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Different trade patterns and inspection rates along with the use of umbrella terms results in variable patterns of substitution in shark, hake, and flatfish sold in Minas Gerais, Brazil

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Substitution and mislabeling of fisheries products are problems across the world. They have been identified as resulting from economic drivers combined with deficits in legislation and inspection, but the role of differential trade between products has not been widely addressed. We investigated rates of mislabeling and substitution in three fisheries products in Minas Gerais, Brazil (shark, hake and flatfish) for which trading patterns vary. Substitutions in internationally traded products (shark and hake) were only found in uncertified products from fishmongers, indicating opportunistic sales of available perishable products. A higher rate of mislabeling was found in nationally traded flatfish, including in certified products, but this was considered unintentional. International differences in cultural demand for products (*e.g.*, shark fins *versus* shark meat) combined with variable food inspection rates across different points of sale can contribute to increasing the risk of substitutions. Frozen products from certified suppliers in Brazil are generally inspected by official government agents in campaigns focusing on supermarkets. These high-inspection systems have lower likelihoods of substitution but may present unintentional mislabeling. In contrast, fresh products from fishmongers are not targets of inspections. These low-inspection systems have higher likelihoods of intentional substitution that may be opportunistic depending on individual circumstances.

Keywords: Actinopterygii, Commercial routes, Elasmobranchs, Food fraud, Opportunism.

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A substituição e rotulagem incorreta de produtos pesqueiros constituem problemas globais. Eles são resultado de fatores econômicos, aliados à déficits de legislação e fiscalização, mas o papel do comércio diferenciado entre produtos não tem sido amplamente abordado. Investigamos as taxas de rotulagem incorreta e substituição em três produtos pesqueiros em Minas Gerais, no Brasil (tubarão, merluza e peixe-chato), onde padrões de comercialização variam. Substituições em produtos comercializados internacionalmente (tubarão e merluza) foram encontradas apenas em produtos não certificados de peixarias, indicando vendas oportunistas de produtos perecíveis disponíveis. Uma taxa maior de rotulagem incorreta foi observada em peixes-chatos comercializados nacionalmente, inclusive em produtos certificados, mas foi considerado não intencional. Diferenças internacionais na demanda cultural por produtos (por exemplo, barbatanas *versus* carne de tubarões), combinada com taxas variáveis de inspeção de alimentos em diferentes pontos de venda, podem contribuir para aumentar o risco de substituições. Produtos congelados de fornecedores certificados no Brasil são geralmente inspecionados por agentes governamentais oficiais em campanhas focando em supermercados. Esses sistemas de alta inspeção apresentam uma baixa probabilidade de substituição de produtos, mas também podem apresentar alguns erros não intencionais de rotulagem. Em contraste, produtos frescos de peixarias não são alvos dessas inspeções. Esses sistemas de baixa inspeção estão mais propensos a apresentar um maior risco de substituição intencional, que pode ser oportunista, dependendo das circunstâncias específicas.

Palavras-chave: Actinopterígeos, Elasmobrânquios, Fraude alimentar, Oportunismo, Rotas comerciais.

INTRODUCTION

The collapse of many commercially important fish stocks has led to an intense focus on seafood identification to support consumer-driven sustainable consumption (Logan *et al*., 2008; Mariani *et al*., 2015; Brechón *et al*., 2016; Carvalho *et al*., 2011, 2017a,b; Guardone *et al*., 2017; Delpiani *et al*., 2020). In Brazil, the official inspection of seafood products made by the Agriculture Ministry (Ministério da Agricultura, Agropecuária e Abastecimento - MAPA) has performed both traditional and molecular identification on seafood products sold in 14 Brazilian states (Carvalho *et al*., 2017a). Brazilian national legislation uses a hybrid system of umbrella terms, common names and taxonomic identification that aims to provide inspection cover for the most lucrative commercial species that are theoretically at most risk from overfishing (Brasil, 2004, 2015, 2020). Because of logistic challenges associated with the geographic scale of the country and the large numbers of artisanal fishermen and local markets, inspection does not cover sales from most local markets and street vendors. This facilitates fraud and mislabeling practices in non-industrial and informal trade routes (Palmeira *et al*., 2013; Ferrette *et al*., 2019; Rodrigues-Filho *et al*., 2020). Additionally, variation in the use of common names further complicates the inspection of fisheries products in different regions (Rodrigues-Filho *et al*., 2009; Brito *et al*., 2015).

