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Original Article

The Serra Spanish mackerel fishery (*Scomberomorus brasiliensis* – Teleostei) in Southern Brazil: the growing landings of a high trophic level resource

A pesca da cavala, *Scomberomorus brasiliensis* (Teleostei), no sul do Brasil: o aumento nos desembarques de um recurso de alto nível trófico

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Abstract

In fisheries, the phenomenon known as *fishing down food webs* is supposed to be a consequence of overfishing, which would be reflected in a reduction in the trophic level of landings. In such scenarios, the resilience of carnivorous, top predator species is particularly affected, making these resources the first to be depleted. The Serra Spanish mackerel, *Scomberomorus brasiliensis*, exemplifies a predator resource historically targeted by artisanal fisheries on the Brazilian coast. The present work analyzes landings in three periods within a 50-year timescale on the Parana coast, Southern Brazil, aiming to evaluate whether historical production has supposedly declined. Simultaneously, the diet was analyzed to confirm carnivorous habits and evaluate the trophic level in this region. Surprisingly, the results show that from the 1970's to 2019 Serra Spanish mackerel production grew relatively to other resources, as well as in individual values. The trophic level was calculated as 4.238, similar to other *Scomberomorus* species, consisting of a case where landings increase over time, despite the high trophic level and large body size of the resource. The results agree with a recent global assessment that has demystified a necessary correlation between high trophic level and overexploitation, but possible factors acting on the present findings are discussed.

Keywords: fishing, overfishing, diet, Scombridae, Brazil.

Resumo

Na pesca, o fenômeno *fishing down food webs*, ou 'pescando teias tróficas abaixo', expressa a redução do nível trófico na composição das capturas, e tem origem tradicionalmente atribuída à sobrepesca. Sob intenso extrativismo, a resiliência das espécies carnívoras, predadoras de topo, é particularmente afetada, sendo seus estoques os primeiros a entrarem em depleção. A cavala, ou serra, ou sororoca, *Scomberomorus brasiliensis*, é exemplo de recurso predador historicamente alvo da pesca artesanal, de pequena escala, na costa brasileira. O presente trabalho analisa os valores de desembarque do recurso em três períodos ao longo de 50 anos na costa paranaense, sul do Brasil, com objetivo de avaliar se sua produção tem efetivamente diminuído. Ainda, estuda-se a dieta da espécie na região, para confirmar seus hábitos carnívoros e avaliar o nível trófico na região. Os resultados mostram que, surpreendentemente, dos anos 1970 para 2019 a produção de *S. brasiliensis* tem aumentado em valores absolutos, bem como relativamente à de outros recursos, em que pese o nível trófico 4,238, similar a outras espécies do gênero. Constata-se que a pesca da cavala na região de estudo constitui um caso de aumento nos desembarques a despeito de elevado nível trófico e grande tamanho corpóreo. Os resultados concordam com recente levantamento em nível mundial, que nega existir correlação necessária entre sobrepesca e nível trófico alto, mas fatores que podem explicar os resultados do presente trabalho são discutidos.

Palavras-chave: pesca, sobrepesca, nível trófico, cavala, Brasil.

1. Introduction

The most valued fisheries resources, and consequently the species preferentially targeted by fishers, are traditionally top predators with larger sizes. In Southern Brazil, the market price of piscivorous resources is approximately 70% higher than that of non-piscivorous resources (Lecheta et al., 2017). Since the 20th century, around the world, fish landings of carnivorous resources have been declining due to overexploitation, starting with a search for fish with smaller, shorter life cycles at lower trophic levels (Pauly et al., 1998). However, *fishing down food webs* are not unanimous, and several authors consider that overfishing does not necessarily explain the lower

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trophic level in landings. For example, Essington et al. (2006) confirmed *fishing down food webs* in the Tropical Atlantic ecosystem and five other oceanographic regions, but with no trends indicating its relatioships to overexploitation of higher carnivores. Pershing et al. (2014) studied diet changes in marine resources and discarded a *top-down* origin, citing invasions of gelatinous plankton (*Aurelia aurita* and others) as the main cause of changes in the trophic web in the Black Sea. Even so, these authors admitted that a decline in predator abundance could provoke a cascade effect, affecting the attainement of the base of the trophic web. A good example is the Cod fishery in the Baltic Sea.

