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ORIGINAL ARTICLE

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Exploring simple ecological indicators on landings and market trends in the South Brazil Shelf Large Marine Ecosystem

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Abstract
Simple ecological indicators were applied to landings and market data from the South Brazil Shelf Large Marine Ecosystem to investigate pressures on the ecosystem over time to contribute to fisheries and ocean assessments in data-poor ecosystems. The indicators showed an increase in larger, long-lived and piscivorous pelagic species landings as well as an increase in offshore fishing over the past few decades. Indicators based on market data showed a decrease of not only the target species but also of some long-lived and large-size coastal species, resulting in an increase of previously undesired fish species in the markets. Each of the selected indicators expressed part of the picture, while putting all together resulted in a more comprehensive view of the historical behaviour of this system.

KEYWORDS
Brazil, fishing impacts, Indicators, market time series, prices, seafood

1 | INTRODUCTION

The use of indicators that consider overall ecosystem structure, functioning and changes over time, followed by the establishment of thresholds for fishery management, has been highlighted as essential for the implementation of the Ecosystem Approach to Fisheries—EAF (Powers & Monk, 2010; Shin et al., 2012; Tudela & Short, 2005).[1] Each indicator should reflect an important ecosystem property that is thought to be modified by fishing. It is also desirable to identify acceptable or unacceptable levels of change (FAO, 2003).

Within this context, the analysis should include not only target species of fish, but also non-target species, the short- and long-term effects of human activities, along with the processes, components, functions and carrying capacity of ecosystems, and seek to include ecological, economic, social, technological and governance aspects (Cury & Christensen, 2005; Shin et al., 2012; Sumaila, 2005). Moreover, multi-specific indicators should provide clarity and sensitivity (Fulton, Smith & Punt, 2005) and should be easily parameterised, with accessible data, communicating a variety of complex processes that occur within an ecosystem, using simple numerical values (Pauly & Watson, 2005).

Several ecosystem and individual properties have been used as indicators. The most widely applied is the trophic level of the catch, termed the Marine Trophic Index (MTI) (Baeta, Costa & Cabral, 2009; Bhathal & Pauly, 2008; Christensen, 1998; da Doria, Lima & Angelini, 2018; Freire & Pauly, 2010; Indiseas, 2015; Milessi, Arancibia, Neira & Defeo, 2005; Pauly, Christensen, Dalsgaard, Froese & Torres, 1998; Pauly et al., 2001; Perez-Espana, Abarca-Arenas & Jimenez-Badillo, 2007; Pincinato & Gasalla, 2010; Vasconcellos & Gasalla, 2001). This indicator investigates the "Fishing Down Marine Food Web" phenomenon, that is, the intense capture of top predators and their consequent depletion. However, this property has been questioned in terms of usefulness, as catches are influenced by several changes, including economics, management, fishing technology and targeting patterns (Branch, 2015; Branch et al., 2010; Caddy & Garibaldi, 2000; Essington, Beaudreau & Wiedenmann, 2006).

In this sense, the Fishing-in-Balance index suggested by Pauly, Christensen and Walters (2000) has been applied in many works (Bhathal & Pauly, 2008; Christensen, 2000; Freire & Pauly, 2010;

[1]Ecosystem Approach to Fisheries may be defined as "a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way" (Fifth Meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 5), Decision V/6).

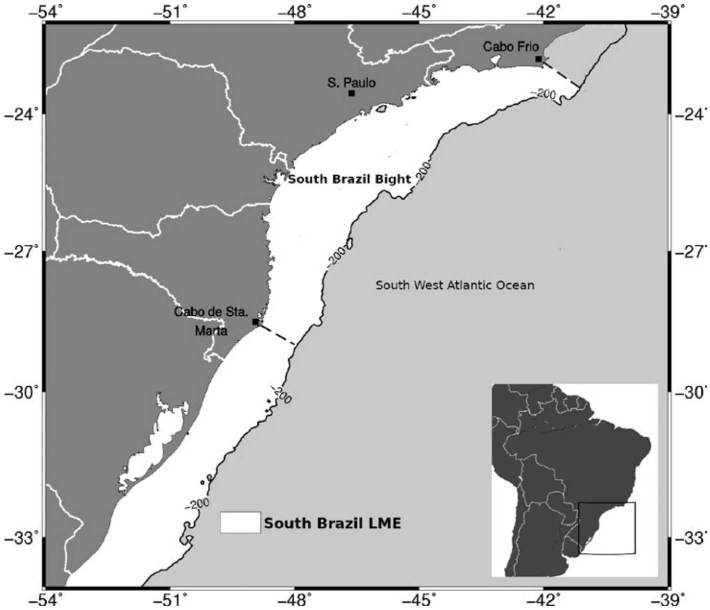

FIGURE 1 Study area: the South Brazil Shelf Large Marine Ecosystem

Milessi et al., 2005; Pauly & Palomares, 2005; Vivekanandan, Srinath & Kuriakose, 2005) to track the impact of fishing on the ecosystem and to assess whether the activity is balanced ecologically or not based on transfer efficiencies between trophic levels.