The global consumption of fisheries products has increased above human population growth and now represents more than 9% of total agricultural exports (FAO, 2018). Much of this trade results from supply and demand issues associated with the differential trading powers, as well as cultural demands for certain products in different countries (Can *et al*., 2015). A combination of the scarcity of resources, the potential for higher profits, and weak legislation also encourage mislabeling (Jacquet, Pauly, 2008), but in some cases species substitution is not always intentional. For example, unintentional substitution may occur due to the difficulty of distinguishing species because of their morphological similarity (Schröder, 2007; Lo, Shaw, 2018; Donlan, Luque, 2019) or because of the use of the same or similar common names across various species (Brito *et al*., 2015). The latter is more likely to occur in processed products which no longer retain clear characteristics for morphological identification (Di Pinto *et al*., 2015). However, even in high value products such as tuna, common names can also be used to mislabel products (Vandamme *et al*., 2016).

Fisheries catch data and commercial trade data are essential to improve management actions/laws and predict economic drivers that can influence the supply and demand for fisheries products (Fox *et al*., 2018; Cawthorn *et al*., 2018; Ehmke *et al*., 2019). Some fish species are targeted for economic interests that result from demands for muscle consistency, flavor, or social status/cultural issues (Can *et al*., 2015). For example, the demand for shark fins, used to make soup in some Asian cultures, drives many shark fisheries across the world, including significant exports from Brazilian waters (Dent, Clarke, 2015; Ferrette *et al*., 2019). Brazil has been identified both as the main exporter of shark in the world (Dent, Clark, 2015) and, curiously, as the greatest importer of shark meat (Barreto *et al*., 2017; Dulvy *et al*., 2017). The high international demand combined with low inspection rates favor mislabeling that threatens protected species (Bornatowski *et al*., 2013). Endangered species including a variety of elasmobranchs and teleosts have been identified in shark products in many countries (Carvalho *et al*., 2015; Almerón-Souza *et al*., 2018; Calegari *et al*., 2019; Ferrito *et al*., 2019; Hobbs *et al*., 2019; Pazartzi *et al*., 2019; Delpiani *et al*., 2020; Bernardo *et al*., 2020; Marchetti *et al*., 2020).

In Brazil, shark fishing represents an important resource, with fins sold overseas and meat sold locally. Although shark meat is considered low quality, it is a cheap protein source for many people (Gemaque *et al*., 2017; Feitosa *et al*., 2018). On the other hand, products such as hake and flatfish are sold as high value products in Brazil, at least in part due to cultural inheritance of diets from Portugal (Maciel *et al*., 2016). Only one species of hake (*Merluccius hubbsi*) is recorded from the Brazilian coast but is not abundant and much of the demand for hake must therefore be supplied by imports (Vaz-dos-Santos, Schwingel, 2015). In comparison flatfish are represented by many species, but only two genera of the family Paralichthyidae (*Syacium* spp. and *Paralichthys* spp.) can be traded as "*linguado*" (Brasil, 2015, 2020). Trade in some fish products such as flatfish may also be reduced because of changes in the quality of tissues during freezing for long distance transport (Massa *et al*., 2005). Furthermore, automated filleting of these morphologically distinct species requires different technologies (Hjorth, 1996) that may not be worth the investment when considering the ratio of sales prices in local and distant markets.

Shark, hake and flatfishes are important fisheries products and easily found in fish markets, supermarkets and online suppliers in Brazil. Therefore, we aimed to assess the true diversity of species represented in products sold under the common names "*cação*" (shark), "*merluza*" (hake) and "*linguado*" (flatfish) from these different commercial sources in southeastern Brazil through molecular identification using the DNA barcoding fragment of the mitochondrial Cytochrome Oxidase Subunit I (CoxI) gene (Hebert *et al*., 2003). Based on this data we have evaluated: (1) whether common names are masking errors in labeling; and (2) whether rates of mislabeling vary based on the different points of sale considering the different inspection probabilities and variation in how supply and demand affect the distinct sales routes.

MATERIAL AND METHODS

Sample collection. A total of 191 samples from products sold as "*cação*" (shark, N = 66), "*merluza*" (hake, N = 49) and "*linguado*" (flatfish, N = 76) were purchased in supermarkets, fishmongers/street vendors and e-commerce at Minas Gerais, southeastern Brazil, between 2014 and 2019 (Tab. **S1**). Small tissue pieces were collected and preserved in 100% ethanol. Information about each sample was recorded for subsequent analysis: total price (R$), weight (kg), brand name, name of vendor (store name or fishmonger), format of product (fillet, slices, whole, etc.), and whether or not there was a Federal Inspection Service stamp (SIF - required and present on branded products from large suppliers and generally sold in supermarkets and e-commerce).

