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Misdescription incidents in seafood sector

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ABSTRACT

Seafood consumption has increased worldwide in the last 50 years considering both wild catches and aquaculture production. According to the Food and Agriculture Organization (FAO), the majority of world fisheries is at maximum exploitation levels or over-exploited. Illegal, unreported and unregulated fishing is contributing to overfishing, as well as intentional or unintentional mislabeling of fish catches or their geographical origin. DNA identification methods can contribute to monitor mislabeling, mainly when dealing with processed seafood or morphologically similar species. It cannot be ignored that seafood mislabeling can also have food safety implications, due to the presence of toxic substances directly related to certain species or to the catch area. In this context, a review has been conducted analyzing scientific reports related to seafood mislabeling incidents published in the last five years to try to identify the level of real mislabeling, as well as, the more relevant gaps in this area. A total of 51 peer-reviewed papers including 4500 samples analyzed globally by DNA methodologies have been taken into account. The average percentage of reported misdescription is 30%. In general, incidents in restaurants and takeaways are much more common than in supermarkets and retailers. Therefore, specific studies should be conducted to confirm it because only 10% of analyzed samples were obtained from restaurants. In addition, we have observed a remarkable absence of appropriate sampling plans prior to sample collection.

1. Introduction

Seafood is the most traded food commodity in the world. Its production has been steadily growing over the last decades, with notable progress in aquaculture over the past two decades, accounting for 42% of global seafood production in 2012 (FAO., 2014). According to the Food and Agriculture Organization (FAO), the world seafood production is close to 158 million tons, with 91.3 million tons of captures (inland and marine) and 66.6 million tons of total aquaculture (inland and marine). Furthermore, it was estimated that in 2012, 50% of the world's fisheries were at maximum exploitation levels and approximately 25% were over-exploited (FAO., 2014). Additionally, IUU (illegal, unreported and unregulated) fishing can lead to inadvertent overfishing, thus contributing to inaccurate estimates of exploitation rates. This might also include possible endangered marine stocks.

Mislabeling and erroneous identification of fish catches, or their geographical origin, is one of the factors involved in underreported exploitation of stocks and could threaten the sustainability of fisheries, therefore contributing to the depletion of fishery resources, or even the eventual extinction of the overexploited species (Agnew et al., 2009).

There is also a potential public health implications since mislabeled species may be toxic like some oilfish species (Cabrero, Hernández, Tango, Hillera, & Marcos, 2015) and puffer fish (Armani, Guardone, La Castellana et al., 2015).

Morphological characteristics are lost when fish are sold filleted while some others, such as color, might be unstable after freezing. Therefore, there is a need to apply currently available DNA analysis methods when visual methods are not good enough for species identification. PCR sequencing is indeed the most commonly used method in fish identification (Griffiths et al., 2014).

In the European Union the identification of seafood is mandatory, as stated in the Council Regulation (EC) No 1379/2013 of 11 December 2013 on the common organization of the markets in fishery and aquaculture products, amending Council Regulations (EC) No 1184/2006 and (EC) No 1224/2009 and repealing Council Regulation (EC) No 104/2000. These regulations require that seafood labels indicate the complete scientific name of the species (i.e. genus and species, Latin binomial nomenclature) without in-

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ducing errors and in order to ensure a high level of protection for human health.

It has been repeatedly recognized that the use of common names or commercial designations to describe various fish types can hamper consumer choice, since this groups together species for sale that have markedly different prices. In this global chaos, the utilization of recognizable both locally and internationally names in seafood product labeling must be officially taken into consideration to ensure traceability in the seafood chain (Armani, Castigliego, & Guidi, 2012). However, "intentional" misdescription should be always considered as fraud or economically motivated adulteration (Spink & Moyer, 2011). For this reason, it is highly unlikely that mislabeling occurs by accident through misidentification by industry workers who handle these species on a daily basis (Miller, Jesse, & Mariani, 2012).

The purpose of the present review is to identify the levels of fraud as well as the more relevant gaps in research described in seafood mislabeling assessment articles published in peer-reviewed journals over the last five years.

2. Approach

Seafood misdescription incidents have been selected by performing a comprehensive analysis of the period 2010 to 2015. In total, 51 peer-reviewed journal articles have been selected. The databases used for the article selection were Science Direct, Web of Science, Google searches and PubMed. Keywords used for this search included: "fish", "seafood", "fraud", "authentication", "misdescription", "substitution", "mislabeling", "adulteration" and their combinations. Primary articles identified were also reviewed for relevant secondary cited references.

