Journal of the Marine Biological Association of the United Kingdom

cambridge.org/mbi

Investigating food assimilation in a carnivorous teleost by stable isotopes analysis: the case of ribbonfish off south-east Brazil

Ana Paula Madeira Di Beneditto, Pedro Viana Gatts
and Vanessa Trindade Bittar

Laboratório de Ciências Ambientais, Centro de Biociências e Biotecnologia, Universidade Estadual do Norte Fluminense Darcy Ribeiro – UENF, Av. Alberto Lamego, 2000, Campos dos Goytacazes, RJ, 28013-602, Brazil

Original Article

Cite this article: Di Beneditto APM, Gatts PV, Bittar VT (2020). Investigating food assimilation in a carnivorous teleost by stable isotopes analysis: the case of ribbonfish off south-east Brazil. *Journal of the Marine Biological Association of the United Kingdom* **100**, 445–451. https://doi.org/10.1017/S0025315420000338

Received: 13 November 2019
Revised: 2 March 2020
Accepted: 16 March 2020
First published online: 20 April 2020

Key words:
Coastal waters; feeding; mixing models; stable isotopes; teleosts

Author for correspondence:
Ana Paula Madeira Di Beneditto,
E-mail: anapaula@uenf.br,
anadibeneditto@gmail.com

Abstract

This study verifies the food assimilation of a carnivorous teleost in different timescales (weeks *vs* months) and evaluates how it uses the food sources. The target species is the adult ribbonfish, *Trichiurus lepturus*, a voracious teleost caught in commercial fisheries off south-east Brazil (21°S–22°S). The isotope models indicated *Chirocentrodon bleekerianus* as the main food in the ribbonfish diet in the last weeks (liver: 38.5%; 95% credible intervals: 3.4–73.9%) and last months (muscle: 36.2%; 95% credible intervals: 3.4–68.7%). The contribution of other food sources ranges from 10–16% (liver) and from 10–20% (muscle). Food assimilation remains similar at different timescales. The isotope models suggested a strong and long-lasting association of the adult females of ribbonfish with coastal waters along the study area.

Introduction

The ribbonfish, *Trichiurus lepturus* (Linnaeus, 1758), is one of the 10 most important species targeted by marine fisheries worldwide. Its annual catch (1.2–1.3 million tons) has been stable since 2008, i.e. fishery data do not indicate species decline over the last 10 years (FAO, 2014, 2019). The species is listed as 'least concern' (LC) in the IUCN Red List of Threatened Species, with a stable population trend (Collette *et al.*, 2015). The latest fishery data from Brazil was published in 2011, indicating its presence in commercial landings (2500 annual tons) (http://www.icmbio.gov.br/cepsul/images/stories/biblioteca/download/estatistica/est_2011_bol__bra.pdf).

This teleost is a widely distributed mesopredator in tropical and subtropical latitudes, forming large shoals in brackish and marine waters up to 350 m depth, being more common up to 120 m depth (Martins & Haimovici, 1997; Alt *et al.*, 2018; Froese & Pauly, 2019). Mesopredators, such as the ribbonfish, are medium-sized predators that drive community structure through predation on small prey. The apex predators (e.g. large sharks and cetaceans), in turn, limit the density of mesopredators so that the total predation pressure over small prey is contained. Therefore, fluctuations in predator populations (both apex and mesopredators) may have cascading effects across the food web, reducing or increasing the prey populations with further implications for all community structure and ecosystem functioning (Estes *et al.*, 2011; Wallach *et al.*, 2015). No data are available on fluctuations in the population dynamics of the ribbonfish, but a parallel can be made with other fish species. Shelton & Mangel (2011) analysed fluctuations of fish populations through a global sample of commercially exploited fish species, and concluded that environmental variations that affect mortality, reproduction and recruitment, together with human exploitation, dramatically alter the temporal variability in abundance of fish populations. The authors also highlighted predator–prey interaction as a hypothesis to explain fluctuations in fish abundance.

The ribbonfish has an aggregate and voracious feeding behaviour, taking advantage of its big eyes (visual predator) and oral apparatus with large jaws to actively catch their prey (Martins *et al.*, 2005; Froese & Pauly, 2019). There is size disparity among conspecifics, with diet shift during the ontogeny: juveniles, sub-adults and small adults up to 100 cm length feed mostly on euphausiids, small pelagic planktonic crustaceans and small fishes, whereas adults over 100 cm length feed mainly on fish, squids and crustaceans (Nakamura & Parin, 1993). Adult cannibalism of juveniles is reported for the ribbonfish (Martins *et al.*, 2005; Bittar *et al.*, 2008; Liu *et al.*, 2009; Cruz-Torres *et al.*, 2014), although it is not a general rule (Yan *et al.*, 2011; Alt *et al.*, 2018). Adults and juveniles display opposite vertical migration in the water column that minimizes feeding competition. Large adults usually feed near the surface during the daytime and migrate to the sea bottom at night, while juveniles remain near the bottom during the daytime and form loose feeding aggregations near the surface at night (Froese & Pauly, 2019). Studies on feeding habits of the ribbonfish showed high prey diversity in the stomach contents (16–58 prey species); however, no more than 10–20% are really important to its diet (Martins *et al.*, 2005; Chiou *et al.*, 2006; Bittar *et al.*, 2008; Liu *et al.*, 2009; Yan *et al.*, 2011).