DNA extraction and COI gene fragment amplification and sequencing. DNA was extracted using a modified salting-out protocol (Aljanabi, Martinez, 1997). Partial COI gene sequences of approximately 650 base pairs (bp) were obtained by PCR (Polymerase Chain Reaction) using the primers FishF1 and FishR1 (Ward *et al*., 2005). PCR reactions consisted of 1.0 µl of 5x GoTaq DNA polymerase reaction buffer (Promega, Madison USA), 0.2 µl of mixed dNTP (40 mM, Promega, Madison USA), 0.3 µl of $MgCl_2$ (Promega, Madison USA), 0.2 µl of each primer (10 µM, Integrated DNA Technologies - IDT), 0.1 µl of Go Taq polymerase (Promega, Madison USA), 7.0 µl of ultrapure water and 1.0 µl of genomic DNA. PCR conditions comprised an initial step of 2 min at 95 °C followed by 35 cycles of 30 s at 95 °C, 30 s at 54 °C and 60 s at 72 °C, and one final step of 10 min at 72 °C. PCR products were visualized using a 1% agarose gel to check amplification. DNA sequencing was then conducted in both directions using primers FishF1 or FishR1 and BigDye Kit v. 3.1 (Life Technologies). Sequences were obtained using an automated DNA sequencer (ABI3130, Life technologies).

Molecular data analysis. DNA sequences were edited using SeqScape® v. 2.7 (Applied Biosystems, Foster City, CA) and MEGA X (Kumar *et al*., 2018). The consensus sequences were compared to existing data on BOLD (http://www.boldsystems.org/) and GenBank (http://www.ncbi.nlm.nih.gov/genbank) as a method of sample identification using the BOLD Identification tool and Blastn available on National Center for Biotechnology Information (NCBI). Top species matches obtained from searches were recorded using a 99% threshold. Scientific names were associated with

the corresponding market names following the official governmental regulatory list of species in Brazil for the relevant time period (Brasil, 2015, 2020). Other vernacular names derived from FishBase (Froese, Pauly, 2020) were used when scientific names of species were not found in the official governmental list. As DNA sequences were not recovered from voucher samples and were only used to assign identity, they were not deposited in GenBank or BOLD.

Import/Export data. Brazilian export and import data (quantity and value) for all three taxonomic groups (including shark fins) were obtained from Comex Stat of the Ministério da Indústria, Comércio Exterior e Serviços (MDIC). We used the Comex categorization "Chapter 03" under the harmonized 2-digit system (SH2) code to obtain all the available data for "Fish and crustaceans, mollusks and other aquatic invertebrates" for the years 2008–2019. This search generated an Excel file for each year with hundreds of types of fish products, including live animals. The information on traded products (volumes and values) is divided by countries of origin and destination and includes an 8-digit Mercosur Common Nomenclature (NCM) commodity code. From this raw data, the commodity code, annual value, quantity and destination or origin for shark, hake, and flatfish products were filtered including the full range of common names (as described above but also including the name '*peixes chatos*' for flatfishes) applied to these products. The filtered data was exported for each of the three taxonomic target groups and summary statistics calculated to compare export and import values and quantities. For flatfish products we noted but eventually excluded data for the commodities named as giant flatfishes ('*linguados* gigantes' – the halibuts) from statistical summaries as these represent very distinct products with distinct patterns of commerce to the smaller flatfishes that were the focus of the molecular identification analyses.

Shark meat availability from fin/dressed weight ratios in export and fisheries statistics. As sharks are exported as meat and fins, we estimated maximum and minimum mass of remaining shark meat in the national market based on fin weight to dressed weight ratios. Fin weight (wet) is considered to represent between 14.72% (Mejuto, García-Cortés, 2004), or between 15.97% (with skin) and 19.2% (without skin) dressed body weight (Espino *et al*., 2010). The ratio between dry fin weight and wet fin weight in sharks varies between 39.5% ±0.7 and 54% depending on species (see tab. 4 in Rose *et al*., 2003). We therefore derived a minimum dry fin weight to dressed weight ratio of 5.81% (14.72 x 0.395). The conversion factor for estimating the maximum weight of shark meat remaining for a given weight of exported fins is calculated based on dry fin weight and was therefore 17.21 (100/5.81). Similarly, the conversion factor for estimating the minimum weight of shark meat remaining for a given value of exported fins is calculated based on the maximal wet fin weight to dressed weight ratio and was therefore 5.21 (100/19.2). The weight of shark meat exports was then deducted from these estimates to provide the theoretical minimum and maximum values for shark meat that remains in the Brazilian market for consumption each year based on exported fins in that year. In order to compare the weight of meat from imports and exports with biomass obtained from fisheries, fisheries catch statistics were obtained from national reports covering all years with available data (Annual fisheries reports - Brasil, 2010, 2012).