On the other hand, to avoid the accuracy problem concerning the trophic level of seafood categories, Sumaila (1998a,b) suggested that fish could be classified by length groups instead of trophic level. Caddy and Garibaldi (2000), for the same reason, suggested an index based on trophic groups (the Piscivorous/Planktivorous ratio).

As an alternative approach, de Leiva Moreno, Agostini, Caddy and Carocci (2000) suggested a ratio based on fish habitats, considering just pelagic or demersal groups. Therefore, this ratio may be not only a proxy for the differential impact of nutrients on the pelagic and benthic system and production, but also indicate which habitats fisheries impact.

Morato, Watson, Pitcher and Pauly (2006) used the mean depth as an index to track the expansion of fishing to include deeper water species over time. Similarly, Bhathal and Pauly (2008) proposed a new "spatial expansion factor" based on the area fished over time.

A key challenge in EAF is the identification of the relative importance of concurrent drivers and, subsequently, how to deal with managing fisheries within the context of these multiple drivers (Link et al., 2010; Shin et al., 2012). In particular, the indicators mentioned above are usually applied to seafood catch or landing data, that is, they show just one side of the whole fishery system (Garcia & Charles, 2007). Furthermore, these data sets are often incomplete or not available to marine scientists (Jennings, Greenstreet & Reynolds, 1999; Pinnegar, Hutton & Placenti, 2006). This approach is challenging, especially for data-poor systems, where catch or landing data are not always available (Pincinato & Gasalla, 2010; Sumaila, Marsden, Watson & Pauly, 2007). Pincinato and Gasalla (2010) applied multi-species indicators of the trophic level of seafood based on market data and found important fishing pressure signals across the marine food web. They also demonstrated that one single indicator can exhibit simplistic interpretations while multiple analyses can provide a broader view of the changes over time.

This paper extends the work by Pincinato and Gasalla (2010) and aims to investigate the performance of literature-based indicators and propose new ones, based on different aspects (trophic level, trophic group, size, longevity, habitat and depth) of a 40-year time series of marine fishing landings and a seafood market database for the South Brazil Shelf Large Marine Ecosystem (SBSLME), to track changes in the data-poor marine fisheries ecosystem over time.

2 | MATERIALS AND METHODS

Fishing landing data for the period 1968–2007 were compiled for the South Brazil Shelf Large Marine Ecosystem (SBSLME) (Supporting Information Table S1) from the "Sea Around Us" project database (Sea Around Us project, 2010) and other complementary sources (Araújo, 1979; IBAMA 1993a,b, 1994, 2007; Krug & Haimovici, 1991; Nakatani, Matsuura & Sato, 1980; Paiva, 1997; SUDEPE, 1969, 1978; Valentini & Cardoso, 1991; Valentini, D'incao, Rodrigues, Neto & Rahn, 1991; Valentini, D'incao, Rodriguez, Rebelo Neto & Domit, 1991; Valentini & Pezzuto, 2006).[2]

Market data were compiled from the São Paulo Wholesale Market (Companhia de Entrepostos e Armazéns Gerais de São Paulo - CEAGESP) for the period 1968–2007. This includes monthly prices and quantities (in kg) of 168 categories of seafood (almost 400 species) mainly from the South Brazil Bight and adjacent areas comprising the SBSLME traded in this wholesale market (Figure 1). According to CEAGESP (2015), 6% of the quantities traded in the São Paulo wholesale market is currently imported from other countries (not considered in the analysis). Considering the period of analysis (1968–2007), and the relatively poor infrastructure in the early periods (Gallo, 1976), access to seafood from other parts of Brazil was much more difficult than it is today. It is plausible, then, to assume that most of the seafood traded at CEAGESP is, in general, from the South Brazil Bight and adjacent areas comprising the SBSLME. In addition, this market is considered the biggest wholesale seafood market in Latin America and is a key point of distribution for the region. The price time series were converted to the Real currency (R$) (base year: 2007) and deflated by the Consumer Price Index-Fipe (Fundação Instituto de Pesquisas Economicas, 2008).

The bio-ecological seafood classification (Supporting Information Table S1) was performed according to the following parameters: trophic level, maximum size, longevity, trophic group (piscivorous or zooplanktivorous), habitat (pelagic or demersal), depth and isobath

[2]Official statistics for the last decade are not available.

of occurrence. These parameters were based on the best-matched available information (e.g., species and area) compiled from available scientific information, including scientific global databases (Fishbase – Froese & Pauly, 2015), as well as from regional theses, and dissertations.

The indicators were calculated for all the species considering the availability of the parameters (see Supporting Information Table S1). However, the indicators were also calculated without some species, such as sardines, shrimps and tunas—"cut-out" species. These species were excluded to reveal other possible changes that could not be observed when considering all the groups due to their possible major influence in the index because they are important categories for fisheries (as per Pauly & Palomares, 2005, who excluded anchovetas from some of their analysis). Moreover, for some analyses, such as Mean Longevity and Pis/Pla ratio, shrimps were not considered because no parameter data were available, and because its trophic group is neither piscivorous or planktivorous.

