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# OVERVIEW OF FOOD FRAUD IN THE FISHERIES SECTOR

***Cover photo:***
Mussel farm in the Philippines. © FAO/A. Reilly.

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# OVERVIEW OF FOOD FRAUD IN THE FISHERIES SECTOR

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## PREPARATION OF THIS DOCUMENT

Food fraud, while not a new phenomenon, has come under the spotlight in recent years. Following on from the 2013 horsemeat scandal in the European Union, which exposed the vulnerability of international food chains to fraud and organised crime, major initiatives are under way by many governments and within the industry to combat food fraud. FAO is following this situation carefully and is engaged in a number of activities to contribute to the preparedness for countries to prevent food fraud or to mitigate its impacts. FAO is particularly concerned with the provision of information and analyses that inform policies and programmes across sectors and in raising awareness in developing countries of the issue and its relevance to them. The fisheries and aquaculture sectors are recognised as among the most vulnerable sectors to food fraud. FAO commissioned Professor Alan Reilly, former Chief Executive Officer of the Food Safety Authority of Ireland, to write this review of fraud in the fisheries and aquaculture sectors and provide recommendations for future actions. This circular was funded through FAO's Strategic Programme of work on "efficient and inclusive food systems", and was implemented jointly by the Agriculture and Consumer Protection Department and the Fisheries and Aquaculture Department.

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**ABSTRACT**

Fish fraud is committed when fish is illegally placed on the market with the intention of deceiving the customer, usually for financial gain. However, its precise scale and nature in the wider global food market is largely unknown. This publication presents evidence highlighting the serious consequences of fraud for the fish sector. It describes the different types of fraud that can take place along the fish supply chain, for example: intentional mislabelling, species substitution, overglazing and overbreading, and the use of undeclared water-binding agents to increase weight.

This publication shows that combating fish fraud is a complex task that requires the strengthening of national food regulatory programmes and the development of effective, science-based traceability systems and improved methods for fish authenticity testing. It highlights the need for the fish industry to develop and implement systems for fish fraud vulnerability assessment in order to identify potential sources of fish fraud within their supply chains, and to prioritize control measures to minimize the risk of receiving fraudulent or adulterated raw materials or ingredients. The publication also indicates an important role for the Codex Alimentarius Commission – to work in collaboration with countries in order to develop international principles and guidelines designed to identify, manage and mitigate fraudulent practices in food trade and to develop guidelines to standardize food safety management systems for fish fraud vulnerability assessment.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| DNA | deoxyribonucleic acid |
| CO1 | cytochrome oxidase subunit 1 |
| EC | European Commission |
| EU | European Union |
| Europol | European Union Agency for Law Enforcement Cooperation |
| FISH-BOL | Fish Barcode of Life |
| HACCP | Hazard Analysis and Critical Control Points |
| INTERPOL | International Criminal Police Organization |
| IUU | illegal, unreported and unregulated (fishing) |
| MSC | Marine Stewardship Council |
| TACCP | Threat Assessment and Critical Control Points |
| USFDA | United States Food and Drug Administration |
| USP | United States Pharmacopeial Convention |

## EXECUTIVE SUMMARY

Food fraud is committed when food is illegally placed on the market with the intention of deceiving the customer, usually for financial gain. This involves criminal activity that can include food mislabelling, substitution, counterfeiting, misbranding, dilution and adulteration. While food fraud primarily results in cheating customers, it can also lead to significant food safety risks for consumers. Public health is endangered when fish species that are toxic are substituted for non-toxic varieties. Public health is also put at risk when farmed or freshwater species from polluted watercourses are substituted for marine fish. The impacts of food fraud include loss of consumer confidence in both the food industry and in the effectiveness of government food control programmes. Some high-profile food fraud incidents in the past decade have also damaged national reputations, with unwanted attention focused on the safety, quality and authenticity of all foods exported to the global market.

Fish fraud is committed when fish is deliberately placed on the market, for financial gain, with the intention of deceiving the customer. There are many different types of fish fraud that can take place at multiple points along the fish supply chain. The most common type of fish fraud involves intentional mislabelling and species substitution. To a lesser extent, fraud occurs when fish is overglazed or overbreaded, leading to deceiving consumers regarding the nature of fishery products. Undeclared use of water-binding agents is also a fraudulent practice that leads to increasing the weight of products and selling additional water substituted for fish.

Species substitution occurs where low-value or less-desirable fish species are swapped for more-expensive varieties, for example, the fraudulent marketing of farmed salmon as wild-capture species. The flesh of many fish species is similar in appearance, taste and texture. It can be difficult to identify or differentiate species once these have been processed or prepared for consumption and presented with flavouring in sauces or in batter. Species substitution can also occur where a higher-value species is marketed as a lower-value species in order to avoid taxation. It can also occur in order to conceal the geographical origin, or to hide an illegally harvested protected species or a species from a protected area.