Should we expect a decline in the top predator species in Brazilian coastal landings, representing a *top-down* fishing pressure? Alternatively, can stability in landings be associated with changes in species' diet and reduction in the trophic level?

The present work focuses on the Serra Spanish mackerel (*Scomberomorus brasiliensis* Collete, Russo & Zavala Camin, 1978), a carnivorous species caught on the Brazilian coast. Locally known as cavala, serra, or sororoca, this species is commonly targeted using gillnets (Fonteles-Filho, 1988; Batista and Fabré, 2001), and their landings are continuous throughout the year in Southern Brazil (Chaves and Robert, 2003; Andriguetto-Filho et al., 2006; Chaves and Silva, 2019). This species' maximum length has exceeded 1.0 m, but the length of the fish for commercial fishing was between 50 and 70 cm. *Scomberomorus brasiliensis* is sympatric with *S. cavalla* and has been mistaken as the Central American *S. maculatus* (Dias-Neto and Dias, 2015), which does not inhabit Brazilian waters. In Venezuela and Northwest Brazil, *S. brasiliensis* feeds on small fish, crustaceans and mollusks (Menezes, 1970; Vasconcelos-Filho et al., 1984; Bashirullah and Acuña, 1988). The trophic level was calculated as 3.3 by considering the northwest coast of Brazil (Vasconcelos-Filho et al., 1984; Vasconcellos and Gasalla, 2001). However, the trophic level of some *Scomberomorus* species reaches 4.5, such as *S. cavalla* and *S. maculatus* in the Gulf of Mexico (Finucane et al., 1990), and *S. semisfasciatus* in Australia (Salini et al., 1998). This work aimed to evaluate the production values of *S. brasiliensis* over 50 years in a study region in Southern Brazil, and discuss them in view of the trophic level of this species.

2. Material and Methods

The study used the historical database on the landings of Serra Spanish mackerel in Matinhos locality, Paraná state, Southern Brazil. Small-scale fisheries act on a fishery zone around 25º30'S; 48ºW (Figure 1), summing approximately 70 boats, as described by Chaves and Robert (2003). Values refer to three periods: 1970–1974 (Loyola-e-Silva and Nakamura, 1975); 1991–1994 (Brasil, 1995); and 2017–2019 (FUNDEPAG, 2020). In the first two periods, the resource was generically cited as 'cavala', misleading *Scomberomorus brasiliensis* and *S. cavalla*. The third period refers exclusively to *S. brasiliensis*. In all periods, the annual values were considered individually. Monthly values were available for the last two periods, and they showed how heterogeneous production occurs throughout the year.

The diet of *S. brasiliensis* was obtained from samples collected from March 2020 to June 2020 in the Matinhos landings. This species was caught using gillnets at depths of approximately 15 m and latitudes of 25–26ºS, which were mainly close to two islands, Currais and