2.1 | Data analyses

The indicators used in this study were Fishing-in-Balance, Mean Longevity, Mean Maximum Length, Mean Depth, Mean Maximum Isobath, Piscivorous/Planktivorous ratio, Pelagic/Demersal ratio and the Mean price for different longevity, maximum length and depth classes. The selection of indicators is based on the availability of data and on the use in the literature.

The Fishing-in-Balance (FiB) index was calculated following the equation (Pauly et al., 2000):

$$FiB_j = \log\left[\frac{\left(\sum Y_{ij}\left(\frac{1}{TE}\right)^{TL_i}\right)}{\left(\sum Y_{i0}\left(\frac{1}{TE}\right)^{TL_i}\right)}\right] \quad (1)$$

where, Y_{it} is landings or market quantities for each category i by each year j; Y_{i0} is the quantity of each category i in the base year (1968); TL is the trophic level of landings or market category i; and TE is the transfer efficiency of energy between the trophic levels, considered as 10%, as in (Pauly & Christensen, 1995; Vasconcellos & Gasalla, 2001). In this case, 119 categories (see Supporting Information Table S1) were classified according to their TL.

The Mean Longevity ($Long_m$) index is based on the parameters of 76 categories (see Supporting Information Table S1) of species weighted by their fishery landings and market quantities, following the definition:

$$Long_{mj} = \frac{\sum Long_i Y_{ij}}{\sum Y_{ij}} \quad (2)$$

where $Long_i$ is the longevity defined for each landing (or market) category. Invertebrates were not included in the longevity analysis due to a lack of ecological parameters (see Supporting Information Table S1).

Mean Maximum Length ($Lmax_m$) is defined as the weighted average of the maximum length of each category by landings or market quantities, following the definition:

$$Lmax_{mj} = \frac{\sum Lmax_i Y_{ij}}{\sum Y_{ij}} \quad (3)$$

where $Lmax_i$ is the maximum length for each category i (114 categories in total—see Supporting Information Table S1).

Mean Depth ($Depth_m$) was estimated each year j by the weighted average of the depth occurrence of 120 categories of species (see Supporting Information Table S1) by their landings and market quantities, following the definition:

$$Depth_{mj} = \frac{\sum Depth_i Y_{ij}}{\sum Y_{ij}} \quad (4)$$

where $Depth_i$ is the mean depth defined for each category i. The categories were classified considering one-third of the total depth range, based on Morato et al. (2006). Moreover, the Mean Maximum Isobath of the occurrence of 121 categories (see Supporting Information Table S1) was calculated over time weighted by their fishery landings and by seafood market quantity, following this definition:

$$Imax_{mj} = \frac{\sum Imax_i Y_{ij}}{\sum Y_{ij}} \quad (5)$$

where $Imax_i$ is the maximum isobaths defined for each category i. The categories were classified based on Morato et al. (2006) and Gasalla (pers. com.). Therefore, this index is based on the information provided by the Mean Depth index adjusted by an ad-hoc classification of the distance from the coastline.

The piscivorous/planktivorous ratio (Caddy & Garibaldi, 2000) was calculated for landings and market quantities over time. Piscivorous or planktivorous groups were defined for 84 categories (see Supporting Information Table S1). This classification was based on different sources of literature to have as many species as possible in the analysis. Therefore, although an effort was made to use quantitative data for feeding habits, studies using qualitative data were also considered. This limited the effort to establish a quantitative classification for piscivorous or planktivorous categories.

The pelagic/demersal ratio (de Leiva Moreno et al., 2000) was also analysed for landings and market quantities over time. It was possible to classify the habitat of 118 categories (see Supporting Information Table S1) in the pelagic or demersal domain. This classification, as well as in the Pis/Pla ratio, was based on different sources of literature to include as many species as possible in the analysis. Categories classified as benthopelagic were discarded from the analysis.

Finally, the Mean Price for different bio-ecological parameters (P_m) were also used as indicators. The annual wholesale market price of each seafood category weighted by its market quantity was used as an indicator. This indicator used just the market data since the ex-vessel price over time was not available. In general, the price can be linearly correlated with market quantity (Pinnegar, Jennings, O'brien & Polunin, 2002; Pinnegar et al., 2006; Sumaila, 1998a). This indicator follows the definition:

$$P_{mj} = \frac{\sum P_{ij} Y_{ij}}{\sum Y_{ij}} \quad (6)$$

where Y_{ij} is the market quantity of each category i in the year j, and P_{ij} is the price in the year j.

In this analysis, the fish categories were classified in groups according to the ecological parameters. In the case of longevity, categories were grouped into three classes: low-Long (Long ≤5 years), int-Long (5 < Long < 20 years) and high-Long (Long ≥ 20 years). In addition, categories were grouped according to their maximum length: low-Lmax (Lmax ≤ 300 mm), int-Lmax (300 < Lmax < 1200 mm) and high-Lmax (Lmax ≥ 1200 mm). In these classes, the groups were based on the weighted average, but because of the wider range, the limits for the low and high groups were pushed down and up, respectively, to highlight the difference between