3. Origin of samples and sampling plan

The number of samples analyzed in this work was 4500. Studies vary in size, ranging from 5 to 386 samples and they have been conducted across all continents. Europe has the highest number of samples reported, comprising 60% of the total, followed by North America (14%) and Africa (13%). In terms of countries, United Kingdom (20%) has the highest number of sample studies on seafood mislabeling, followed by Spain (16%) and Italy (13%) (Fig. 1). The vast majority of studies (90%) focused their sampling efforts at the retail end of the supply chain, mainly supermarkets and fishmongers. Few studies (10%) used samples from hotels, restaurants and catering (HORECA) (Armani, D'Amico et al., 2012; Armani, Guardone, Castigliego, et al., 2015; Armani et al., 2013; Carvalho, Palhares, Drummond, & Frigo, 2014; Cawthorn, Duncan, Kastern, Francis, & Hoffman, 2015; Cline, 2012; Hanner, Becker, Ivanova, & Steinke, 2011; Heyden, Barendse, Seebregts, & Matthee, 2010; Khaksar et al., 2015). Most of these studies determined that HORECA mislabeling is significantly higher than that of supermarkets and retailers (Cline, 2012; Hanner et al., 2011; Khaksar et al., 2015). For instance, a higher rate of misdescription was recently identified in restaurants (14.8%) compared with retailers (2.2%) from the San Francisco Bay area in USA (Khaksar et al., 2015). Conversely, the misdescription rates reported in other studies described similar misrepresentation rates between restaurants and retailers (Armani, Guardone, Castigliego, et al., 2015; Cawthorn et al., 2015). In addition, some studies addressed other considerations such as the spatial distribution of sampling efforts among different areas representing varied demographic (Miller, Jesse, et al., 2012) or geographical characteristics (Cawthorn et al., 2015; Cawthorn, Steinman, & Witthuhn, 2012). Seasonal concerns were also addressed in some surveys (Carvalho et al., 2014; Hanner et al., 2011). Regarding the sampling plan, the estimation of the number of seafood samples required to conclude any percentage of fraud or misdescription in a given market, country or region was only specified in two references (Cawthorn et al., 2015; Changizi, Farahmand, Soltani, Darvish, & Elmdoost, 2013). Other authors indicated that the sampling plan was assessed "randomly" (Armani, Guardone, Castigliego, et al., 2015; Barbuto et al., 2010; Carvalho et al., 2014; E. Garcia-Vazquez et al., 2011; Pappalardo & Ferrito, 2015) but the majority of studies did not provide any information regarding the organization of the sampling plan. Finally, it must be highlighted that the name of the commercial products companies were not disclosed in any of the references included in this review to protect the confidentiality of the data.

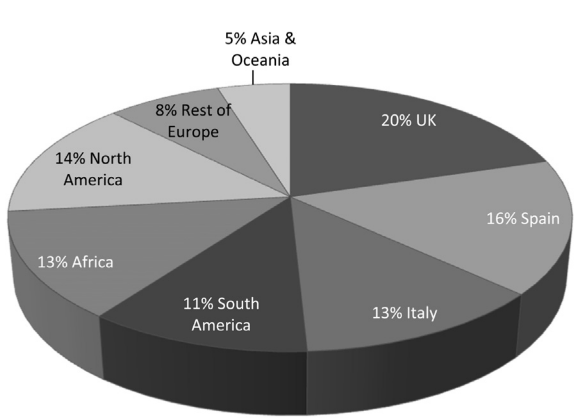

Fig. 1. Representative pie chart showing the main fish surveys by regions.

4. Analytical methodologies

In recent years, DNA-based techniques have been widely used in species identification, including the assessment of mislabeling. DNA shows numerous advantages such as high stability and relative ease of isolation, even from highly processed foods. DNA-based methods show high sensitivity, specificity and reliability of results. In this sense, PCR-sequencing is the method most commonly employed (Griffiths et al., 2014).