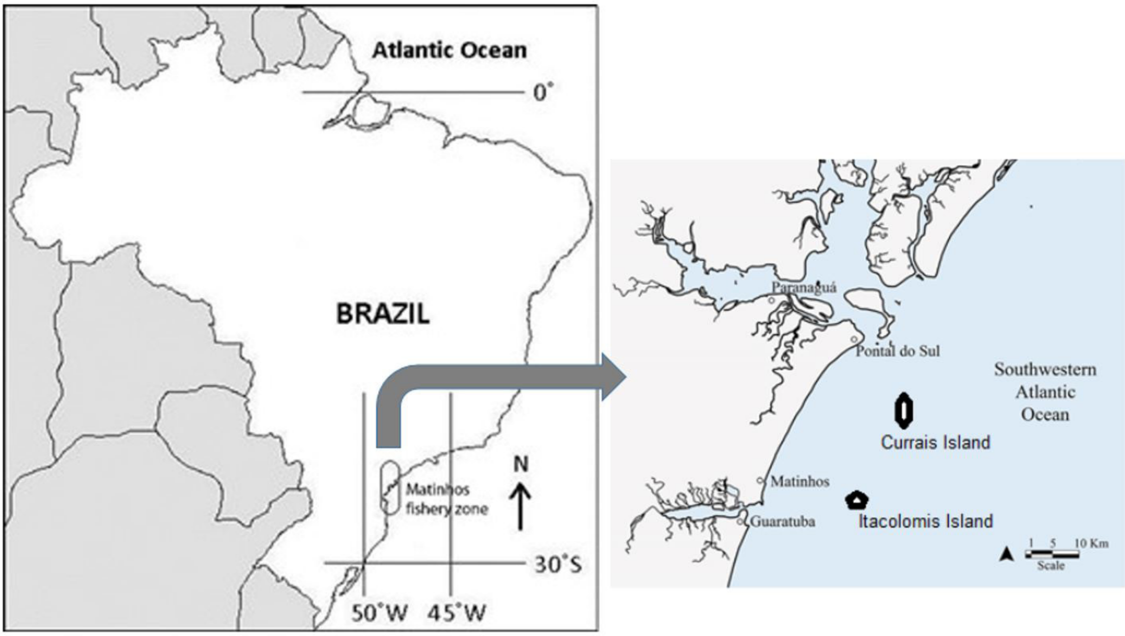

Figure 1. Map indicating Matinhos fishery zone (25º30' S; 48'W), and Currais and Itacolomis Islands, in the Brazilian coast, Southwestern Atlantic Ocean.

Itacolomis (Figure 1). After landing, the fork length (FL) of the specimens was obtained, and their stomachs were extracted and fixed in 10% formalin. In the laboratory, the stomach contents were filtered, and the retained fraction was weighed. All contents were then determined under a microscope and grouped according to the prey category. Each prey item was weighed, and the number of structures representing each prey was recorded.

2.1. Data processing

Landing is presented in absolute and relative values, and the total catches including crustaceans and mollusks.

A total of 74 specimens, FL 250-670 mm, had stomach content recognized (Figure 2). Structures were grouped by prey number, and the mass of the preys were processed using three methods (Pinkas et al., 1971):

(1) Frequency of Occurrence: FOi = Ni/N *100, where Ni is the number of stomachs containing prey 'i' and N the number of stomachs where a prey was identified;

(2) Numerical Importance: %Ni = Ni/N *100, where Ni is the number of preys 'i' in all stomachs summed, and N the sum of all preys, all stomachs considered; and

(3) Relative Biomass: %Bi = Bi/B *100, where Bi is the total mass of prey 'i', preys individually weighed, and B the sum of the mass of all preys, all stomachs considered.

These results were assembled to calculate the Relative Importance Index, by prey 'i': RIIi = (%Ni + %Bi) *FOi, adapted from Pinkas et al. (1971) replacing volume by mass.

Finally, the trophic level was estimated as TL = Σ (Bi *TLi) + 1, where Bi is the relative contribution of prey in mass, and TLi is the trophic level of such prey. In order to improve the accuity in the study, the TL values for prey were imported from Cortés (1999), who assembled data on shark prey to estimate the TL values in shark species.

3. Results

3.1. Landings retrospective

Historical data indicated an important growth in the Serra Spanish mackerel landings from 1970-1974 to 2017-2019. During the first period, the annual production increased from 0.4-74.7 t (*Scomberomorus brasiliensis* + *S. cavalla*) to 45.5-89.2 t (*S. brasiliensis*) in the second period. During an intermediary period (1991-1994) the summed annual production of the two species varied between 4.1-13.6 t. Additionally, *S. brasiliensis* landings increased over the last three years: 45.5 t in 2017, 52.4 t in 2018, and 89.1 t in 2019 (Figure 3).

The relative participation of *Scomberomorus* in the total production of Matinhos increased from 0.6-8.4% in 1970-1974, and 5.4-15.3% in 1991-1994, to 32.8-37.9% in 2017-2019 (Figure 3).