RESULTS

Overall substitution rates were low (17/191 or 8.9%), but molecular identification detected clear cases of fraud by substitution in non-SIF certified products sold by fishmongers (Tab. 1). These included 41.6% (5/12) of hake samples and 2.56% (1/39) of shark samples (Tab. 1), and both were substituted by freshwater catfishes. Mislabeling was otherwise only found in flatfish samples (from all sources), but was assigned to be a result of misidentification error rather than intentional substitution because of the morphological similarity of the named species (other flatfishes).

Of the 66 shark samples analyzed, 63 were identified as *Prionace glauca* (blue shark or *tubarão-azul* in Portuguese and now officially classified on ZooBank (urn:lsid:zoobank.org:act:C8D7ACD8-600C-4918-A406-4B899CA849B2), two as *Carcharhinus glaucus*, Rodrigues-Filho *et al*., 2023), one identified as *Carcharhinus leucas* (bull shark or *tubarão-touro* in Portuguese), one as *Carcharhinus acronotus* (blacknose shark or *cação-lombo-preto* in Portuguese) and one as *Brachyplatystoma vaillantii* (Laulao catfish or *piramutaba* in Portuguese) (Tab. **S1**). Almost all products were labeled only with the name "*cação*", but six of the brands indicated the specific name *Prionace glauca* on their packaging, and all 16 of the samples from these brands were identified by DNA barcode to belong to this species. The price per kilo of the shark products analyzed ranged from R$ 11.27 to R$ 53.89 (Tab. **S1**), with higher cost for some supermarket products and for the one fish market sample that was a bull shark rather than a blue shark. The substituted sample CA_AM63 sold at R$ 17.00 per kilo as "*cação*", compares reasonably in value to the actual product sold (*piramutaba*) which varied between R$ 10 and R$ 25 per kilo in 2014 (minimum and maximum prices from online searches of wholesaler data for the relevant sampling period, with lower prices in northern Brazil and higher prices in southern Brazil).

Of the 49 hake samples analyzed, 27 were identified as the Argentine hake, *Merluccius hubbsi*, 12 as the North Pacific hake *Merluccius productus*, five as the South Pacific hake *Merluccius gayi* and five as the freshwater catfish *Hypophthalmus marginatus* (Highwaterman catfish or *mapará* in Portuguese) (Tab. **S1**). Hake from different regions were found mixed in one supermarket pack (both Argentine and North Pacific hake in pack 5). All five mislabeled products were obtained from a fishmonger (no pack, label or SIF certification) and are equivalent to 41.6% (5/12) of fishmonger samples and just

TABLE 1 | Summary of the samples of shark, hake and flatfish obtained from the different points of sale in southeastern Brazil for molecular identification with the number of mislabeled samples indicated in parentheses.

Label	Total sample number	Supermarket samples (SIF stamp)	Fish market samples (no SIF stamp)	Online supplier samples (no SIF stamp)	Number of species identified
"*Cação*" (shark)	66 (1)	27	39 (1)	0	4
"*Merluza*" (hake)	49 (5)	37	12 (5)	0	4
"*Linguado*" (flatfish)	76 (11)	46 (6)	8 (3)	22 (2)	3
Sum	**191 (17)**	**110 (6)**	**59 (9)**	**22 (2)**	**11**

over 10% (5/49) of all hake samples. The price per kilo of the hake products analyzed ranged from R$ 8.90 to R$ 25.50, with the substituted products sold at R$ 14.90 per kilo (Tab. 2). Fish sold as "*mapará*" at the time cost between R$ 10 and R$ 20 per kilo (prices paid for samples at the same time but not used in this study).

Of the 76 flatfish samples analyzed, 34 were identified as the Patagonian flounder *Paralichthys patagonicus*, 31 as *P. isosceles* and 11 as *Xystreurys rasile*. All the packs were identified only with the umbrella term "*linguado*" (flatfish). *Xystreurys rasile* is not on the official list of species allowed to be sold as "*linguado*" in Brazil (Brasil, 2015, 2020). These Normative Instructions only allow species of the genera *Paralichthys* and *Syacium* to be sold under the label "*linguado*". However, *X. rasile* is also a member of the pleuronectiform family Paralichthyidae and we have considered that this mislabeling represents both an inability to distinguish these taxa and a lack of awareness of the limitations of the umbrella term "*linguado*" in legislative terms rather than an example of intentional substitution. This mislabeling was also found across all sources of samples, though the mislabeling rate was highest in samples from fishmongers (3/8 or 37.5%, compared to 6/45 or 13.3% in supermarket sourced samples and 2/21 or 9.5% in e-commerce sourced samples). Multiple species were identified packed together in single packs. Packs 1, 15 and 16 from supermarkets contained mixes of *P. isosceles* and *X. rasile*, while packs 7 and 10 contained fillets of all three species (Tab. **S1**). Mislabeled products (or packs containing these) were generally sold within the same per kilo price range of the other samples sold as "*linguado*".