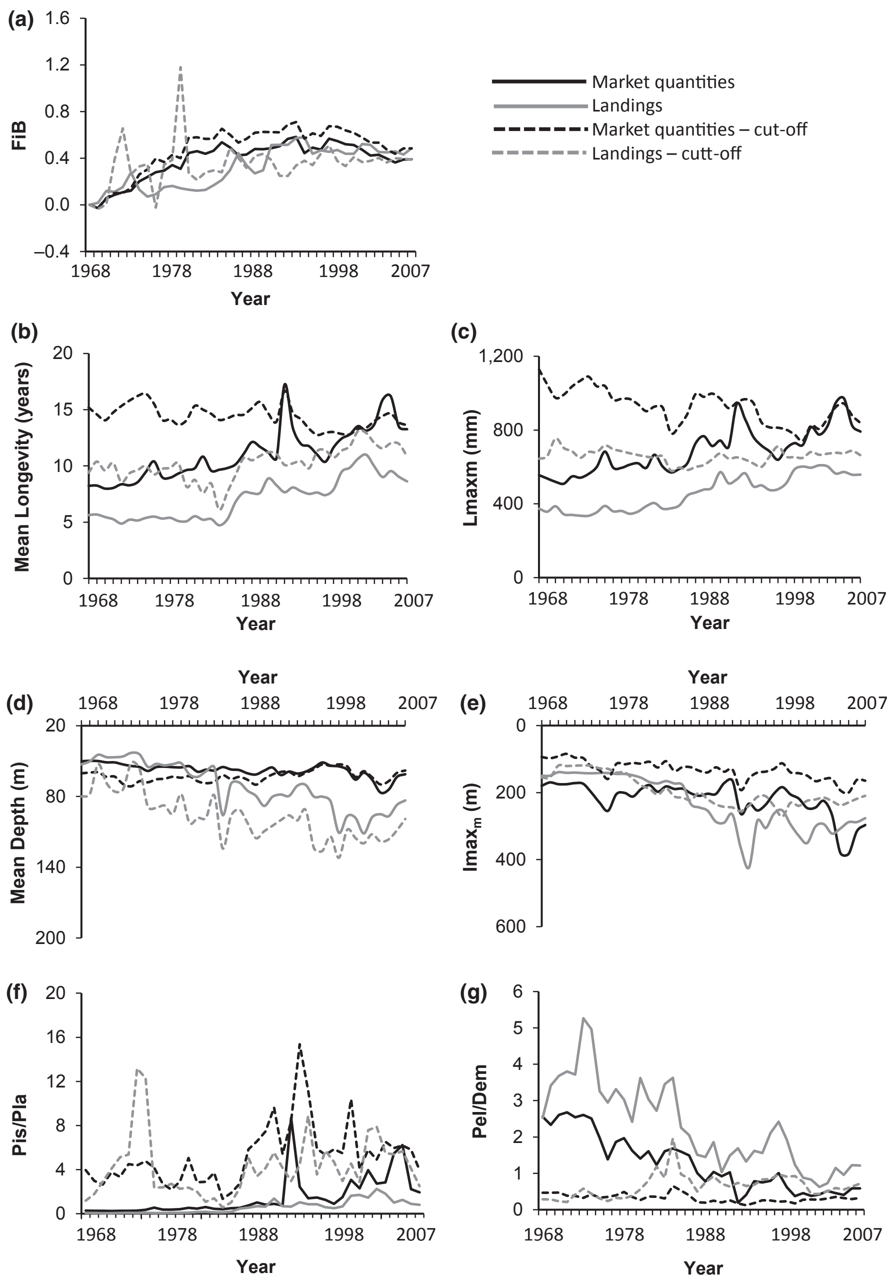

FIGURE 2 Multi-species indicators from 1968 to 2007, considering all categories and cutting-out Brazilian sardine, shrimps and tunas, for landings and market quantities data: (a) Fishing-in-Balance, (b) Mean Longevity, (c) Mean Maximum Length, (d) Mean Depth, (e) Mean Isobath, (f) Pis/Pla ratio, and (g) Pel/Dem ratio