Mitochondrial DNA (mtDNA) is a common target for species identification since mitochondrial sequences help to differentiate between closely relates species (Meyer, 1993). Most of the methodologies are based on mitochondrial DNA markers since they have a high number of copies per cell, facilitating the amplification. In general, Genbank and other public databases contain more sequences of mitochondrial genes than nuclear genes of fish. However, in the case of some tuna species, there is a problem of mitochondrial introgression that cannot be solved by mitochondrial markers and requires nuclear markers such as internal transcribed spacer 1 (*ITS1*) (Chow, Nakagawa, Suzuki, Takeyama, & Matsunaga, 2006). This region has been used in the genetic identification of other species suffering mitochondrial introgression events such as Arctic char and Brook trout, flounder and plaice (Gross, Gum, Reiter, & Kühn, 2004; Kijewska, Burzyński, & Wenne, 2009).

The most widely used identification technique by far is PCR-FINS (Forensically informative nucleotide sequencing); based on PCR amplification followed by direct sequencing of specific mitochondrial DNA markers like cytochrome *b* (*CytB*) (Armani, Castigliego, Tinacci, Gianfaldoni, & Guidi, 2011; Cutarelli et al., 2013; Espiñeira & Vieites, 2012a; Huang et al., 2014; Melo Palmeira et al., 2013) 16S rDNA (Melo Palmeira et al., 2013) and cytochrome *c* oxidase I gene (*COI*) (Hanner et al., 2011). The DNA barcoding method, based on the sequencing of a standardized region of the *COI*, has become a useful tool for ensuring the rapid and accurate identification of species. It is currently being used to differentiate animal taxa, including the authentication of fish and fish-derived products

(Armani et al., 2013; Barbuto et al., 2010; Carvalho, Neto, Brasil, & Oliveira, 2011; Carvalho et al., 2014; Cawthorn et al., 2012; Cline, 2012; Cutarelli et al., 2013; Changizi et al., 2013; De Brito, Schneider, Sampaio, & Santos, 2015; Galal-Khallaf, Ardura, Mohammed-Geba, Borrell, & Garcia-Vazquez, 2014; Hanner et al., 2011; Haye, Segovia, Vera, Gallardo, & Gallardo-Escárate, 2012; Keskin & Atar, 2012; Lamendin, Miller, & Ward, 2014; Maralit, Aguila, Ventolero, Perez, & Santos, 2013; Miller, Clarke, & Mariani, 2012; Pappalardo & Ferrito, 2015; Pinto et al., 2013), and has been recently adopted by the Fish Barcode of Life Initiative (FISH-BOL), which aims to barcode all fish species of the world (Hanner et al., 2011; Ward, Hanner, & Herbert, 2009). The databases employed to analyze sequencing results were GenBank (www.ncbi.nlm.nih.gov) and BOLD (www.barcodinglife.org). When dealing with highly processed samples, thermally treated samples, standard DNA barcoding is not valid and other techniques need to be employed such as real-time PCR, mini DNA Barcoding, SSCP and RFLP (Armani, Guardone, Castigliego, et al., 2015; Crego-Prieto et al., 2012; Helyar et al., 2014; Stamatis et al., 2015). In the case of mixtures of fishes, RFLP, real-time PCR and Pyrosequencing can be helpful (De Battisti et al., 2014; H. Rehbein, 2002).

5. Seafood species commonly mislabeled

The percentage of seafood misdescription incidents ranges from 0%; in a survey carried out in Tasmania region (Lamendin et al., 2014), to 84% in a Turkish survey focused on surimi derived products (Keskin & Atar, 2012). The average percentage of misdescription reported during last five years is 30%; whereas a slight decrease has been identified during last year with a percentage of 27%. The main commercial seafood species analyzed in the different surveys are listed in Fig. 2, while the main misdescription incidents detected are reported in the Table 1.

5.1. Gadoids

A gadoid is a fish of the suborder Gadoidei which includes several commercially important fish such as cod, hakes, haddock, whiting and pollock. The importance of these species is noticeable attending to the number of references (21) which include gadoids in the survey. The number of gadoid samples reported in this review is 1755 which comprises almost 40% of the total samples. The misdescription incidents ranged from 2% to 84% with an average percentage of misdescription of 30%. Nevertheless, and attending to the last surveys, this trend has changed with a remarkable drop in the reported mislabeling incidents to 20%. As an example of this, in 2014, a study encompassing a large-scale assessment of UK retailers detected 94% of gadoid samples correctly labeled (Helyar et al., 2014). The wide range of misdescription percentages

