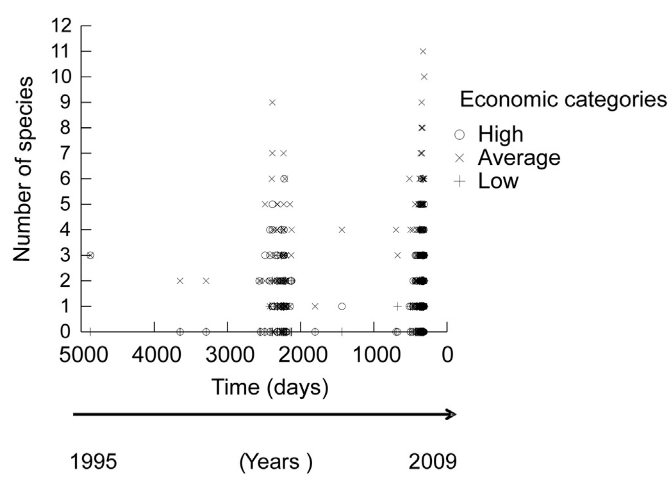

Fig. 8. Relationship between time (days since reported fishing as from January 1st 2010) of last fishing and number of species of three economic categories of fishing resources mentioned by interviewed fishers (n=396) in the Brazilian southeastern coast. The scale of the x axis was reversed to better show the passage of time from older to more recent reported fishing.

dedicated to fishing, or frequency of fishing) had declined along the studied period, resulting in the observed reduced catches. Unfortunately fishing effort was not available from fishers' interviews, but this variable is largely absent for most statistics on fish landings, despite the relevance of effort data to evaluate the sustainability of coastal fisheries [32]. Nevertheless, an overall reduction in fishing effort along the last 14 years would be very unlikely in the southeastern Brazilian coast, as population and tourism have increased, which increases the demand for fish. Furthermore, a trend of increased fishing capacity through modernization and more efficient fishing gear have been observed worldwide [2,56]. For example, in the south Brazil (1000 km south of the studied region) coastal fishers increased their fishing effort (size of gillnets) along a period of approximately 10 years [49]. Although there are evidences of a gradual transition from fishing to tourism related activities among the small-scale fisheries in the studied region [4,46], this is a more recent phenomenon and at least part of these touristic activities consist of recreational fishing, which may not totally alleviate fishing pressure. Considering that fishing effort has increased in the studied region (more probable) or at least has remained stable over the study period, results from this study indicate a decrease in catches, which is possibly related to a reduced availability of fishing resources. However, this may have multiple, non-exclusive causes, such as increased fishing pressure by small-scale fishers (who could buy larger boats and more gillnets), increased market demand for fishing resources in a touristic area [46], over-fishing by larger fishing boats that invade the coast, coastal pollution and unpredictable climatic or environmental changes. Another possibility is that the observed decrease in reported catches over time is related to an increase in the total number of fishers, so that the total catch is spread (or shared) among more fishers. This may cause a decrease in the catch per fisher even if the availability of fishing resources remained stable. Unfortunately, we lack data about temporal variation in the number of fishers, but the relatively short time scale addressed in this study (14 years) should not be sufficient for a noticeable increase in the number of fishers, as the average age of fishers were 45 years. Furthermore, the inverse relationship observed between time and fishers' age indicated that most of the recent interviews were made with older fishers. Therefore, younger people may have been not engaging in fishing in those communities studied more recently (closer to 2010), which also suggests that the number of fishers might not have increased. Furthermore, a study on population dynamics of fishers in the southeastern Brazilian coast indicates that local populations have not increased in fishing communities, but fishers may migrate among communities [4].