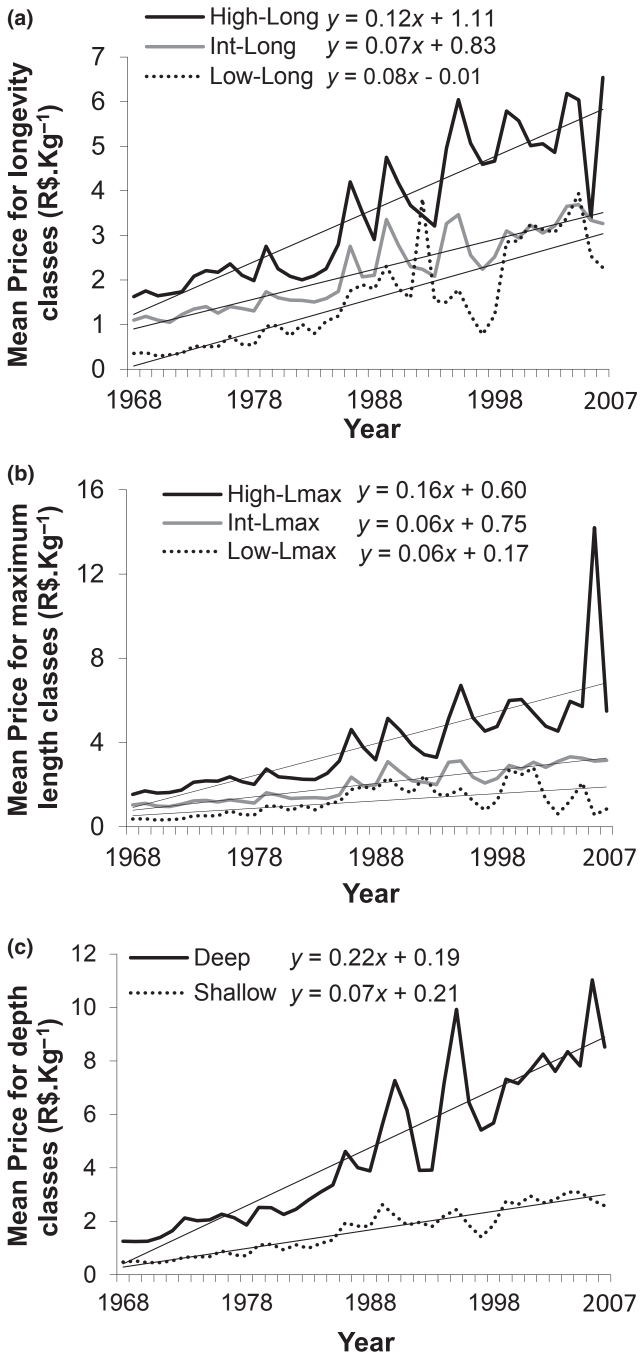

FIGURE 3 Mean price for different classes of the bio-ecological parameters: (a) longevity, (b) maximum length, and (c) depth, from 1968 to 2007

these groups. Finally, categories were grouped into two classes related to their depths: shallow (Depth ≤ 66 m) and deep (Depth > 66 m). These groups were defined according to the weighted average of depth (above and below 66 m). Invertebrates were not considered in this analysis.

The non-parametric Cox–Stuart test (Conover, 1980) was applied to the time series (FiB, Mean Longevity, Mean Maximum Length, Mean Depth, Mean Isobath, Pis/Pla and Pel/Dem) to test for trend significance.

3 | RESULTS

The Fishing-in-Balance (FiB) index applied for landings showed an increasing trend until 1994 ($p < 0.001$) (Figure 2a), but with a smooth decline from 1994 onwards. With regard to market quantities, the FiB index also showed an increasing trend ($p = 0.06$) until 1985, after which a smoother increase was observed until 1993, when a downward trend started. The trends not considering the cut-out categories (sardines, shrimps and tunas) were similar to those considering it, but also not significant ($p = 0.08$).

Mean Longevity ($Long_m$) over time for landings and market quantities displayed significant ($p < 0.001$) increasing trends (Figure 2b). However, Mean Longevity using landings was relatively constant for the first 15 years. When the cut-out categories were excluded from the analyses, the upward trend of the Mean Longevity index for the landings became smoother (but significant, $p = 0.00$), showing a first period of decline up to the early 1980s, and then an increase, while the trend of the index of market quantities turned downwards ($p = 0.02$).

There was a significant increase in Mean Maximum Length ($Lmax_m$) of landings and market quantities over time (Figure 2c). When the cut-out categories were not considered in the analyses, the trend turned downwards for market quantities ($p < 0.001$), but no trend was found for landings ($p = 0.25$).

Landings and market quantities weighted by mean depth ($Depth_m$) over time (Figure 2d) exhibited a significant upward trends against depth (Landings - $p < 0.001$; market quantities - $p = 0.01$). When the cut-out categories were excluded from the analysis, the upward trend in depth remained significant ($p < 0.001$) only for landings, whilst for market quantities, it turned downward at 10% level of significance ($p = 0.06$).

For landings and market quantities, the $Imax_m$ trend increased significantly over time whether the cut-out categories were considered or not (Figure 2e, $p = 0.00$).

The ratios between piscivorous and planktivorous (Pis/Pla) increased significantly over time for both landings and market quantities (Figure 2f; $p < 0.001$). The trends remained upward for both landings ($p < 0.001$) and market quantities ($p = 0.02$), even when the cut-out species were excluded from the analyses.

The Pelagic/Demersal (Pel/Dem) ratio showed a significant downward trend ($p < 0.001$) for both data sets (Figure 2g). The exclusion of the cut-out categories highlighted an upward trend for landings ($p = 0.06$), while the trend remained downward ($p = <0.001$) for market quantities.

The Mean Price trends for all the longevity classes (Figure 3a) were upward ($p = 0.00$), but the high-Long (angular coefficient = 0.12) showed a higher increase than int-Long and low-Long (angular coefficient = 0.07 and 0.08) (Figure 3).

The Mean Price for different classes of Maximum Length showed a significant increase ($p < 0.001$) over time (Figure 3b). However, high-Lmax class (angular coefficient = 0.16) showed a higher increase than int-Lmax and low-Lmax (angular coefficient = 0.06 and 0.06, respectively).

Both shallow and deep depth class showed significant upward trends with Mean price (Figure 3c; $p < 0.001$). A lower price increase was observed for the shallow category (angular coefficient = 0.07) than for the deep one (angular coefficient = 0.22).