Export and import data for shark, hake and flatfish products between 2008 and 2019 provides an overview of supply and demand (Tabs. 2–3). Most products are grouped under generalized fisheries products codes (*e.g.*, "shark meat" or "flatfish") that do not allow species level analyses. Generally, imports far exceed exports, but for specific products there is some variation. This is clear for sharks where there was a net excess export of shark fins and net excess import of shark meat (Tabs. 2–5). There is a clear shift in trading partners from countries speaking Spanish and Portuguese to Taiwan for shark imports (predominantly meat) from 2012 to 2013 but shark exports (predominantly fins) were always to the far east.

TABLE 2 | Value in 1000s of US$, weight in tons, and main origin of Brazilian imports of shark, hake and flatfish products between 2008 and 2019.

	Shark (*Tubarão*)			Hake (*Merluza*)			Flatfish (*Linguado*)		
Year	**1000s US$**	**Tons**	**Origin**	**1000s US$**	**Tons**	**Origin**	**1000s US$**	**Tons**	**Origin**
2008	33,495.5	17,856.6	Portugal	698.7	459.3	Chile	282.9	114.7	Uruguay
2009	37,938.0	21,230.5	Chile	1,328.8	1,123.3	Singapore	480.2	206.6	Argentina
2010	40,594.0	18,605.3	Uruguay	3,055.9	2,170.5	Argentina	144.4	87.2	Uruguay
2011	44,151.4	19,373.9	Uruguay	3,735.5	2,086.3	Argentina	12.0	6.5	Uruguay
2012	36,818.5	21,315.4	Uruguay	186,128.5	76,449.9	China	1,913.1	702.6	China
2013	41,085.0	19,384.1	Taiwan	209,596.8	92,728.9	China	2,420.5	1,069.8	China
2014	45,254.0	17,412.6	Taiwan	177,037.4	69,919.4	China	2,610.7	1,136.0	China
2015	26,855.8	12,833.0	Taiwan	154,986.7	60,427.0	China	6,191.5	2,915.8	China
2016	24,836.3	15,939.9	Taiwan	107,804.7	45,530.4	China	2,372.0	1,267.8	China
2017	37,403.3	20,799.6	Taiwan	150,998.9	55,854.8	Argentina	1,082.6	354.3	China
2018	40,767.0	18,372.0	Taiwan	135,345.7	46,002.6	Argentina	301.3	67.2	China
2019	33,010.7	15,865.3	Taiwan	135,914.3	43,589.3	Argentina	1,173.8	306.1	China

TABLE 3 | Value in 1000s of US$, weight in tons, and main destination of Brazilian exports of shark, hake and flatfish products between 2008 and 2019.

	Shark (*Tubarão*)			Hake (*Merluza*)			Flatfish (*Linguado*)		
Year	**1000s US$**	**Tons**	**Destination**	**1000s US$**	**Tons**	**Destination**	**1000s US$**	**Tons**	**Destination**
2008	2,825.5	112.5	Hong Kong	420.2	137.4	Belgium	174.4	73.7	United States
2009	2,338.1	85.4	Hong Kong	34.5	10.9	U.K.	38.0	16.6	United States
2010	1,431.4	51.0	Hong Kong	-	-	-	2.2	2.0	United States
2011	2,203.7	83.2	Hong Kong	0.5	0.1	Paraguay	17.2	26.3	China
2012	1,789.2	43.9	Hong Kong	1.3	0.2	Paraguay	955.7	436.0	Angola
2013	1,293.5	31.2	Hong Kong	12.4	1.3	Equat. Guinea	524.2	265.3	South Korea
2014	978.3	27.7	Hong Kong	7.1	1.5	Angola	859.8	448.5	South Korea
2015	812.6	27.5	Hong Kong	-	-	-	703.9	337.7	China
2016	810.7	34.5	Hong Kong	68.6	29.7	China	156.8	73.4	Vietnam
2017	1,063.4	44.1	Hong Kong	50.2	21.1	China	2,312.0	639.1	United States
2018	1,320.1	44.0	Hong Kong	1,211.6	415.6	China	532.4	267.0	China
2019	934.8	63.6	Hong Kong	979.7	265.8	Argentina	1,165.6	637.7	China

TABLE 4 | Value in US$, weight in Kg, and mean price US$ per Kg for shark products (meat and fins) exported from Brazil between 2008 and 2019.