The hypothesis 3 regarding temporal changes in the species composition of catches was only partially confirmed: only three of the eight ecological categories showed a change in occurrence over time. As expected, the occurrence of invertebrates and of generalist reef fishes that are omnivorous or invertebrate feeders were more often mentioned in recent interviews. However, contrarily to this hypothesis, large piscivorous reef fish were more often mentioned in recent interviews, while the occurrence of pelagic and large piscivorous fishes was unrelated with time of interview. Reef and demersal herbivores were less often mentioned than other ecological categories and their occurrence did not vary with time of interview. The diversity (number of species inferred from common names) of fishing resources mentioned by fishers increased in more recent interviews for all ecological categories, including the expected increase in the number of species of invertebrates, herbivores and generalists and an unexpected increase in the diversity of predators. Overfishing has severely reduced the abundance of large marine fishes, such as predators and herbivores, which perform important ecological functions in tropical oceans worldwide [16,50,51]. Marked decreases in the abundance of these large fish has caused major ecological shifts, such as an increase in algal growth in tropical reefs or changes in fish and invertebrate communities [17,25,27,34]. The results of the present study did not fully conform to the processes of fishing down the food web [55], trophic cascades [25,62], nor trophic downgrading [27], as fishers did not indicate a decrease in the number of species or occurrence of fish from higher trophic levels. The increases in the presence of small to medium sized reef fish (generalists) and invertebrates, besides the overall increase in the number of species exploited in recent interviews, suggest that ecological changes may be under way in the southeastern Brazilian coast, but these changes had not reached the point of eliminating larger species of higher trophic levels. By one hand, the increased citation of generalist reef fish in recent interviews, most of which have low commercial value in the studied region [14,65], may be an alert that abundance of preferred large fish decreased over time. On the other hand, the exploitation of these less valued fish may be an opportunity to diversify fish catches and alleviate fishing pressure on remnant populations of large and preferred fish, which still occur in the studied region according to the interviewed fishers. Nevertheless, at least some species, such as groupers (Epinephelidae) and large pelagic fish, have been threatened by intense fishing along the Brazilian coast, as most individuals have been caught before reaching sexual maturity and few fishers have seen these fishes with mature gonads [9,15,66]. Large piscivorous reef fishes, such as groupers, are more susceptible to intense fishing pressure, due to their large size, delayed sexual maturity, sex change (females turn to males at larger sizes), long life spans and the formation of spawning aggregations [36,60]. Indeed, previous studies using qualitative and quantitative data from fishers' knowledge have revealed major declines in the abundance of large pelagic and reef fish, including groupers and sharks, in the Brazilian coast [18,30,31,65] and elsewhere [59].

The hypothesis 4 was not confirmed: fishing resources with high value were more frequently mentioned in recent interviews, contrarily to an expected decrease in high valued resources over time [63]. Although there was an increase in the number of species with low and average values in more recent interviews, the number of species with high value did not change over time. Declines in fishing resources caused by overfishing could be more related to the economic value of species exploited than to their trophic level [63]. The expected pattern under this scenario would be a decline in high valued species over time in heavily fished regions, irrespective of trophic levels, as some of these high valued fishing resources may be invertebrates, such as shrimps or lobsters [63]. This decline in high valued species was not observed in the southeastern Brazilian coast over the studied timeframe, which further indicated that fishing pressure had not reached critical levels. On the contrary, high valued species were more often mentioned in recent interviews, possibly related to increased exploitation of shrimps and large reef predators, such as groupers and snappers (Lutjanidae) [11,15,41,52]. Other possibility would be that the relative value of these fishing resources increased over time, so fishers interviewed more recently may be applying a more intense fishing effort to catch these fishing resources. In such case, an increased citation would reflects higher exploitation levels and higher relative value instead of higher abundance or availability. Unfortunately, we do not have detailed data on fishing effort to check this possibility. Nevertheless, at least some of these high valued fishing resources, such as groupers, shrimps or snook (*Centropomus* spp.), have been mentioned by fishers from the southeastern coast in interviews made in 1986–1990 [8], 2000 [65] and 2011 [14]. Furthermore, a comparison of fish landings in one fishing community in the southeastern Brazil show that the main fish targeted and the fishing techniques did not change during 10 years (from 1993 to 2003) [42]. These data indicated that preference for these high valued fish probably did not change during the timeframe of 14 years analyzed here. Future studies are needed to confirm if populations of high valued fishing resources are in sustainable levels or to evaluate temporal variations in fishing effort to catch distinct species.