The production throghouth the year was not uniform. Peaks higher than 30% of the total catch per year were registered in autumn months (1991-1994) and winter months (2017-2019), while the period from any month in

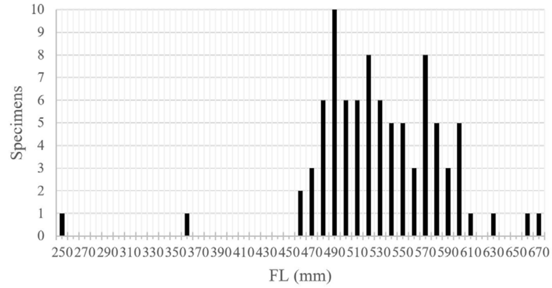

Figure 2. Number of *Scomberomorus brasiliensis* specimens landed by Matinhos fleet from March to June 2020 and studied respect to diet, according to the fork length (FL) class.

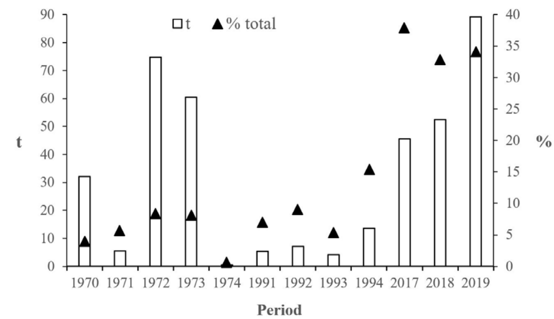

Figure 3. Annual landings of *Scomberomorus* species (1970-1973 and 1991-1994) and of *S. brasiliensis* (2017-2019) (t), and relative participation in fishery total landings (%) in Matinhos, Southern Brazil. Data sources: 1970-1974: Loyola-e-Silva and Nakamura (1975); 1991-1994: MMA/IBAMA (Brasil, 1995); and 2017-2019: FUNDEPAG (2020).

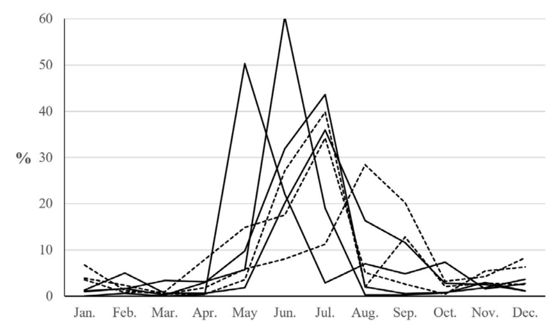

Figure 4. Monthly values of *S. brasiliensis* landings per month, relative (%) to total landing per year, in Matinhos, Southern Brazil. Solid lines: 1991-1994 period; dotted lines: 2017-2019 period. Data source: MMA/IBAMA (Brasil, 1995) and FUNDEPAG (2020).

October to April accounted for less than 10% of the annual production (Figure 4).

3.2. Diet

Three prey groups were found: 'fish' Frequency of Occurrence 100%; Proboscis worms "Nemertea" 12.2%, and 'squids' 5.4%. The last two prey items only occurred in May and June, with a FO inferior to 25% (Table 1). Furthermore, 40.5% of the stomachs had parasites.

The most common structure observed in prey 'fish' was crystalline lenses, which could number up to 59 in a single stomach. Otoliths, vertebral column, cycloid scales, and two types of ctenoid scales were also common. Other recognized fish structures were the head, tail and fins. The size of the heads and vertebral columns, which were about 0.5 to 7 cm long, indicated that the fish ingested were small in size, with 30 vertebrae in a 4 cm extension and the mouth of the prey fish in a superior position. In some stomachs, fish were mixed with small bivalves (1 mm). Concerning the prey 'Nemertea' the body was sometimes almost complete but displayed evidence of digestion, indicating that it was not a parasite. Among 'squids' the radula of *Ornithoteuthis antillarum* and *Hyaloteuthis pelagica* were identified (Table 2).

In order to calculate the numerical importance (%Ni), the number of vertebral columns, or the number of pairs of crystalline, or each of the three pairs of otoliths (the highest value between them) found in stomach contents indicated the number of fish ingested. Ctenoid plus cycloid scales in the stomach indicated a minimum of two fish ingested; each part of a Proboscis worm indicated one Nemertea, and each radula corresponded to one squid (Table 1). The %Ni values obtained were: 94.57% for fish, 3.99% for Nemertea and 1.45% for squids.