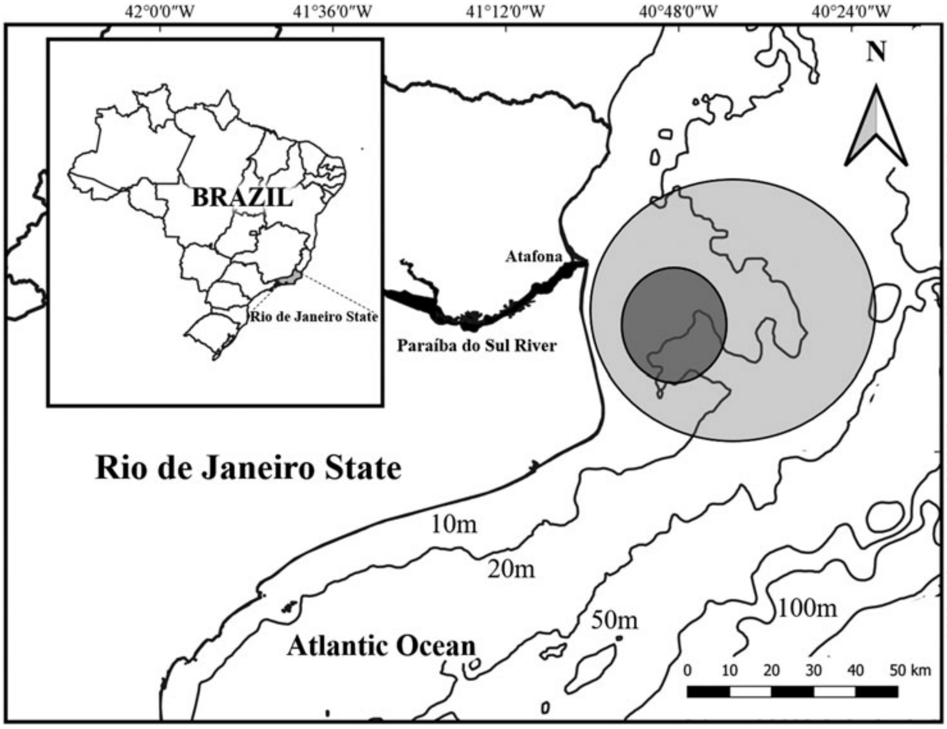

Fig. 1. Sampling area where adult ribbonfish (light grey) and their food sources (dark grey) were caught off south-east Brazil.

Stomach content analysis is a traditional method to evaluate feeding habits, which is applied in fish trophic ecology studies (e.g. Elston *et al*., 2015; Greenwell *et al*., 2018; Jansen *et al*., 2019). This low cost method allows prey identification, quantification and original size estimates, but it has bias in data interpretation. Stomach content analysis shows a diet 'snap-shot' (sometimes only the last meal), and can lead to misinterpretation because of differences in prey digestion rates, under- or overestimating the contribution to consumer diet, especially when the sample size is low and/or the sampling effort was not done in the long term (Pierce & Boyle, 1991).

Stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotopes have provided data on fish feeding ecology to understand trophic relationships and feeding assimilation, integrating diet over time (Di Beneditto *et al*., 2018; Landry *et al*., 2018). The enrichment for $\delta^{15}N$ among trophic levels is more obvious than for $\delta^{13}C$, which is usually applied to indicate different carbon source diets (e.g. inshore *vs* offshore, pelagic *vs* benthic, coastal *vs* oceanic) (Fry, 2008). Because different tissues metabolize proteins and carbohydrates at different rates, food is incorporated into consumer tissues at rates specific to each tissue-turnover rate. The liver has a faster turnover rate as compared with muscle, reflecting the food assimilation over the last weeks and months, respectively (Caut *et al*., 2009).

The discrimination factors ($\Delta^{15}N$ and $\Delta^{13}C$), also known as trophic enrichment factors, are key parameters in any isotope model, representing the isotopic difference between consumer tissue and their food sources after they reached equilibrium (Parnell *et al*., 2010). In the absence of species-specific discrimination factors from controlled diet experiments (constant isotopic diet), these variables can be obtained from phylogenetically related species, considering the same tissue (Newsome *et al*., 2007). There will always be some uncertainty and variability associated with discrimination factors; however, a well-known diet of a wild population can also be useful for $\Delta^{15}N$ and $\Delta^{13}C$ estimates when controlled experiments are lacking or when values from phylogenetically related species do not fit the isotope model (Newsome *et al*., 2010; Phillips *et al*., 2014).

This study verifies the food assimilation of the adult ribbonfish caught off south-eastern Brazil (~21°–22°S) in different timescales (weeks *vs* months) by applying isotope models to evaluate how this mesopredator uses the food sources. In this region, its feeding habit was well described by Bittar *et al.* (2008, 2012) through stomach content analysis of 350 individuals caught monthly from 2004 to 2006. Unfortunately, nothing else about its local feeding habit has been updated since then, and these previous data are the only available information to support the isotope models to predict the feeding assimilation. The question raised here is: Is the food assimilation similar or variable at different timescales? The answer may indicate how lasting is the association of the ribbonfish with the feeding area.

The ribbonfish populations are not threatened by fisheries, but the species' ecological role as a mesopredator, limiting prey populations, is important for top-down control in the marine environment. Thus, the understanding of its trophic relationships with the prey species is a baseline to track eventual changes in prey availability and, in turn, changes in the marine food web structure.

Materials and methods

Sampling area

The sampling area encompassed coastal waters off south-east Brazil, from 21°18′–22°01′S, up to 50 m depth (Figure 1). Along this area, commercial fisheries with gillnets, trawl nets and fishing lines are practised with 10–13 m long motorized wooden boats (Di Beneditto *et al*., 2001; Bonfim *et al*., 2017).