4.2. Fishers' knowledge as indicator of temporal trends

Fishers' knowledge has been regarded as an invaluable tool to evaluate the magnitude of temporal ecological changes in the abundance or composition of aquatic organisms, especially from remote periods when research was unavailable or in places that lack monitoring [39,48,61,67]. Therefore, fishers' information may help to deal with the problem of shifting baseline syndrome, which is a change in perception of the severity of changes over time [54]. Most of the previous studies that apply fishers' knowledge to evaluate the occurrence of shifting baseline syndrome focus on particular species and address long time spans (decades). These studies have conducted comparisons of perceptions between fishers of different ages (generations) or on recalls of previous resource abundance by experienced fishers e to analyze temporal changes in the abundance of fishing resources [18,21,30,31,35,59]. The present study in the southeastern Brazilian coast differ from these previous studies, as perceptions of interviewed fishers were compared among different times along 14 years, besides comparisons among answers from fishers of distinct ages. Contrarily to patterns observed in previous studies [31,59], none of the indicators of ecological changes in catches (number of species and occurrence of ecological or economic categories) were related to the age of interviewed fishers in this study. The fishers' age did not influence the reported biomass of fish caught, except for the observed interaction between fishers' age and time of interview (Table 1). Information from interviews with resource users have been positively related to scientific sampling of resource use for fish catches [21,35] and hunted mammals [33], thus contributing to understand patterns of exploitation and consumption of natural resources. Notwithstanding the recognized contributions of this approach, there is the possibility of systematic bias on perceptions of people with different ages, or a shifting baseline syndrome of perceptions [53]. Older people could overestimate past resource abundance, while younger people may fail to notice the decline of exploited resources [53]. The ability of people to properly recall past events of resource exploitation may be also influenced by the season when interview occurs and people may provide better averaged estimates over longer time periods (past year) than more punctual estimates (past month) [33]. The data analyzed in this study have the advantage of not being susceptible to shifting baselines in perceptions, as time when the interview was performed had a stronger influence on reported catches than the age of the interviewed fisher. This was possibly because all fishers, including older ones, were active at the time of interviews, so they mentioned past fishing events that occurred recently and were thus linked to the time when interview was conducted.

4.3. Policy and management implications

Although the temporal frame was limited to about 14 years (from 1995 to 2009) and sampling was discontinuous in time and could not be standardized (different communities and regions in distinct years), this study provided one of the most comprehensive and broad assessment of changes in coastal fish catches based on interviews with local fishers. These data are scarce or absent for most tropical small-scale fisheries [6,15,38] and can be a timely and invaluable contribution to support fisheries management. It is noteworthy that the temporal pattern of decrease in catches indicated by interviews with small-scale fishers was not observed in the official governmental statistics of fish landings during the same period of time [37]. This may be because official statistics group several kinds and scales of fisheries, including larger boats. Therefore, an increase in fishing effort or in the area exploited could maintain high catches in spite of reduced availability of fishing resources. Fishing effort was not considered by these official statistics, nor by our interview data, but we can expect that effort would be more variable and more intense in large scale mixed fisheries of official statistics compared to effort of fishing communities. This illustrates that governmental landing data that mix distinct fisheries over a wide region may not fully reflect temporal trends in catches of small-scale coastal fishing communities. Although they may be not the most important providers of fish to large markets, these smaller and scattered fishing communities may support local fish markets and be important sources of animal protein to guarantee regional food security [13]. Therefore, the observed decline in catches of small-scale fisheries should be duly considered by managers.

The results from this large-scale study based on fishers' interviews indicate the temporal trends of: (1) a decrease in the biomass of fish caught; (2) an increase in the occurrence of smaller fish and invertebrates in the catch; (3) an increase of large reef fish and high value fishing resources (mainly shrimp) in catches; and (4) maintenance of large predators. The first two indicators suggest excessive fishing, but the later indicators (3 and 4) suggest that the socioecological system of the southeastern Brazilian coast had not yet undergone major ecological shifts, as observed in other tropical regions of the world subjected to intense fishing [17,19,20]. Therefore, the scenario emerging from this study indicates a strategic opportunity for management actions in the Brazilian southeastern coast, aiming to reverse the trend of declining catches and to rebuild or stop the decline of populations of large fish before is too late. Considering the lack of monitoring for small-scale coastal fisheries, our results could serve as a baseline to assess future changes and could be discussed with fishers to better investigate potential causes of fish declines (that may vary for each region) and to propose feasible solutions or management approaches. In this sense, the data here provided follow the proposed approach of 'data-less' management of tropical small-scale coastal fisheries [38], which include information that better reflect the reality, the problems and the concerns of local fishing communities. Previous management measures issued in a top-down fashion by the Brazilian government, although grounded in sound biological background [1,28,29], have generated conflicts with fishers and have been less effective than expected. For example, a MPA recently enforced in the Paraty Bay has excluded fishers from fishing grounds and has not shown clear ecological nor socioeconomic benefits [44,45], while a recent law banned the catch of some endangered fish and invertebrate species, generating strong political opposition by fishers [24]. Besides being a cost-effective way to track temporal changes in resource abundance in the absence of regular monitoring [22,35], data from fishers' knowledge can provide a common ground for dialogue between fishers, biologists and managers [6], which can ultimately lead to comanagement initiatives [43]. These initiatives may include granting exclusive territorial rights to small-scale fishers [5,23], payments for ecosystem services or other compensation schemes to establish closed fishing seasons or protected areas [12], or diversification of economic activities by allocating more time to tourism [46].

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