	Shark meat			Shark fins		
Year	**U$$**	**Kg**	**Mean price**	**U$$**	**Kg**	**Mean price**
2008	-	-		2,825,451.00	112,505.00	25.11
2009	-	-		2,338,059.00	85,382.00	27.38
2010	-	-		1,431,446.00	50,957.00	28.09
2011	94,979.00	24,508.00	3.88	2,108,735.00	58,740.00	35.90
2012	12,678.00	4,580.00	2.77	1,776,538.00	39,355.00	45.14
2013	-	-		1,293,518.00	31,191.00	41.47
2014	-	-		978,308.00	27,741.00	35.27
2015	-	-		812,554.00	27,542.00	29.50
2016	18,114.00	10,426.00	1.74	792,584.00	24,105.00	32.88
2017	26,100.00	12,617.00	2.07	1,037,341.00	31,474.00	32.96
2018	26,023.00	11,333.00	2.30	1,294,042.00	43,706.00	29.61
2019	104,914.00	41,149.00	2.55	829,852.00	22,487.00	36.90
All years	282,808.00	104,613.00	2.70	17,518,428.00	555,185.00	31.55

Hake products were imported in large quantities but there is little export, and flatfish were neither imported nor exported in large quantities (<1,000 tonnes per year). In many cases flatfish and hake exports showed onward shipping of non-native fish species that must have come from previous imports *e.g.*, although we excluded them from statistical analyses, we noted that data in 2011 indicted export of northern cold-water halibuts (*Reinhardtius hippoglossoides*, *Hippoglossus hippoglossus*, *H. stenolepis*) to Singapore.

By analyzing the discrepancy in mass of shark fins and body (meat) in export data from 2008 to 2019, we estimate a minimum excess of ~76 tonnes of shark meat in 2019 and that since 2012, when export volumes of shark fins stabilized, an average of between 151 and 522 tonnes of excess shark meat is available annually in the domestic market (Tab. 5). Unfortunately, data is not available between 2011 and 2022, but Brazilian fishing statistics indicate annual catches ranging from 9,147.5 tons for a "number of shark species" in 2000 to 11,750 tons for "sharks and blue sharks" in 2011 (Brazil, 2010, 2012).

TABLE 5 | Analysis of the permanence of shark meat in the Brazilian consumer market between 2008 and 2019 based on the registered commercial weights of exported fins and meat and using minimum and maximum conversion factors between the fin's weight and the individual (see methods for details about conversion factors). *Mean and standard deviation calculated only for 2012–2019 used as they represent the most recent data with relatively stable values.

Year(s)	Fin exports (kg)	Minimum excess meat (kg) based on a conversion factor of 5.21	Maximum excess meat (kg) based on a conversion factor of 17.21	Meat exports (kg)	Minimum excess meat (kg) left to internal market	Maximum excess meat (kg) left to internal market
2008	112,505.00	586,151.05	1,936,211.05	0.00	586,151.05	1,936,211.05
2009	85,382.00	444,840.22	1,469,424.22	0.00	444,840.22	1,469,424.22
2010	50,957.00	265,485.97	876,969.97	0.00	265,485.97	876,969.97
2011	58,740.00	306,035.40	1,010,915.40	24,508.00	281,527.40	986,407.40
2012	39,355.00	205,039.55	677,299.55	4,580.00	200,459.55	672,719.55
2013	31,191.00	162,505.11	536,797.11	0.00	162,505.11	536,797.11
2014	27,741.00	144,530.61	477,422.61	0.00	144,530.61	477,422.61
2015	27,542.00	143,493.82	473,997.82	0.00	143,493.82	473,997.82
2016	24,105.00	125,587.05	414,847.05	10,426.00	115,161.05	404,421.05
2017	31,474.00	163,979.54	541,667.54	12,617.00	151,362.54	529,050.54
2018	43,706.00	227,708.26	752,180.26	11,333.00	216,375.26	740,847.26
2019	22,487.00	117,157.27	387,001.27	41,149.00	76,008.27	345,852.27
2012–2019* Mean	**30,950.13**	**161,250.15**	**532,651.65**	**10,013.13**	**151,237.03**	**522,638.53**
2012–2019* Standard deviation	**7,310.27**	**38,086.53**	**125,809.82**	**13,671.88**	**44,494.95**	**130,941.70**