Sampling of adult ribbonfish and their food sources

The ribbonfish were caught by gillnet fisheries during 2010 (Table 1). The individuals were sampled at Atafona fishing harbour (21°35′S) during landings, and only fish greater than 100 cm length (adults) were considered in this study. The length of maturity for this species is 50.6 cm, and individuals with 100 cm

Table 1. Sampling month, sample size, length and mean isotopic values ($\delta^{15}N$ and $\delta^{13}C$) of the adult females of ribbonfish and preferred food sources off south-east Brazil (21°S–22°S)

Species	Sampling month (2010)	Sample size	Length (cm) (min to max, mean ± SD)	$\delta^{15}N$ (‰) (mean ± SD)	$\delta^{13}C$ (‰) (mean ± SD)
T. lepturus (adult females)					
Liver	Jan, May, Jul, Oct	35 (8–9 per month)	122.0 to 154.0, 140.5 ± 7.7	14.5 ± 0.8	−17.1 ± 0.6[a]
Muscle	Jan, May, Jul, Oct	26 (6–7 per month)	107.0 to 161.0, 143.5 ± 10.2	14.9 ± 0.5	−16.8 ± 0.6
Sources					
T. lepturus (juvenile)	May, Oct	12 (6 per month)	37.0 to 49.0, 43.5 ± 4.4	12.9 ± 0.4	−17.3 ± 0.5
Pellona harroweri	May, Oct	10 (5 per month)	7.0 to 12.0, 10.0 ± 1.0	13.0 ± 0.7	−17.3 ± 0.5
Doryteuthis spp.	May, Oct	20 (10 per month)	4.0 to 6.0, 5.0 ± 0.7	11.7 ± 0.6	−17.1 ± 0.5
Chirocentrodon bleekerianus	May, Oct	18 (9 per month)	8.0 to 11.0, 10.0 ± 0.8	12.3 ± 0.3	−17.2 ± 0.3
Xiphopenaeus kroyeri	May, Oct	16 (8 per month)	7.0 to 12.0, 8.0 ± 1.4	10.9 ± 0.6	−15.9 ± 0.6

[a] Lipid-corrected value.

or greater are already adults (Froese & Pauly, 2019). During necropsies for muscle and/or liver sampling, a visual inspection of the gonads was done; however, histological procedures to check the reproductive activity were not done. Thus, the individuals were considered adults based on the total length only (>100 cm).

The individuals were already eviscerated during landings, and stomach and intestine were discharged at sea by the fishers. The fishers kept the gonads because this organ has commercial value in local markets. In some individuals, the liver was kept in the abdominal cavity and we could sample it. It justifies why the stomach contents were not analysed, and why we did not have muscle and liver samples from the same individual. A sample from the back dorso-lateral muscle (3 g of wet weight) and/or liver (2 g of wet weight) was removed and kept frozen (−18 °C) in dry sterile vials prior to stable isotopes analyses.

The sampling of the main prey species (hereafter named food sources) was based on Bittar *et al.* (2008, 2012) for the same study area. The food sources that support the isotope models are: juvenile conspecifics, the fish *Pellona harroweri* and *Chirocentrodon bleekerianus*, the squid *Doryteuthis* spp. and the shrimp *Xiphopenaeus kroyeri*. Phillips *et al.* (2014) highlighted that the isotope models should not miss relevant food sources to the consumer's diet, but also should consider the number of sources to include. These authors alert that the number of food sources should be kept as low as possible, since the discriminatory power of models starts to decline markedly above six or seven food sources.

In 2010, the main food sources were sampled along the sampling area of the adult ribbonfish (Figure 1). The samplings were done during regular trawl net fisheries. A sample from the muscle (1 g of wet weight) was removed and kept frozen (−18 °C) in dry sterile vials prior to stable isotopes analyses (Table 1).

Stable isotopes analysis

Freeze-dried samples (ribbonfish and food sources) were ground with mortar and pestle to a homogeneous fine powder. Approximately 0.4 mg (dry weight) of tissues were weighed in tin capsules for the analysis. The elemental and isotopic composition of all samples were determined by using an Elemental Analyzer (Flash 2000) with interface CONFLO IV coupled to an isotope ratio mass spectrometer Delta V Advantage (Thermo Scientific, Germany) in Laboratório de Ciências Ambientais at Universidade Estadual do Norte Fluminense Darcy Ribeiro – UENF.

The samples were analysed with analytical blanks and urea analytical standards (IVA Analyzentechnik-330802174; CH_4N_2O $M_w = 60$, $C = 20\%$, $N = 46\%$), using certified isotopic compositions ($\delta^{13}C = -39.89‰$ and $\delta^{15}N = -0.73‰$). Analytical control was done for every 10 samples using certified isotopic standard (Elemental Microanalysis Protein Standard OAS: 46.5 ± 0.78% for C; 13.32 ± 0.40% for N; −26.98 ± 0.13‰ for $\delta^{13}C$; + 5.94 ± 0.08‰ for $\delta^{15}N$). Carbon and nitrogen contents were expressed as per cent element (%) and the detection limits were 0.05% and 0.02%, respectively. Carbon and nitrogen isotope ratios were expressed in δ notation as ‰ relative to Pee Dee Belemnite (PDB) and atmospheric nitrogen, respectively. Analytical reproducibility was based on triplicates for every 10 samples: ± 0.3‰ for $\delta^{15}N$ and ± 0.2‰ for $\delta^{13}C$. The $\delta^{13}C$ values for liver, a high lipid tissue, were arithmetically corrected by the equation proposed by Logan *et al.* (2008) ($\delta^{13}C' = 0.967 \times \delta^{13}C + 0.861$) to not compromise the $\delta^{13}C$ interpretation (Post *et al.*, 2007).