In order to calculate relative biomass, all prey structures were considered, resulting in the following values: 99.24% for fish, 0.27% for Nemertea and 0.49% for squids.

Therefore, the Relative Importance Index has resulted in 188.37 for fish, 1.00 for Nemertea and 0.18 for squid, and the relative participation of prey in the diet of *S. brasiliensis* was 99.68%, 0.27% and 0.05%, respectively.

Finally, the following TLi values were used to calculate the trophic level: 3.24 for fish: vertebral columns showed that they were teleosts; 2.5 for Nemertea, also following Cortés (1999); according to McDermott and Roe (1985), most of Nemertea have carnivorous habits; and 3.2 for *Hyaloteuthis pelagica* and *Ornithoteuthis antillarum*: these two squids feed on cephalopods, benthic and planktonic crustaceans, and worms (Palomares and Pauly, 2020; Arkhipkin et al., 1998, respectively). The trophic level of *S. brasiliensis* was 4.238 (Table 3).

4. Discussion

Commercial catch assessments must be done with caution. Many captures have not been reported, and because of the periodical turnover in fishing techniques, changes in landings do not necessarily reflect fish abundance (Pauly et al., 2013). The accuracy of the data is also limited when sampling methods change over time, which probably occurred in the present assessment. Even so, it was unequivocal to observe growth in *S. brasiliensis* landings with respect to total fishery production. Moreover, while the first two periods accounted for two *Scomberomorus* species together, the third period considered only *S. brasiliensis*. These facts highlight the role played by Serra Spanish mackerel in catches, performing better in 2017 to 2019 compared to the 70's and 90's.

Increased landings from 2017 to 2019 do not necessarily reflect the availability of this resource. These landings can be a result of higher fishery effort/efficacy by Matinhos fleet, including fishing gear and fishing areas; and/or low availability of other pelagic resources. The decline in mullet catches (*Mugil liza*) since the 2000s is one example; its catch increased due to purse seines fishing in Southern Brazil, and

Table 1. Number of specimens (n) of *S. brasiliensis* which stomach contents was recognized; fork length range (FL) of specimens; minimum-maximum number of prey units by stomach; and Frequency of Occurrence by prey (FO).

	n	FL (mm)	Preys: number by stomach and occurrence					
			Fish	FO	Nemertea	FO	Squids	FO
March	23	470-580	1-30	100%	0	0	0	0
April	17	250-600	1-7	100%	0	0	0	0
May	23	460-600	1-7	100%	1	22.7%	1	4.5%
June	24	360-670	1-8	100%	1-3	18.2%	1	13.6%

Table 2. Structures identified in stomach contents of *S. brasiliensis* according to prey: estimated prey number (N); percentage of stomachs where structures corresponding to such prey were present (%); mean number of stomachs structures by stomach (n); and fork length range of specimens (FL). Scales, tail and head of fish are omitted.

Prey	N	Structure	Stomach %	n (mean)	FL range (mm)
Fish	87	Crystalline	64.4	4.8	250-670
		Column	33.3	0.8	
		Otolith	9.2	0.2	
Nemertea	6	Body	100.0	1.0	460-600
Squids	4	Radula	100.0	1.2	460-600

Table 3. Values of Relative Biomass (%Bi), trophic level by prey (TLi), and resulting value of trophic level of *S. brasiliensis*.

Prey	%Bi	TLi	Bi*TLi
Fish	99.24	3.24	3.215
Nemertea	0.27	2.5	0.007
Squids	0.49	3.2	0.016
	TL= Σ(%Bi*Ti) + 1		4.238

affected small-scale fisheries (Herbst and Hanazaki, 2014; Abreu-Mota et al., 2018). They shifted attention to other targets such as mackerel, with emerged due to the loss in stock of mullet. Unfortunately, the data on the individual's length and weight are not available to compare with the three periods the present study considered to evaluate possible changes in catch selectivity.