4 | DISCUSSION

4.1 | The multi-species indicators

The upward trend of the Fishing-in-Balance (FiB) index for landings suggests an intense period of exploitation and expansion of fishing that was disrupted in 1986. This disruption could be associated with the end of fisheries fiscal incentives in Brazil (Abdallah & Sumaila, 2007). The index also highlighted certain changes considering its upward trend in market quantities. This trend may be explained by: (a) an unbalanced ecosystem, probably due to overexploitation; and/or (b) an increase of alternative markets, such as large retailers, instead of the link through the wholesale market (CEAGESP) (Sonoda, Conte, Scorvo-Filho, Shirota & Cyrino, 2002).

Christensen (2000) suggested that considering a transfer efficiency of 10% between trophic levels, it would, in theory, be expected that catches would increase ten-fold by fishing one trophic level lower. If this happens, the index remains constant and fishing can be deemed "balanced." In this study, for landings as well as for market quantities, the index did not remain constant over time, that is, the fishing is not "in balance." An unbalanced FiB trend was found in other regions, such as in the North Atlantic (Christensen, 2000; Pauly & Palomares, 2005), Portugal (Baeta et al., 2009), India (Bhathal & Pauly, 2008), and northeast and north Brazil (da Doria et al., 2018; Freire & Pauly, 2010), all being related to fishing pressure.

For both data sets, considering all available categories included the Mean Longevity, Mean Maximum Length and Mean Depth increased over time, which were related mainly to changes in Brazilian sardine, tuna, and shrimp landings and, following this, market quantities. When these categories were excluded, other changes could be observed. The following discussion concerns such indexes. For landings, the Mean Longevity and the Mean Depth increased over time, suggesting an increase in landings of higher longevity and deeper-living species (e.g., skipjack tuna *Katsuwonus pelamis* (L.) and monkfish *Lophius gastrophysus* Miranda-Ribeiro) or a decrease of lower mean longevity species (e.g., mullet *Mugil* spp.) (Pincinato, 2010).

The Mean Maximum Length for landings did not show a trend over time. This was influenced by the snowy grouper, *Hyporthodus niveatus* (Val.), which had a high relative importance at the beginning of the series, but gradually reduced over time (Pincinato, 2010). The results of both Mean Longevity and Mean Maximum Length can be related to the increase of offshore fishing over the last few decades, which is confirmed by the increase of Mean Depth over time.

The decrease of Mean Longevity and Mean Maximum Length for the market data may be due to the overexploitation of some high-Long and high-Lmax, which have had their market quantity reduced (e.g., angel-shark *Squatina* spp., swordfish *Xiphias gladius* L., sand-perch *Pseudopercis spp.*, and serra mackerels *Pristis pectinate* Latham, *Sarda sarda* (Bloch), *Scomberomorus brasiliensis* Collette, Russo & Zavala-Camin) (Pincinato, 2010). In addition to an increase in commercialisation of some by-catch categories of shrimp fishing (Cattani, Santos, Spach, Budel & Guanais, 2011; Lopes, 1996), usually int-Long and int-Lmax (see Supporting Information Table S1), a downward trend was found for Mean Depth when considering the market data without Brazilian sardine, shrimps and tunas (cut-out species), that may corroborate this suggestion.

Although there are some signs of offshore expansion over time in these landing trends, the Mean Depth did not surpass 140 m. In the case of southeast Brazil, this means a shorter distance than the slope region, where fleets are directing offshore expansion. Therefore, a multi-species indicator was proposed that accounts for distance from the coast, and not only the depth of occurrence, since this depth alone does not necessarily differentiate oceanic and neritic zone. In this case, Mean Maximum Isobath, for both market quantities and landings, showed an offshore expansion beyond the slope region (Figure 2e). Therefore, this indicator seems to be more sensitive to the fleet displacement power.

The piscivorous and planktivorous ratio (Figure 2f), as recommended by Caddy and Garibaldi (2000), is an independent indicator of trophic relationships between seafood categories. These authors proposed that a reduction of this indicator suggests effects other than the "fishing down marine food web" observed by Pauly et al. (1998), such as bottom-up control due to eutrophication (Caddy, Csirke, Garcia & Grainger, 1998), changes in demand, catch technology and environmental conditions (Caddy & Garibaldi, 2000). However, the results did not show the expected decreasing trend in Pis/Pla ratio, whether all the species were considered or not. Landings showed an increasing trend even when excluding the cut-out species, mainly due to a decrease of other planktivorous, such as chub mackerel *Scomber colias* Gemlin, which was responsible for a peak of the Pis/Pla ratio in 1974/1975 (Pincinato, 2010). The Pis/Pla ratio also suggests an increase of piscivorous landings, such as skipjack tuna, after 1984. On the other hand, the increasing trend for the market is explained by increasing sales of piscivorous fish through until 1993, followed by a decline, whilst the sales of planktivorous fish increased until 1984, at which point it declined; its commercialisation has been relatively constant since then (Pincinato, 2010). The lowest Pis/Pla ratio, in 1984, was due to an increase in the commercialisation of menhaden *Brevoortia* spp. Gasalla (2004). This is in contrast to landings from the south Brazil Bight from the 1950s to 1990s, where a decrease in the Pis/Pla ratio was found, which is consistent with the "fishing down marine food web" phenomenon (Pauly et al., 1998).