Data analysis

A *t*-test and ANOVA with Tukey *post hoc* test ($\alpha = 0.05$) in the software R version 3.6.1 (R Core Team, 2019) evaluated the difference of means between the ribbonfish tissues (liver *vs* muscle) and among the ribbonfish tissues and each food source ($n = 5$) regarding isotopic values, respectively. When necessary, a maximum likelihood function (boxcox, MASS package, Venables & Ripley, 2002) was used for variable transformation to meet the parametric tests assumptions (linearity, normality, homoscedasticity).

The contribution of food sources to ribbonfish diet was estimated using Bayesian mixing models in the R package MixSIAR (Stock & Semmens, 2016). These models allow for the uncertainty associated with isotopic values and diet-to-tissue discrimination factors. The isotopic values for liver and muscle were modelled separately because they have different discrimination factors and represent food assimilation in different timescales. Each model was run with Markov Chain Monte Carlo (MCMC) (three replicate chains) in a chain length of 100,000 iterations, a burn-in of 50,000 iterations and a thinning rate of every 50th iteration across three chains. Models included a residual error term. The Gelman–Rubin and Geweke diagnostics were used to check model suitability (Stock & Semmens, 2016). MixSIAR results were reported for each tissue and food source as a posterior density distribution of proportional contributions

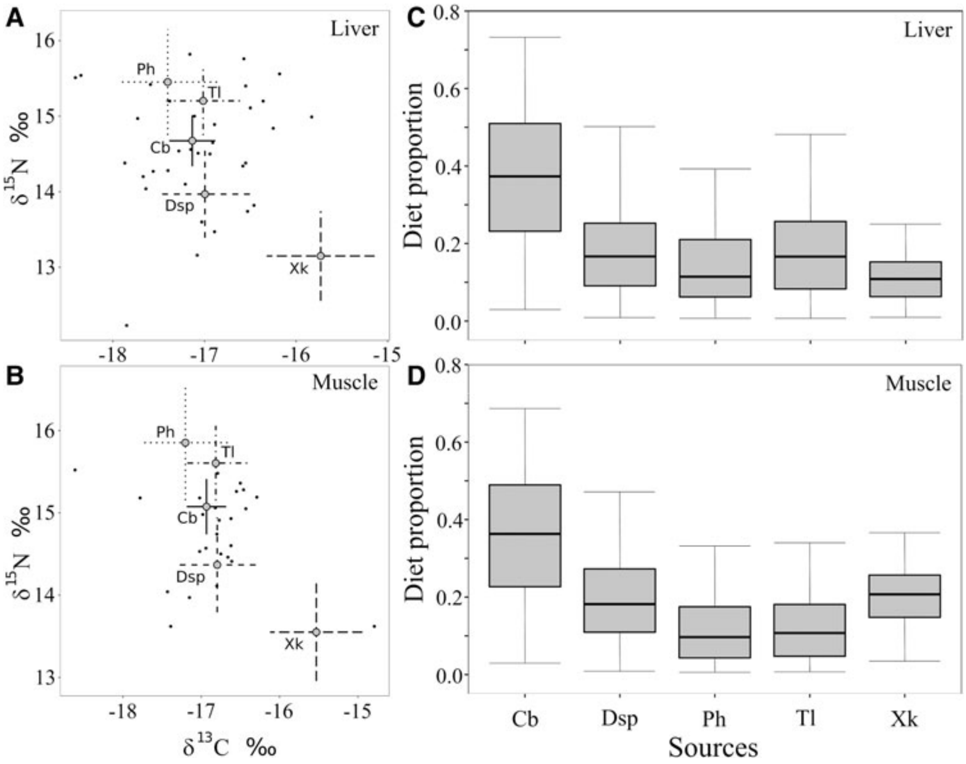

Fig. 2. Biplot of stable isotope values of the adult females of ribbonfish (small black dots) and food sources represented with the mean value of each group and 95% confidence intervals, which incorporate the error in the food source isotopic values and in the diet-to-tissue discrimination factors (A: liver and B: muscle), and isotopic model results (95, 75 and 50% credibility intervals) showing the estimated contributions of food sources to the ribbonfish diet off south-east Brazil (21°S–22°S) (C: liver and D: muscle). Cb: *Chirocentrodon bleekerianus*, Dsp: *Doryteuthis* spp., Ph: *Pellona harroweri*, Tl: *Trichiurus lepturus* and Xk: *Xiphopenaeus kroyeri*.

to consumer mixture data (median dietary proportions with associated credibility intervals).

Since there are no available data in literature on discrimination factors for the ribbonfish and the available data for other carnivorous teleosts varied widely among species and tissues (Matley *et al.*, 2016), we calculated the discrimination factors based on isotopic values of the ribbonfish and their food sources (mean of the five preferred prey species). The $\Delta^{15}N$ and $\Delta^{13}C$ applied to the models were 2.2‰ and 0.1‰ (liver) and 2.6‰ and 0.3‰ (muscle), respectively. MixSIAR permits a zero (0) value as standard deviation to discrimination factors data (Stock & Semmens, 2016).