Data on feeding habits only referred to four months, which neglected the possible role played by algae, cnidarians, and mollusks in other seasons. This possibility was reinforced by the fact that these items, together with fish, worms, and squids, comprise the diet of *S. brasiliensis* in Northeast Brazil (Menezes, 1970; Fonteles-Filho, 1988). Depending on availability, carnivorous species can add invertebrates to a diet based on fish; this is supported by observations of Winemiller (1989) in nine freshwater species, and by Hanson and Chouinard (2002) and Hall-Scharf et al. (2016) in cod and weakfish, respectively. The absence of invertebrates other than Nemertea and squid explains the high estimated trophic level for *S. brasiliensis*. It is similar to the average value of 4.2 cited by Cortés (1999) for scombrids, which is lower than 4.5 calculated for *S. cavalla* and *S. maculatus* in the Gulf of Mexico (Finucane et al., 1990), and higher than 3.6-3.8 in 'bentho-pelagic and large bentho-pelagic fishes' from the southeastern Brazilian bight (Nascimento et al., 2012), or 3.3 in *S. brasiliensis* from the northeast coast (Vasconcelos-Filho et al., 1984). However, the trophic level value that Vasconcelos-Filho et al. (1984) obtained for *S. brasiliensis* included estuarine juvenile specimens in their analysis.

The most common structure found in the samples is crystalline lenses. The size diversity of vertebral columns and crystalline lenses indicates that different sizes of fish, such as juveniles, adults, and/or different fish species, were ingested. This possibility was strengthened owing to findings ctenoid and cycloid scales within the same stomach content. Taking into account the scale shape, *S. brasiliensis* feeds on at least three species of fish. The mouth position of the prey's heads indicates they may be surface feeders that probably feed on small bivalves. Nemertea, with 45 species on the Brazilian coast (Mendes et al., 2016), is a food source for at least 27 fish species in the Northwest Atlantic, and it is also used as live bait for fishing off the coast of Africa (McDermott, 2001). Nematode worms, but not Nemertea, were determined to be part of the diets of *S. brasiliensis* and *S. maculatus* in the Northeast Brazilian coast and the Gulf of Mexico, respectively (Vasconcelos-Filho et al., 1984; Finucane et al., 1990). Squid predation is well known in Scombridae (Gorni et al., 2013). It includes the *Scomberomorus* species (Vasconcelos-Filho et al., 1984; Finucane et al., 1990), and *S. brasiliensis* (Loliginidae, pelagic – Fonteles-Filho, 1988). *Hyaloteuthis pelagica* and *Ornithoteuthis antillarum* are commonly found in the guts of tuna, swordfish and birds on the Brazilian coast (Vasque-Junior, 2005; Cherel et al., 2007), including Southern Brazil (Santos and Haimovici, 2002), but none of these studies cited ingestion by *S. brasiliensis*.

It has been argued that mackerels show an inherent resilience to overfishing, which Juan-Jordá et al. (2011) attributed to their fast-growing, early-maturing, and short lifespan. In some areas in Northern Brazil *S. brasiliensis* fisheries were considered as collapsed (Almeida et al., 2011), but the collapse of a fishery resource is not necessarily a consequence of trophic restrictions. Gaichas et al. (2015) showed that control mechanisms (top-down, bottom-up, mixed) vary between ecosystems, resulting in different responses to fishery resources. This is the case when comparing the Bering Sea and Gulf of Alaska, where food web structures differ when viewed from the perspective of the walleye pollock, *Gadus chalcogrammus* (Gaichas et al., 2015). In fact, a global assessment by Pinsky et al. (2011) has demystified a necessary correlation between high trophic levels and overexploitation. Among top predators, those with trophic level > 4.2 have collapsed in only 12% of stocks around the world, while low trophic-level resources < 3.3 have collapsed up to 25%.

The Serra Spanish mackerel in Matinhos, trophic level 4.238, exemplifies a case where landings have increased over time, despite the high trophic level of this resource. The effect this fact plays on the trophic level of local fisheries remains unknown. Potentially, it is similar to that described by Vasconcellos and Gasalla (2001) in Southern Brazil during the late 1980's and early 1990's, when the important catches of tuna and shark, and the collapse of the Brazilian sardine, lead to an increase in the mean trophic level of fisheries (from 2.8 to 3.1). It highlights the importance of continuous assessments on fishery dynamics in Brazilian coast, evaluating biomass, effort, landings, and the life history traits of resources, a basis for fisheries management.

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