DISCUSSION

This study targeted three main groups of fisheries products to investigate how substitution might be affected by inspection rates and market forces. The substitution rate encountered (8.9% overall and 0% in SIF certified products when discounting accidental mislabeling in flatfish) are lower than that found in most previous work (Carvalho *et al*., 2011; Staffen *et al*., 2017; Souza *et al*., 2021), but follows the trend found by Brazilian government monitoring of SIF certified products in recent years. The Ministério da Agricultura Agropecuária e Abastecimento (MAPA) started checking mislabeling of SIF certified products bought in 2014, when mislabeling was found in 23% of products (DIPOA, 2015). In 2016 this had reduced to approximately 16% (DIPOA, 2016) and 3% in 2017 (DIPOA, 2018) but then increased again in 2018 to 13% (DIPOA, 2019). Most of our samples were obtained in 2016 after inspection in the region had already become a newsworthy issue (Carvalho *et al*., 2015). This shows that inspection has an effect in reducing mislabeling in certified sources. However, inspection at local markets remains a problem because of the distributed nature of these markets and the dominance of uncertified fresh products for sale. These are the main locations where substitution has been identified, both in this study (41.6% in hake products and 37.5% in flatfish products) and in others in Brazil (Almerón-Souza *et al*., 2018; Carvalho *et al*., 2017a) and around the world (Cawthorn *et al*., 2012; Marchetti

et al., 2020). Indeed, 62% of fishes marketed as grouper were found to represent sharks with most of this substitution occurring in informal markets and fishmongers compared to much lower rates in supermarkets and restaurants in São Paulo State (Estrella *et al*., 2016). These informal markets and fishmongers are also recorded as more likely to sell products from protected species (Palmeira *et al*., 2013; Bernardo *et al*., 2020).

Intentional substitution can be predicted to be governed by opportunism in the context of the sale environment (Estrella *et al*., 2016) and not just because of price differences (Donlan, Luque, 2019). The sale environment includes both risk factors for those attempting substitution and economic factors that control the market. Both the legislation (use of umbrella terms *vs.* species specific labelling) and the frequency and coverage of inspection determine the risk of performing substitution in the sale environment. Economically, supply, demand and transportability regulate the species available at given prices, with temporal management of product stock more manageable for frozen processed products than for fresh products. This context dependent analysis of substitution likelihood explains the results of our analyses.

The substitution of shark and hake by the freshwater catfishes (*B. vaillantii* and *H. marginatus*, respectively) appears to be a result of intentional but opportunistic substitution. We conclude this because: 1) before being prepared for sale the species are morphologically very distinct from each other (so fishmongers should know very well which one is which); and, 2) the catfish species have similar or higher prices to shark or hake so no, or limited, direct profit is made on the item. Substitution of products with similarly priced or more expensive products may be a common opportunistic practice for fishmongers. Their products are mainly perishable (fresh fish) that, unlike frozen fillets, must be sold as soon as possible to minimize economic losses. In comparison SIF certified products are normally frozen and can be sold over a longer time so that the percentage of loss in unsold goods is minimized by store management practices that balance supply and demand. This also may explain why catfish have been substituted rather than marine fishes with similar quality meat and/or taste. To a consumer, the size, shape and color of the final processed products may be more similar to their expectations for the requested product than any of the available marine species in the fishmonger's stock.

Although previous studies have already pointed out substitution in flatfish species in Brazil (Carvalho *et al*., 2015, 2017a; Staffen *et al*., 2017), the substitutions indicated in the present study can be interpreted as unintentional. The adoption of broad terms for legislative purposes must consider the common use of the term itself and the likelihood of its misapplication. Many flatfish from various families of the Order Pleuronectiformes are morphologically very similar to each other and are commonly identified under the term "*linguado*" in the southeastern and southern regions of Brazil, with different vernacular names (often "*solha*") more often used in the northeastern and northern regions. The use of the term should therefore be restricted to only two genera of a given family as more recently applied in Normative Instruction Nº 53 (Brasil, 2020) so that there can be a consistent application of names by fishermen, as well as fish processing and distribution centers, reducing the chance of mislabeling of some products.