Results

The sampled ribbonfish included adult females only, as verified by ovaries presence. The isotopic values of ribbonfish's liver and muscle were comparable between each other ($\delta^{15}N$: $t = 1.0262$, $P = 0.3089$; and $\delta^{13}C$: $t = 1.5277$; $P = 0.1319$) (Table 1). The comparison among ribbonfish and food sources showed higher $\delta^{15}N$ values for the former, with differences among food sources (liver: $F = 95.54$ and muscle: $F = 124.66$; $P < 0.0001$; ribbonfish > conspecifics = *Pellona harroweri* = *Chirocentrodon bleekerianus* > *Doryteuthis* spp. > *Xiphopenaeus kroyeri*). For $\delta^{13}C$, the shrimp *X. kroyeri* presented higher values than ribbonfish and other food sources (liver: $F = 19.49$ and muscle: $F = 19.01$; $P < 0.0001$; *X. kroyeri* > ribbonfish = conspecifics = *P. harroweri* = *C. bleekerianus* = *Doryteuthis* spp.) (Table 1).

The isotope models had a good convergence because the Gelman–Rubin diagnostics were smaller than 1.05 and Geweke dignostics were similar among 3 chains (liver: chain 1 = 0, chain 2 = 0, chain 3 = 1; muscle: chain 1 = 1, chain 2 = 0, chain 3 = 0). The trophic mixing space shaped by food sources that contributed to the diet of each ribbonfish is indicated in Figure 2. The models indicated *C. bleekerianus* as the main contributor to the ribbonfish diet in the last weeks (liver: 38.5%; 95% credible intervals: 3.4–73.9%) and last months (muscle: 36.2%; 95% credible intervals: 3.4–68.7%). Thus, this fish is responsible for the greatest energy transfer to the ribbonfish. The contribution of other food sources ranged between 10 and 16% (liver) and between 10 and 20% (muscle) (Figure 2).

Discussion

The isotope models showed that the feeding assimilation of the adult ribbonfish remained similar in different timescales. The species showed a lasting association with coastal waters in the sampling area, and a diet shift was negligible, at least from the last weeks (liver) to the last months (muscle). The fish *Chirocentrodon bleekerianus* was the most assimilated food source in both timescales, whereas the contribution from other food sources to the diet was two or three times lower. These findings diverge from previous data reported by Bittar *et al.* (2008, 2012), whose stomach content analysis pointed to juvenile conspecifics as the main food source and indicated cannibalism as an important feeding tactic to this mesopredator.

Our sampling area overlaps with the one studied by Bittar *et al.* (2008), and the ribbonfish analysed in both studies were all adult individuals, with similar length class amplitude (107.0–161.0 cm *vs* 100.0–163.0 cm). Although juvenile conspecifics represented only 8% of the fish frequency in the stomach contents analysed by Bittar *et al.* (2008), this food source represented 40% of the fish biomass ingested by the adult ribbonfish. For *C. bleekerianus*, these percentages were 9% and 10%, respectively. Meanwhile, the caloric value of both food sources are comparable, around 420 kcal g^{-1} dry mass (Bittar *et al.*, 2012). For teleosts, cannibalism has been reported for only 1% of the species (Pereira *et al.*, 2017). For adult ribbonfish, this behaviour was related to a decrease in other food sources (Martins *et al*., 2005; Lin *et al*., 2009), but it is also an ancestral behaviour of fish from the Trichiuridae family (Prikryl & Novosad, 2009). The opposite vertical migration in the water column is not only a ribbonfish behaviour to minimize feeding competition between adults and juveniles (Froese & Pauly, 2019), but it also probably decreases the cannibalism rate.

Differences in methodological approaches (stomach contents *vs* isotope models) might explain, at least in part, divergences between Bittar *et al*. (2008, 2012) and this study. Stomach content analysis considers what was ingested in the last meals, while isotope models analyse the food assimilation over time (days, weeks, months or years, according to the tissue); i.e. what was really incorporated by the consumer after ingestion, digestion and excretion. Moreover, prey identification and quantification through stomach content analysis of marine predators are made mainly by hard remains recovered, such as otoliths, bones, beaks and carapaces. Since prey have different digestion rates, under- or overestimates of feeding preference may happen (Pierce & Boyle, 1991). This is another possible explanation for the observed differences in ribbonfish feeding preferences (conspecifics in 2004–2006 *vs C. bleekerianus* in 2010) according to different methodological approaches.

The time interval between Bittar *et al*. (2008, 2012) and this approach probably influences the comparison between studies because prey availability (and predator feeding preference) could have changed over the years. Bittar *et al*. (2008, 2012) described the feeding preference for samples obtained from 2004 to 2006, and our sampling was done in 2010, 4–6 years later. The fish feeding in natural habitats can temporarily change because of environmental influences (e.g. temperature, dissolved oxygen), biological influences (e.g. competition) and/or human exploitation that alter the prey availability (Bearzi *et al*., 2006; Baumgartner, 2007; Costalago *et al*., 2012). The combined analysis of tissue samples for the isotopic approach and stomach contents from individuals caught in the same sampling or in different samplings, but respecting a temporal interval for isotopic assimilation is recommended for reliable comparisons between different methods (Polito *et al*., 2011; Kohlbach *et al*., 2017; Silveira *et al*., 2020). Since our stable isotopes data were not compared with stomach content analysis from the same ribbonfish and/or temporal interval, more inferences to explain these differences would be somewhat speculative.

The isotope mixing models are particularly powerful when the results of previous dietary studies are used in the analysis to address questions about feeding preference and assimilation, for instance, and when predators and food sources are obtained in close temporal and spatial scales (Phillips *et al*., 2014). In this study, the isotope models were based on previous dietary studies from the same sampling area, and both adult ribbonfish and food sources were sampled in the same area during 2010. Moreover, the Bayesian model for solving isotope mixing models yields consistent results even in low sample size (from 10 samples) (Jackson *et al*., 2011). Thus, our sampling meets the assumptions of isotope mixing models.