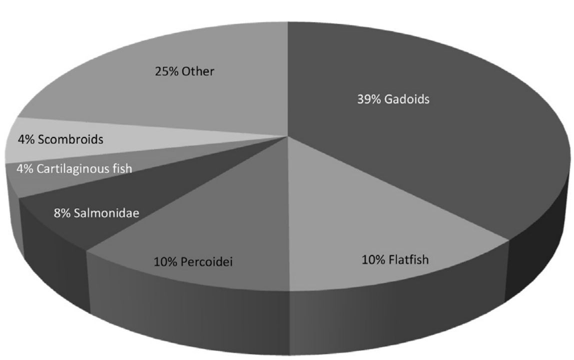

Fig. 2. Representative pie chart showing the main commercial fish species analyzed in the peer-reviewed journal articles included in this review.

obtained can be due to the lack of statistically significant sampling plan between different surveys in different regions or countries.

Atlantic cod (*Gadus morhua*) is probably the most valuable and appreciated gadoid and therefore its substitution with other fish species like Alaska pollock (*Theragra chalcogramma*) Pacific cod (*G. macrocephalus*), pollock (*Pollachius polachius*) or saithe (*P. virens*) is very recurrent (Cutarelli et al., 2013; Hanner et al., 2011; Lamendin et al., 2014). The potential motive behind this misdescription is the greater abundance along with the lower price of species such as pollocks or saithe. In the case of mislabeling Atlantic cod as Pacific cod, financial motivation is less obvious (Miller, Jesse, et al., 2012). In fact, all species that were mislabeled as Atlantic cod are phenotypically distinct from this gadoid. Another clear case of fish substitution was observed with Alaska Pollock, which was substituted by other species like pink cusk-eel (*Genypterus blacodes*) (Carvalho et al., 2014), striped catfish (*Pangasius hypophthalmus)* (Helyar et al., 2014) or southern blue whiting (*Micromesistius australis*) (Changizi et al., 2013). Hake (*Merluccius* spp.) comprises a relevant group of commercial fish species frequently mislabeled; generally among species belonging to the same genus (Cawthorn et al., 2012; Garcia-Vazquez, Machado-Schiaffino, Campo, & Juanes, 2012) and more recurrently in frozen products (Muñoz-Colmenero et al., 2015). Mislabeling in hakes is probably accidental as the species are morphologically similar and often difficult to identify by visual inspection (Garcia-Vazquez et al., 2012).

5.2. Flatfish

A flatfish is a member of the order Pleuronectiformes; with more than 600 species including flounder, sole, turbot, plaice, and halibut. The importance of these species is also evident attending to the number of references (9) which includes flatfish in the survey, and the number of samples (458) reported; which comprise 10% of the total. The misdescription incidents ranged from 20% to 60% with an average percentage of misdescription of 38%.

European plaice (*Pleuronectes platessa*) is a commercially important flatfish that has been frequently replaced by European flounder (*Platichthys flesus*) and common dab (*Limanda limanda*) (Pappalardo & Ferrito, 2015). Common sole (*Solea solea*) was also replaced by Mediterranean scaldfish (*Arnoglossus laterna*) (Pappalardo & Ferrito, 2015) and yellowfin sole (*L. aspera*) substituted with flathead sole (*Hippoglossoides elassodon)*, butter sole (*Isopsetta isolepis*), and Northern rock sole (*Lepidopsetta polyxystra*) (Hartmut Rehbein & Oliveira, 2012). Summer flounder (*Paralichthys dentatus*) is a flatfish commonly consumed in USA that is replaced by species belonging to the same genus such as *P olivaceus* (Khaksar et al., 2015). In some Brazilian restaurants, cheaper species imported from Asia instead of flounder have been found (Carvalho et al., 2014). However, all of these substitutions cannot always be considered as deliberate due to the difficulty in identifying different species caught together in the same fishery, on the basis of morphological characteristics alone (Pappalardo & Ferrito, 2015). For instance, European common megrim (*Lepidorhombus whiffiagonis*) and the four-spotted megrim (*L. boscii*) are frequently confused between them, having found misdescription rates close to 50%. In this case, can be discarded since both species are morphologically very similar and their trade price is the same (Crego-Prieto et al., 2012).

5.3. Percoidei fish

Percoidei is one of eighteen suborders of bony fish in the order Perciformes. Many commercially harvested fish species are contained in this suborder, including the snappers, jacks, whiting,

Table 1
List of commercial fish species more frequently substituted with.