Brazilian legislation does not require the use of species names on packaging. Umbrella terms such as "*cação*", "*merluza*" and "*linguado*" (shark, hake and flatfish, respectively)

are used (Brasil, 2020), and multiple species were found to be commercialized under each of these three umbrella terms. However, some seafood brands named the shark species on their packaging and molecular analysis of these samples confirmed the labels to be correct. A lack of proper identification on packages prevents consumers from making choices important for sustainability and human health (Jacquet, Pauly, 2008; Vitale *et al*., 2020), especially for top predators such as sharks that can accumulate heavy metals and other toxic substances (Lopes *et al*., 2019; Pancaldi *et al*., 2019). Mercury has been found above allowed concentrations in blue shark meat from the South Atlantic (Carvalho *et al*., 2014) and blue sharks were the predominant species identified in our shark samples, indicating health risks for consumers of these products.

International trade is currently one of the main drivers that determine the value of products (Garcia, Rosenberg, 2010; Purcell *et al*., 2017) and is an important consideration in the development of sustainable fisheries (Potts, Haward, 2007; Stephenson *et al*., 2019). Price in turn is a driver of the likelihood of substitution (EFSA, 2012; USP, 2016:1586–1621). There are clear differences in the trading of the three taxonomic groups studied here with variation in the balance of imports and exports and distinct differences for trade of the different shark products (fins *vs.* meat). Cultural demands are well known as the cause of some of these differences (Can *et al*., 2015; Maciel *et al*., 2016) and the processing capacity and transportability of products may also impact their trade (Hjorth, 1996; Massa *et al*., 2005). But how these factors act as drivers for substitution will also vary based on the fisheries products harvested by any given country and the role of that country within the trading network. Here we show for sharks that despite considerable volumes of excess meat generated by fisheries (Tab. 5) after the export of fins to the orient (Tabs. 3–4) there is still a huge demand for cheap protein and that shark meat is still imported in large amounts (Tab. 2). Hake is also imported to Brazil in large volumes for consumption (Tab. 2). For both hake and shark products the retail chain of certified products can easily adapt to sell only legal products, with substitutions only occurring at points of sale where inspection is less risky. In comparison, international trade of flatfish is minimal (Tabs. 2–3) and local supply and demand factors are dominant in determining sales prices. When problems associated with the use of umbrella terms and the morphological similarity of flatfish are also considered, a higher likelihood of substitution and mislabeling in these products is expected.

Elasmobranchs represent less than 1% of all marine fisheries worldwide (FAO, 2014, 2016), but these species have biological characteristics including slow growth, late sexual maturation and limited reproductive output, that make them particularly prone to overfishing (Bornatowski *et al*., 2014) and many species have experienced severe population declines in the last 20 years (Stevens *et al*., 2000; FAO, 2020; Gebremedhin *et al*., 2021). Although no substitutions for protected species were detected in certified shark products sold in supermarkets, some shark species identified here are classified as Endangered (EN) (*C. acronotus*), Vulnerable (VU) (*C. leucas*), and Near-Threatened (NT) (*C. glaucus*) (Rigby *et al*., 2019, 2021; Carlson *et al*., 2021). The role of informal markets in the sale of shark meat means that there are many distributed outlets for illegal products, and conservation strategies must consider that inspection is unlikely to be viable in such situations. Our results show predominant commercialization of the blue shark (*C. glaucus*) in Brazil, as previously documented (Staffen *et al*., 2017; Bernardo *et al*., 2020). Despite being classified as NT by the IUCN and being listed in Appendix II

of CITES, 2025 – Convention on International Trade in Endangered Species of Wild Fauna and Flora (Rigby *et al*., 2019), it is the most common shark caught by longline fishing around the world (Compagno *et al*., 2005), representing approximately 56% of commercially captured pelagic sharks (Camhi *et al*., 2009). As pelagic oceanic species, they are not frequently caught by artisanal fishermen and are more commonly landed in Brazil by multinational companies that fish in international waters and that export high-value products, selling the remaining meat (Bornatowski *et al*., 2015; Barreto *et al*., 2017; Bernardo *et al*., 2020). Protected species may end up having their fins exported (Hobbs *et al*., 2019; Fields *et al*., 2020) and their meat may eventually be sold in less supervised establishments. Inspection of exported shark fins is a viable and important control point for the conservation of elasmobranchs, especially considering the volume of exports of these products from Brazil (Barbosa-Filho *et al*., 2017).

Overall, the context dependent analysis of substitution likelihood identified here shows that frozen products from major certified suppliers in Brazil that are generally sold in high-inspection systems and have a low likelihood of substitution but includes some apparently unintentional mislabeling. In contrast, fresh products from local fishmongers in Brazil are low-inspection systems with a higher risk of opportunistic substitution.

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The authors declare no competing interests.

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