The most ingested and assimilated food sources by the adult ribbonfish are coastal species (<50 m depth) that are common year-round targets or by-catch in coastal fisheries (Di Beneditto *et al*., 2001; Fernandes *et al*., 2014). These food sources have been recorded as prey for other coastal vertebrates locally, such as dolphin, penguin and catfish (Bittar & Di Beneditto, 2009; Di Beneditto *et al*., 2015; Tavares & Di Beneditto, 2017; Di Beneditto & Tavares, 2019). Thus, these indirect indicators (presence in fisheries and food sources to other predators) reveal their high abundance to the ribbonfish locally. However, even inhabiting tropical and subtropical waters with high prey diversity, this mesopredator selects a few food sources as preferred, as previously reported in other areas throughout its home range (Martins *et al*., 2005; Chiou *et al*., 2006; Lin *et al*., 2009; Yan *et al*., 2011).

Adult ribbonfish usually feeds near the sea surface, migrating to the bottom at night (Froese & Pauly, 2019). In the sampling area, the fish *C. bleekerianus* (most assimilated food source) and *Pellona harroweri* are typical pelagic species that form shoals near the sea surface, favouring their catches. Meanwhile, the other food sources have distinct behaviour in the water column. The juvenile conspecifics, the squid *Doryteuthis* spp. and the shrimp *Xiphopenaeus kroyeri* remain near (or buried at) the bottom during the daytime, swimming near the sea surface (or vertically migrating in the water column) at night (Roper *et al*., 1984; Willems *et al*., 2016; Froese & Pauly, 2019). The presence of these prey in the ribbonfish's diet indicates that in the sampling area its feeding activity is intense, occurring both at daytime and night.

The nitrogen isotope values indicate the higher trophic position of the adult ribbonfish relative to their food sources, as expected (Fry, 2008). The $\delta^{15}N$ values of the food sources may reflect their own feeding habits and/or features such as body size, age and excretion metabolism, that either alone or combined may influence the isotopic values (Caut *et al*., 2009). The carbon isotopic values are within the expected range for marine coastal species from the study area (Di Beneditto *et al*., 2012). Higher $\delta^{13}C$ values for the shrimp *X. kroyeri* reflect its benthic habit, with strong association with sediment (Willems *et al*., 2016).

The isotope models that predicted the feeding assimilation of the ribbonfish showed a strong and lasting association of adult females with coastal waters off south-east Brazil (21°S–22°S). Although many prey species are recorded as food sources, as demonstrated by previous stomach content analysis, the isotope models highlighted only one as the most assimilated prey in the sampling area. Therefore, local temporal changes in prey availability might be assessed through the feeding preference of this mesopredator. Since the ribbonfish is a commercial species and, therefore, easy to sample in fishing harbours, it is an interesting model for monitoring eventual fluctuations in prey populations, not only in coastal waters off south-east Brazil, but also along its home range.

Acknowledgements. We are grateful to Dr Marcelo Gomes de Almeida from UENF for the stable isotopes analysis in the consumer and sources samples and to Silvana Ribeiro Gomes for the help during the sampling.

Financial support. This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (grant number 301.259/2017-8) and the Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro – FAPERJ (grant numbers E-26/202.770/2017, E-26/210.064/2018, E-26/210.883/2016).

References

Alt KG, Kuhn T, Münster J, Klapper R, Kochmann J and Klimpel S (2018) Mesopredatory fishes from the subtropical upwelling region off NW-Africa characterized by their parasite fauna. *PeerJ* **6**, e5339.

Baumgartner LJ (2007) Diet and feeding habits of predatory fishes upstream and downstream a low-level weir. *Journal of Fish Biology* **70**, 879–894.

Bearzi G, Politi E, Agazzi S and Azzellino A (2006) Prey depletion caused by overfishing and the decline of marine megafauna in the eastern Ionian Sea coastal waters (central Mediterranean). *Biological Conservation* **127**, 373–382.

Bittar VT and Di Beneditto APM (2009) Diet and potential feeding overlap between *Trichiurus lepturus* (Osteichthyes: Perciformes) and *Pontoporia blainvillei* (Mammalia: Cetacea) in northern Rio de Janeiro, Brazil. *Zoologia* **26**, 374–378.

Bittar VT, Castello BFL and Di Beneditto APM (2008) Hábito alimentar do peixe-espada adulto, *Trichiurus lepturus*, na costa norte do Rio de Janeiro, sudeste do Brasil. *Biotemas* **21**, 83–90.

Bittar VT, Awabdi DR, Tonini WCT, Vidal Júnior MV and Di Beneditto APM (2012) Feeding preference of adult females of ribbonfish *Trichiurus lepturus* L. 1758 through prey proximate-composition and caloric values. *Neotropical Ichthyology* **10**, 93–203.

Bonfim BC, Santos AFGN and Di Beneditto APM (2017) A pesca extrativa marinha no porto de Atafona, São Joção da Barra – RJ: passado e presente. *Brazilian Journal of Aquatic Science and Technology* **21**, http://dx.doi.org/10.14210/bjast.v21n1.10346.

Caut S, Angulo E and Courchamp F (2009) Variation in discrimination factors (d15N and d13C): the effect of diet isotopic values and applications for diet reconstruction. *Journal of Applied Ecology* **46**, 443–453.

Chiou WD, Chen CY, Wang CM and Chen CT (2006) Food and feeding habits of ribbonfish *Trichiurus lepturus* in coastal waters of south-western Taiwan. *Fisheries Science* **72**, 373–381.