Fish species		Substitute with	References
Cod	*Gadus morhua*	*Gadus* spp, *Theragra chalcogramma, Pollachius spp*	(Cutarelli et al., 2013; Hanner et al., 2011; Lamendin et al., 2014)
Alaska pollock	*Theragra chalcogramma*	*Genypterus blacodes, Pangasius hypophthalmus, Micromesistius australis*	(Carvalho et al., 2014; Changizi et al., 2013; Helyar et al., 2014)
European hake	*Merluccius merluccius*	*Merluccius* spp	(Cawthorn et al., 2012; Garcia-Vazquez et al., 2012; Muñoz-Colmenero et al., 2015)
European plaice	*Pleuronectes platessa*	*Platichthys flesus, Limanda limanda*	(Pappalardo & Ferrito, 2015)
Common sole	*Solea solea*	*Arnoglossus* spp, *Hippoglossoides* spp, *Pangasius hypophthalmus*	(Carvalho et al., 2014; Pappalardo & Ferrito, 2015)
Atlantic salmon	*Salmo salar*	*Oncorhynchus* spp	(Hanner et al., 2011; Herrero, Vieites, et al., 2011a; Nebola et al., 2010)
White tuna	*Thunnus alalunga*	*Thunnus* spp, *Sarda* spp	(Cawthorn et al., 2015)
Red tuna	*Thunnus thynnus*	*Thunnus obesus*	(Maralit et al., 2013; Santaclara et al., 2015)
Dusky grouper	*Epinephelus marginatus*	*Gadus* spp, *Pollachius* spp, *Reinhardtius hippoglossoides, Oreochromis niloticus*	(Cutarelli et al., 2013)

groupers, perches and porgies. The great variety of misdescription percentages described in this review, ranged from 10% to 80%, with an average of 28%. The number of references (12) and samples (431) including percodei species reflects the complexity of this group. In fact, the wide range of misdescription percentages obtained from different studies is probably due to the complexity of this group and also to the lack of statistically significant sampling plans among different surveys. In fact, porgies, belonging to the family Sparidae, is an excellent example of this complexity; mislabeling of porgies species could be voluntary and aimed at charging higher prices on low commercial value species (Armani, Guardone, Castigliego, et al., 2015). However, other cases were due to the improper use of commercial denomination, such as the utilization of a generic name for the whole genus rather than the specific commercial name (Armani, Guardone, Castigliego, et al., 2015; Cawthorn et al., 2015; Hanner et al., 2011). Groupers are appreciated fish species and dusky grouper (*Epinephelus marginatus*) is indeed considered the best taste of all Mediterranean fish. It is now considered an endangered species due to overfishing. As a matter of fact, these species are frequently substituted by other fish species to obtain economic gain (Cutarelli et al., 2013). Other misdescription incidents are the substitution of red snapper and meagre with a wide variety of fish species (Filonzi, Chiesa, Vaghi, & Nonnis Marzano, 2010; Hanner et al., 2011; Heyden et al., 2010).

5.4. Salmonids

Salmonids are a variety of fish within the family Salmonidae, which includes salmon, trout, grayling, and whitefish. Salmon commodity is very important but their marketplace substitution is not as high as the one described in previous fish groups. Actually, the misdescription incidents ranged from 2% to 25% with an average percentage of misdescription of 13% which represents the lower misdescription percentage detected (Rasmussen Hellberg et al., 2011). Anyway, some misdescription incidents have been reported such as the substitution of the Atlantic salmon (*Salmo salar*) with Pacific salmon (*Oncorhynchus* spp). The Pacific Salmon samples often lacked required species designation (e.g. Coho, Sockeye, Pink), and were also sometimes substituted with Atlantic salmon (Hanner et al., 2011; Herrero, Vieites, & Espiñeira, 2011a; Nebola, G.Borilova, & Kasalova, 2010). Interestingly, one study described the strong trend towards higher substitution rates in winter than in spring suggesting that substitution may be driven by scarcity of fresh wild salmon during seasons without salmon runs (Cline, 2012).