The Pel/Dem ratio reflects the effects of the different availability of nutrients in different habitats of the marine ecosystem. The local availability of nutrients (natural and/or anthropogenic) has different effects on pelagic and demersal stocks, under different conditions of enrichment (Caddy et al., 1998). In this study, the increasing trend, when excluding the cut-out species of the Pel/Dem ratio for landings, is related to the increase in pelagic landings (Pincinato, 2010).

Conversely, for market data (Figure 2g), in general, a higher quantity of demersal resources than pelagic ones was observed over time when the cut-out species were excluded. Additionally, the decline of target species caught by the groundfish fishery is followed by the landings increasing for other demersal species, such as triggerfish, *Balistes capriscus* (Gmelin), and big-tooth corvine, *Isopisthus parvipinnis* (Cuvier) (Ataliba, De Castro & Carneiro, 2009; Dias Neto, 2011).

According to de Leiva Moreno et al. (2000), some regions of the world showing a Pel/Dem ratio of under six were classified as oligotrophic, and therefore, they were not associated with bottom-up control process. In this study, the Pel/Dem ratio was under 4 for both landings and market. Thus, according to the framework shown by these authors, the changes detected here are not related to the eutrophication process.

Last, the Mean Price for different bio-ecological parameters showed a general increase. However, the high Longevity, Maximum Length and Depth showed the highest increase in relation to the other groups. Similar to the results of Pincinato and Gasalla (2010), this could reflect the scarcity of the "high" groups, as there was an increase in the price of species previously not targeted, such as triggerfish and big-tooth corvina, which belong to the "int" and "low" groups.

In particular, according to Sethi, Branch and Watson (2010), the depths at which fishery resources live can provide a proxy for the costs of fishing, where the harvest of deeper sea organisms presumably entails higher travel costs and fishing technology investment. However, for at least some fleets operating in the SBLME that is not necessarily the case. Longliners fishing for tunas offshore present overall lower operational costs than other fleets operating coastally, such as pair-bottom-trawlers (Gasalla, Rodrigues, Duarte & Rashid Sumaila, 2010; Rodrigues, Abdallah & Gasalla, 2018).

The indicators not only accounted for important bio-ecological aspects of the target and non-target species of this ecosystem, but also considered another key component, the market. Social, technological and governance aspects are still a challenge to be added to the set of indicators, mainly due to difficulties in gathering data regarding these components.

To summarise, changes for the indicators applied in this study highlighted some changes in the South Brazil Shelf Large Marine Ecosystem (Table 1). In general, these indicators suggested an increase in fishing pressure by both data sets, especially towards the end of the period. This was associated with larger, more long-lived and piscivorous pelagic species that have been caught while offshore fishing expanded over the last few decades. The results indicate the scarcity of not only the target species but also of some coastal high-longevity and large-size species, resulting in a market increase of previously undesired fish species.

4.2 | Application of the multi-species indicators

The main advantage of using multi-species indicators is that it synthesises a complex analysis of the changes of seafood categories

TABLE 1 Index trend summaries

	Indexes trends			
	Landings data set		Market data set	
Indexes	With all spp.	Without all spp.	With all spp.	Without all spp.
Fishing-in-balance	↑***	↑*	↑*	↑*
Mean longevity	↑***	↑***	↑***	↓**
Mean maximum length	↑***	-	↑***	↓***
Mean depth	↑***	↑***	↑**	↓*
Mean maximum isobath	↑***	↑***	↑***	↑***
Piscivorous/planctivorous	↑***	↑**	↑***	↑***
Pelagic/demersals	↓***	↑*	↓***	↓***
Mean price for longevity classes			↑***	
Mean price for maximum length			↑***	
Mean price for depth			↑***	

Notes. Source: "Sea Around Us" project database (Sea Around Us project, 2010), and other complementary sources (Araújo, 1979; IBAMA, 1993a,b, 1994, 2007; Krug & Haimovici, 1991; Nakatani et al., 1980; Paiva, 1997; SUDEPE, 1969, 1978; Valentini & Cardoso, 1991; Valentini & Pezzuto, 2006; Valentini, D'incao, Rodrigues, Neto, et al., 1991; Valentini, D'incao, Rodriguez, Rebelo Neto, et al., 1991) used for landings data set; while CEAGESP (1968–2007) used for market data set. * 10% significance level, ** 5% significance level, and *** 1% significance level.

over time into fewer numbers and trends. It also links the different fields involved in the fisheries system. According to Powers and Monk (2010), there are at least four key uses of indicators in an ecosystem approach to fisheries: (a) to motivate socio-political action; (b) to provide information for individual users to modify their behaviour; (c) to implement decision rules for an EAF evaluation, through ecosystem indicators monitoring ecosystem characteristics; and (d) to identify the ecosystem structure and function. These are not mutually exclusive; actually, they represent a continuum from socio-political to scientific uses. The indicators applied in this study provided information on the structure and function of the SBSLME. This is helpful for future socio-political actions and may support the implementation of decision rules for monitoring the ecosystem characteristics.