Collette BB, Smith-Vaniz WF, Hartmann S, Bishop J, Almukhtar M, Al-Husaini M, Alghawzi Q, Kaymaram F, Abdulqader E and Alam S (2015) *Trichiurus lepturus. The IUCN Red List of Threatened Species.* Cambridge: IUCN, e.T190090A57283875 (Accessed 20 January 2020).

Costalago D, Navarro J, Álvarez-Calleja I and Palomera I (2012) Ontogenetic and seasonal change in the feeding habits and trophic levels of two small pelagic fish species. *Marine Ecology Progress Series* **460**, 169–181.

Cruz-Torres J, Martínez-Pérez JA, Franco-Ló J and Ramírez-Villalobos AJ (2014) Biological and ecological aspects of *Trichiurus lepturus* Linnaeus, 1758 (Perciformes: Trichiuridae) in Boca Del Rio, Veracruz, Mexico. *American-Eurasian Journal of Agriculture & Environmental Science* **14**, 1058–1066.

Di Beneditto APM and Tavares MTM (2019) Notes on the diet of adult yellow catfish *Aspistor luniscutis* (Pisces: Siluriformes) in northern Rio de Janeiro State, southeastern Brazil. *Journal of Threatened Taxa* **11**, 13920–13924.

Di Beneditto APM, Ramos RMA and Lima NRW (2001) *Os Golfinhos: Origem, classificação, captura acidental, hábito alimentar*, 1st Edn. Porto Alegre: Editora Cinco Continentes.

Di Beneditto APM, Bittar VT, Camargo PB, Rezende CE and Kehrig HA (2012) Mercury and nitrogen isotope in a marine species from a tropical coastal food web. *Archives of Environmental Contamination and Toxicology* **62**, 264–271.

Di Beneditto APM, Santos RA, Rosa KR and Siciliano S (2015) Magellanic penguins: stomach contents and isotopic profiles to assess the feeding demands of juveniles in a wintering area off Brazil. *Journal of the Marine Biological Association of the United Kingdom* **95**, 423–430.

Di Beneditto APM, Tavares MTM and Monteiro LR (2018) Isotopic niche of the catfishes *Bagre bagre* and *Genidens barbus* in a coastal area of southeastern Brazil. *Biota Neotropica* **18**, e20180527.

Elston C, von Brandis RG and Cowley PD (2015) Gastric lavage as a non-lethal method for stingray (Myliobatiformes) diet sampling. *African Journal of Marine Science* **37**, 415–419.

Estes JA, Terborgh J, Brashares JS, Power ME, Berger J, Bond WJ, Carpenter SR, Essington TE, Holt RD, Jackson JBC, Marquis RJ, Oksanen L, Oksanen T, Paine RT, Pikitch EK, Ripple WJ, Sandin AS, Csheffer M, Schoener TW, Shurin JB, Sinclair ARE, Sulé mE, Virtanen R and Wardle DA (2011) Trophic downgrading of planet earth. *Science (New York, N.Y.)* **333**, 301–306.

FAO – Food and Agriculture Organization of the United Nations (2014) FAO Fisheries and Aquaculture Department. Summary tables of fishery statistics. http://www.fao.org/fishery/docs/STAT/summary/default.htm (Accessed 10 November 2019).

FAO – Food and Agriculture Organization of the United Nations (2019) FAO Yearbook. Fishery and Aquaculture Statistics 2017. http://www.fao.org/fishery/static/Yearbook/YB2017_USBcard/booklet/CA5495T_web.pdf (Accessed 20 January 2020).

Fernandes LP, Keunecke KA and Di Beneditto APM (2014) Produção e socio economia da pesca do camarão sete-barbas no norte do Estado do Rio de Janeiro. *Boletim do Instituto de Pesca* **40**, 541–555.

Froese R and Pauly D (2019) FishBase. http://www.fishbase.org (Accessed 15 September 2019).

Fry B (2008) *Stable Isotope Ecology*, 3rd Edn. New York, NY: Springer-Verlag.

Greenwell CN, Coulson PG, Tweedley JR and Loneragan NR (2018) Regional differences in the feeding of the ambush predator *Neosebastes pandus* and comparisons of diets in the Scorpaenidae, Triglidae and Platycephalidae. *Journal of Fish Biology* **93**, 95–109.

Jackson AL, Inger R, Parnell AC and Bearhop S (2011) Comparing isotopic niche widths among and within communities: SIBER – Stable Isotope Bayesian Ellipses in R. *Journal of Animal Ecology* **80**, 595–602.

Jansen T, Post S, Olafsdottir AH, Reynisson P, Oskarsson GJ and Arendt KE (2019) Diel vertical feeding behaviour of Atlantic mackerel (*Scomber scombrus*) in the Irminger current. *Fisheries Research* **214**, 25–34.

Kohlbach D, Schaafsma FL, Graeve M, Lebreton B, Lange BA, David C, Vortkamp M and Flores H (2017) Strong linkage of polar cod (*Boreogadus saida*) to sea ice algae-produced carbon: evidence from stomach content, fatty acid and stable isotope analyses. *Progress in Oceanography* **152**, 62–74.

Landry JJ, Fisk AT, Yurkowski DJ, Hussey NE, Dick T, Crawford RE and Kessel ST (2018) Feeding ecology of a common benthic fish, shorthorn sculpin (*Myoxocephalus scorpius*) in the high arctic. *Polar Biology* **41**, 2019–2102.

Liu Y, Cheng J and Chen Y (2009) A spatial analysis of trophic composition: a case study of hairtail (*Trichiurus japonicus*) in the East China Sea. *Hydrobiologia* **632**, 79–90.