5.5. Scombroids

Any of the various marine fish of the suborder Scombroidei, which includes swordfish, mackerel and tuna, are included under the definition of scombroids. The commercial importance of these species is also evident attending to the number of references found (12). Nevertheless, the commercial importance of scombroids is not in accordance with the number of samples analyzed over the last 5 years; only 198 (4% of total). In the case of *Thunnus* species, the average of misdescription ranges from 0% to 20% with an average percentage of misdescription of 18%. However, there is a significant bias in these results since tuna is one example where DNA barcodes of mitochondrial *COI* were not able to differentiate samples to the species level, given that at least four species share the same haplotype in the BOLD database: *Thunnus albacares, T. maccoyii, T. obesus, and T. atlanticus*. Actually, in one study published in 2011, a considerable number of tuna samples analyzed were unresolved (Hanner et al., 2011). Nonetheless, some tuna misdescription incidents were described like the substitution of the most valuable tuna species (*T. thynnus*) with bigeye (*T. obesus*) (Maralit et al., 2013; Santaclara et al., 2015). In some sushi restaurant studies, this mislabeling reached 100% of the analyzed samples (Hanner et al., 2011). Another very common fraudulent substitution is the mislabeling of albacore (*T. alalunga*) with other tuna species like yellowfin (*T. albacares*) (Cawthorn et al., 2015). Finally, the swordfish (*Xiphias gladius*) is also frequently substituted by shark species like *Prionace glauca* or *Isurus oxyrinchus* (Herrero, Lago, Vieites, & Espiñeira, 2011; Pappalardo, Guarino, Reina, Messina, & De Pinto, 2011).

5.6. Cartilaginous fish

During the last years, cartilaginous fish are becoming increasingly important in many areas of the world, mainly sharks and rays. The average of misdescription ranges from 2% (Griffiths et al., 2013) to 80% (Barbuto et al., 2010) with the higher average percentage of misdescription described in this review; close to 50%. The interesting case of "palombo"; Italian designation that is referred to the shark *Mustelus mustelus* and *M. asterias*, showed a high level of commercial fraud (Barbuto et al., 2010). The wide range of misdescription incidents percentages identified in this review highlights the need for further surveys with an adequate sampling plan. Moreover, scientific opinion is concerned about the need to control the commercialization of sharks because, in many cases, these species are critically endangered under the illegal unreported and unregulated fishing practices (Melo Palmeira et al., 2013).

5.7. Others

In this section, we have collected data from those groups of species that have not been widely researched to be included as a separate group in this review. These species include very important commercial fish species like anchovies and sardines (Bréchon, Coombs, Sims, & Griffiths, 2013), new species from traditional and local markets like jellyfish (Armani, D'Amico et al., 2012; Armani et al., 2013), coral reef fish (Cox et al., 2013), edible aquatic invertebrates (Aranceta-Garza, Perez-Enriquez, & Pedro, 2011; Espiñeira & Vieites, 2012b; Haye et al., 2012; Wen et al., 2010; Wen, Hu, Zhang, & Fan, 2011) and ice fish species (Armani et al., 2011). The misdescription percentages ranged from 10%, in the case of anchovies and sardines (Bréchon et al., 2013), 33% monkfish (Herrero, Vieites, & Espiñeira, 2011b), 50% striped catfish and rockfish (Espiñeira & Vieites, 2012a; Galal-Khallaf et al., 2014) to 80% catfish in Brazilian markets (Carvalho et al., 2011). Nevertheless, these percentages should be taken into account with caution since the studies are very limited and in some cases it is not even feasible to identify which species are more frequently substituted with. New surveys are required to identify the main misdescription incidents in these important commercial seafood products.

6. Food safety implications

Nowadays, the scientific community has pointed out the extremely hazardous consequence that seafood mislabeling may cause on public health. Misdescription incidents might involve the inadvertent presence of toxic substances, potentially harmful to consumers. In this review we have collected a number of references where these risky concerns were described.

Escolar (*Lepidocybium flavobrunneum*) and oilfish (*Ruvettus pretiosus*) are two of the most common fish species that contain high levels of indigestible wax esters. Their consumption can cause mild keriorrhea; a condition characterized by excretion of an orange to brown oil without causing loss of body fluid as in ordinary diarrhea after consumption (Cabrero et al., 2015). In fact, the commercialization of both species is either banned or requires specific warning labels, depending of the country. Despite this fact, misdescription incidents involving these species have been reported leading to adverse consequences for the consumers. Three cases have been described in which escolar was swapped for mackerel (Nebola et al., 2010) and butterfish (Cabrero et al., 2015; Maralit et al., 2013). Similarly, puffer fish (*Lagocephalus* spp), a poisonous species banned from the EU market, has been identified in samples labeled as squid in Italy (Armani, Guardone, La Castellana et al., 2015). In other countries, like Taiwan, the consumption of nontoxic puffer fish species is allowed, but, recently, their substitution with less expensive but potentially toxic puffer fish species has been reported (Huang et al., 2014).