An essential aspect of the use of ecosystem indicators in an EAF is the relationship between indexes and decision criteria. Under these circumstances, it is possible to direct, for example, the increase of the research budgets, fishery rules and consumption patterns (Powers & Monk, 2010). The establishment of acceptable levels is an important next step for the management of fisheries in the South Brazil Shelf Large Marine Ecosystem.

However, any of the indicators used here have their own limitations, and these should be accounted for when considering their practical use. One single indicator may have multiple and controversial interpretations (Branch, 2015). Besides, according to Blanchard et al. (2010), clear trends of multi-species indicators are hard to find for many reasons. First, the relationship between the fishing pressure and the multi-species indicator trend is not necessarily linear, and hence, the trend may not be real. Second, the response time to fishery pressure may be different among different indicators and may only be applicable in some cases. In this sense, indicators using market data can show a time lag relating to the response time to fishing pressure compared with indicators using landings, or it is possible that neither follow the same change directions. Third, relative indicators such as ratios between pelagic/demersal or piscivores/planktivores are dangerous to interpret, because changes can come from increases or declines in one of the components.

The data set coverage is another source of bias. Both discards and unreported fishing are not included in the analysis using a landings data set, thus leading to an additional bias. Landings-based indicators, usually available over a relatively long time span, essentially reflect the fishing pressure on the ecosystem, and fishing behaviour and management decisions should be taken into consideration when interpreting the landings-based indicators (Shannon et al., 2014).

Some other potential limitations should be considered when evaluating the indicator results. First, ecological parameters (trophic level, longevity, maximum length, depth, maximum isobath, habitat and trophic group) can incorporate uncertainties, as they are estimated using data based upon different methods, periods and areas. Besides this, some of them were obtained from the grey literature (theses, abstracts, proceedings). In this study, there was limited availability of parameters for the categories regarding longevity, followed by maximum length, depth of occurrence, trophic level, trophic group and habitat. This limitation cannot be overcome until new studies on ecological parameters are performed for the study area and/or published in widely read scientific journals. It is important to note that missing parameters were not distributed evenly across the categories. This should be taken into consideration when interpreting indicators.

Moreover, changes over time in the ecological parameters of each species (or categories) were not considered in this study. For example, the maximum length of species currently found may be different from that formerly estimated. In the same way, the diet of some species may change over time due to environmental changes or fishing. Basically, environmental changes or fishing can lead to changes in abundance and/or shifts in the spatial and/or vertical distribution of species in the marine environment, thus the availability of food changes, and therefore so does the diet.

The absence of better taxonomic resolution, that is, species aggregation, also influences estimates of the trophic level, as shown by Baeta et al. (2009) and Freire and Pauly (2010). This is also true for other parameters estimated in this study (maximum length, longevity, depth).

Furthermore, the inclusion of categories such as "mixed," representing other fish of low commercial value and small specimens, may change the results of the analysis because they represent a significant proportion of total landings, that is, more than 15% in the past 24 years for the SBSLME (Valentini & Pezzuto, 2006). However, there is not sufficient information to include this category in the analysis of the indicators, such as in Freire and Pauly (2010).

5 | CONCLUSIONS

In general, the set of indicators used to track changes over time seemed useful to detect some potential fishing ecosystem impacts, especially in an EAF context for data-poor systems. The Fishing-in-Balance index suggested an overall unbalanced fishing. Besides, the indicators Mean Longevity, Mean Maximum Length and the Mean price for different bio-ecological parameters applied to the market data set showed the intensifying scarcity over time of valuable largest long-lived fish and an increase of market interest on previously undesired fish. On the other hand, the indicators Mean Depth and Mean Maximum Isobath illustrate the offshore expansion over time, supporting the increase of the Mean Longevity of landings.

Different signals are captured depending on the aspect of the system considered: the market data better reflected the scarcity of species with high longevity and maximum lengths, while the landings data better reflected the offshore expansion of the fisheries. The increasing trend of the Pis/Pla ratio was associated with both the increase of piscivorous and the decrease of planktivorous species in landings and market, which makes this particular indicator less objective than the others. The Pel/Dem ratio tracked the expansion of the pelagic offshore fishing when applied to the landings data, while when used on the market data it highlighted the increase of by-catch categories from trawlers.

The associated use of market variables in addition to the traditional landing data helped to approach the complexity and nonlinearity of a fisheries ecosystem. This was particularly true when applied to a comparatively data-poor marine ecosystem such as the SBSLME (compared to, for example, the North Sea LME). A single indicator is not sufficient for track changes regarding the marine ecosystem over time. Each of the selected indicators expressed just a part of the puzzle, whereas a joint analysis of multiple indicators presented a more complete picture of the changes.

Therefore, in general, this exercise also demonstrates the need to consider as many aspects as possible to reach a better understanding of the status of marine ecosystems. This set of indicators detailed certain characteristics of the fishing pressure over time that if combined with additional environmental, oceanographic, technological, social and governance indicators will certainly provide a better overview of the ecosystem and fisheries historical behaviour as a whole.

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