Logan JM, Jardine TD, Miller TJ, Bunn SE, Cunjak RA and Lutcavage ME (2008) Lipid corrections in carbon and nitrogen stable isotope analyzes: comparison of chemical extraction and modelling methods. *Journal of Animal Ecology* **77**, 838–846.

Martins AS and Haimovici M (1997) Distribution, abundance and biological interactions of the cutlassfish *Trichiurus lepturus* in the Southern Brazil subtropical convergence ecosystem. *Fisheries Research* **30**, 217–227.

Martins AS, Haimovici M and Palacios R (2005) Diet and feeding of the cutlassfish *Trichiurus lepturus* in the Subtropical Convergence ecosystem of southern Brazil. *Journal of the Marine Biological Association of the United Kingdom* **85**, 1223–1229.

Matley JK, Fisk AT, Tobin AJ, Heupel MR and Simpfendorfer CA (2016) Diet-tissue discrimination factors and turnover of carbon and nitrogen stable isotopes in tissues of an adult predatory coral reef fish, *Plectropomus leopardus. Rapid Communications in Mass Spectrometry* **30**, 29–44.

Nakamura I and Parin NV (1993) FAO Species Catalogue (Vol. 15). Snake mackerels and cutlassfishes of the world (families Gempylidae and Trichiuridae). An annotated and illustrated catalogue of the snake mackerels, snoeks, escolars, gemfishes, sackfishes, domine, oilfish, cutlassfishes, scabbardfishes, hairtails and frostfishes known to date. *FAO Fisheries Synopsis* 125, 136 pp.

Newsome SD, Del Rio CM, Bearhop S and Phillips DL (2007) A niche for isotopic ecology. *Frontiers in Ecology and Environment* **5**, 429–436.

Newsome SD, Bentall GB, Tinker MT, Oftedal OT, Ralls K, Estes JA and Fogel ML (2010) Variation in δ^{13}C and δ^{15}N diet-vibrissae trophic discrimination factors in a wild population of California sea otters. *Ecological Applications* **20**, 1744–1752.

Parnell AC, Inger R, Bearhop S and Jackson AL (2010) Source partitioning using stable isotopes: coping with too much variation. *PLoS ONE* **5**, e9672.

Pereira LS, Agostinho AA and Winemiller KO (2017) Revisiting cannibalism in fishes. *Review of Fish Biology and Fisheries* **27**, 499–513.

Phillips DL, Inger R, Bearhop S, Jackson AL, Moore JW, Parnell AC, Semmens BX and Ward EJ (2014) Best practices for use of stable isotope mixing models in food-web studies. *Canadian Journal of Zoology* **92**, 823–835.

Pierce GJ and Boyle PR (1991) A review of methods for diet analysis in piscivorous marine mammals. *Oceanography and Marine Biology: an Annual Review* **29**, 409–486.

Polito MJ, Trivelpiece WZ, Karnovsky NJ, Ng E, Patterson WP and Emslie SD (2011) Integrating stomach content and stable isotope analyses to quantify the diets of Pygoscelid penguins. *PLoS ONE* **6**, e26642.

Post DM, Layman CA, Arrington DA, Takimoto G, Quattrochi J and Montaña CG (2007) Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. *Oecologia* **152**, 179–189.

Prikryl T and Novosad B (2009) Direct evidence of cannibalism in the Oligocene cutlassfish *Anenchelum glarisianum* Blainvillei, 1818 (Perciformes: Trichiuridae). *Bulletin of Geosciences* **84**, 569–572.

R Core Team (2019) *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. Available at https://www.R-project.org/.

Roper CFE, Sweeney MJ and Nauen CE (1984) *FAO Species Catalogue (Vol. 3) – Cephalopods of the World*, 1st Edn. Rome: FAO. Available at http://www.fao.org/3/ac479e/ac479e00.htm.

Shelton AO and Mangel M (2011) Fluctuations of fish populations and the magnifying effects of fishing. *Proceedings of the National Academy of Sciences USA* **108**, 7075–7080.

Silveira EL, Semmar N, Cartes JE, Tuset VM, Lombarte A, Ballester ELC and Vaz-dos-Santos AM (2020) Methods for trophic ecology assessment in fishes: a critical review of stomach analyses. *Reviews in Fisheries Science & Aquaculture* **28**, 71–106.

Stock BC and Semmens BX (2016) *MixSIAR GUI User Manual*. Version 3.1. Vienna: The R Foundation. Available at https://github.com/brianstock/MixSIAR/.

Tavares MTM and Di Beneditto APM (2017) Feeding habits and behaviour of *Bagre bagre* and *Genidens barbus*, two ariid catfishes (Pisces: Siluriformes) from Southeastern Brazil. *Journal of Threatened Taxa* **9**, 10771–10775.

Venables WN and Ripley BD (2002) *Modern Applied Statistics with S*, 4th Edn. New York, NY: Springer-Verlag.

Wallach AD, Izhaki I, Toms JD, Ripple WJ and Shanas U (2015) What is an apex predator? *Oikos* **124**, 1453–1461.

Willems T, De Backer A, Kerkhove T, Dakriet NN, De Troch M, Vincx M and Hostens K (2016) Trophic ecology of Atlantic sea-bob shrimp *Xiphopenaeus kroyeri*: intertidal benthic microalgae support the subtidal food web off Suriname. *Estuarine Coastal and Shelf Science* **182**, 146–157.

Yan Y, Hou G, Chen J, Lu H and Jin X (2011) Feeding ecology of hairtail *Trichiurus margarites* and largehead hairtail *Trichiurus lepturus* in the Beibu Gulf, the South China Sea. *Chinese Journal of Oceanology and Limnology* **29**, 174–183.