Moreover, another health risk for consumers is the consumption of fish species contaminated with pollutants. Nile perch (*Lates niloticus*), which is subject to commercial restrictions, is often used as a substitute for other perches, or several other species. In these cases, beyond obvious economic consequences, the substitutions could lead to health risks, since Nile perch comes from certain African rivers contaminated by methylmercury and other pollutants (Filonzi et al., 2010). The replacement of European plaice or Nile perch by farmed striped catfish can be problematic from a product safety perspective due to the pollutant contamination of the habitat where this highly tolerant species lives and is farmed (Galal-Khallaf et al., 2014; Pappalardo & Ferrito, 2015).

7. Sustainability implications

Worldwide fish consumption causes a great impact on oceans. Therefore, erroneous identification of fish catches leads to inaccurate estimates of exploitation level thus contributing to the exhaustion of stocks and ultimately to the loss of genetic diversity. From a sustainable point of view, governments and the scientific community are focusing their attention on deterring the problem of illegal, unreported and unregulated fishing practices. In this sense, the correct labeling of seafood products would help controlling the commercialization of endangered or vulnerable fish species. Some examples have been reported such as the commercialization of several highly endangered shark species (Melo Palmeira et al., 2013) or the Argentine hake (*M. hubbsi*) overexploited stock (Cawthorn et al., 2015); the case of the European common megrim (*L. whiffiagonis*) which led to design a separate management plan for each megrim species (Crego-Prieto et al., 2012); the example of shallow water *M. capensis* stock which is above sustainable levels and the restoration of *M. paradoxus* to sustainable levels (Helyar et al., 2014).

In this regard, only one misdescription incident was reported in which 8% of MSC-certified Chilean sea bass, coming from the Marine Stewardship Council-certified fishery, was substituted by other species (Marko, Nance, & Guynn, 2011).

8. Gaps in research

i. First results indicate that restaurant and takeaway seafood misdescription incidents rate is significantly higher than that of supermarkets and retailers. However, in order to confirm this fact, further HORECA sector specific surveys should be undertaken.
ii. The vast majority of studies have focused sampling at restaurants and retailers. Sampling distributors and processors would be extremely valuable, since these two sectors are poorly represented.
iii. There is a notable lack of adequate sampling plans involving insightful prior statistical analysis. Therefore, in those cases showing a wide range of misdescription, such as gadoids, the average percentage obtained in this review must be interpreted with caution. Further surveys are required to solve these deficiencies. Sampling plan must include the prior statistical calculation of the "sample size" of the population under consideration, together with the "confidence interval" (also called "margin of error") and "confidence level" selected in each specific study.
iv. There are not enough surveys aimed at identifying extremely important misdescription incidents in seafood sector; such as correct identification of fishing areas, differentiation between farmed and wild fish, and authentication of fresh versus frozen/thawed fish. These deficiencies could be due to the low availability of validated analytical methodologies.
v. During 2014, a slight decrease in a percentage of published misdescription incidents has been detected but this fact must to be confirmed with further surveys including adequate sampling plans.
vi. Many authors categorize a given misdescription incident as a fraudulent business without conclusive evidences of any economic gain. Further analysis will help to identify trends that can help reveal weaknesses in existing quality control systems and it will create further challenges to determine the extent of food fraud risk.
vii. Gadoids, flatfish and salmonids comprise almost 60% of the total reported samples. New surveys should resolve the percentage of misdescription in other very important commer-

cial seafood like; anchovies, sardines, tunas, porgies, monkfish, sharks and shellfish.

viii. Food safety and sustainability aspects of seafood products have a negative impact on public perception that could be alleviated by ensuring properly labeled seafood products commercialization.

ix. As a result of comprehensive scientific results, strong management programs, and enforcement inspection, monitoring and control must be conducted by governments and food industry introducing voluntary control systems. The publicity given to these actions would reinforce significantly consumer confidence in seafood products.

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