Recent studies and surveys have demonstrated that the fish chain is particularly vulnerable to fraud, primarily to species substitution and mislabelling. While the scale of the problem has been investigated and reported in developed countries, much less is known about fish fraud in developing countries. In 2015, an INTERPOL–Europol investigation demonstrated that fish traded internationally was the third-highest risk category of foods with the potential for fraud, while in 2013 the European Commission classified fish in the second-highest category for fraud. The numbers of reports and reviews published in both the scientific literature and the popular media in the past decade provide adequate documentary evidence that fraud through mislabelling and species substitution is a widespread problem in both national and international markets for fish and fishery products. Fish mislabelling can occur at every stage of the fish marketing chain, from the point of landing through to processing, distribution, retail and catering. In 2016, a major report by Oceana that reviewed more than 200 published studies on fish fraud from 55 countries worldwide found that, on average, 20 percent of all fish in the retail and catering sectors was mislabelled. Published studies reviewed for this report, involving both large- and small-scale surveys on fish fraud from different parts of the world in the past decade, all indicate that species substitution and mislabelling are serious problems.

Species substitution and mislabelling are difficult to detect when fish morphological features such as heads, tails and fins are removed and fish are processed into fillets, ready-to-eat breaded or battered products, or highly processed in pre-prepared fish meals. With the advent of molecular identification methods, such as DNA barcoding and next-generation sequencing, the possibility exists for far greater transparency in the fish marketing chain. Fish traceability is key to combating fish fraud, enforcing food safety regulations and ensuring high standards of sustainable fisheries management. Traceability is also critical for ensuring the quality of fish products and minimizing health risks for consumers. One of the principal challenges in tackling fish fraud is establishing an agreed list of common names that are linked to scientific nomenclature. This is an essential first step for national governments in introducing official fish fraud control programmes.

Combating fish fraud is a complex task for national authorities as, usually, no single government agency has the regulatory mandate to do so and no single food law or regulation directly addresses all aspects of food fraud. Responsibilities are usually shared across national food regulatory authorities, border protection agencies, customs import authorities and specialist agencies within the national police force. Close collaboration between all of these different agencies of government is essential for an effective response. There is a need to strengthen official national food control programmes by: developing new regulations to combat fish fraud; enhancing enforcement activities prohibiting landings and market access for products from illegal, unreported, and unregulated fishing; introducing monitoring and surveillance programmes for assessing the degree of compliance with fish labelling regulations; and upgrading laboratory detection methods based on DNA barcoding.

To meet current demands of the global fish marketing chain to combat fish fraud, an effective science-based fish traceability system must be able to identify the fish species and its geographical origin, and to distinguish between wild-capture and farmed products. The system must also be able to identify fresh and frozen fish, and the many different forms of processed fish currently traded. The traceability system must be able to reliably track fish from the point of harvest to the consumer's plate. Current traceability systems rely on a paper trail that documents data such as geographical origin, species, and registration details of vessels. What is required is a traceability system that is science-based and verified by independent scientific analytical methodologies to trace fish and fishery products throughout the marketing chain. Food control authorities require definitive analytical tools for the identification of fish species based on molecular DNA techniques.

There is a need for the harmonization and standardization of analytical techniques and for universal access to a standard database with relevant data on genetic primers based on scientific names. Greater cooperation between food control authorities and law enforcement agencies, both nationally and internationally, is required in order to combat the criminal activities involved in fish fraud. Food regulations need to be strengthened and penalties made proportionate to criminal infringements. Fish labelling regulations need to provide sufficient data for consumers to be able to make informed choices about the products they purchase. The introduction of new analytical technologies for fish species identification means that food inspectors and laboratory staff will need to be adequately trained. Food inspectors will also need to be trained in the investigation of fraud.

While DNA barcoding using the mitochondrial cytochrome c oxidase subunit 1 has been established as a reliable method to identify fish to species level, it has certain drawbacks for use in the identification of geographical origin of fish species. Hence, DNA analysis based on next-generation sequencing and other advanced genetic techniques have been proposed in order to identify the origin or provenance of fish catches. These methods need further development before their use in routine official food control programmes.

The fish industry needs to put systems in place to protect against the risk of fraudulent activities in the food chain. Food safety management systems need to be expanded to include vulnerability and threat assessments to analyse risks and to put control and prevention strategies in place. Routine analytical procedures for species authentication and systems for validating traceability documentation need to be introduced. The industry needs to develop and implement systems for fish fraud vulnerability assessment to identify potential sources of fish fraud within its supply chains and to prioritize control measures to minimize the risk of receiving fraudulent or adulterated raw materials or ingredients.

The Codex Alimentarius Commission, in association with its member countries, should develop international principles and guidelines designed to identify, manage and mitigate fraudulent practices in food trade and to develop guidelines to standardize food safety management systems for fish fraud vulnerability assessment.

## 1. INTRODUCTION

Food fraud, while not a new phenomenon, has come under the spotlight in recent years. Following on from the 2013 horsemeat scandal in the European Union (Member Organization), which exposed the vulnerability of the international food chain to organized crime, major initiatives are under way to combat food fraud. National, regional and international food fraud networks and platforms have been established for sharing information and fostering cooperation to combat food fraud. These include collaborative activities by Europol (Europol, 2017), the Food Fraud Database of the United States Pharmacopeial Convention (USP) (United States Pharmacopeial Convention, 2018), and the Food Fraud Network of the European Commission (European Commission, 2018a). Many countries have established specialist units or dedicated task forces to strengthen food control systems to tackle food fraud (Food Safety Authority of Ireland, 2017; Food Standards Agency, 2016; United States Food and Drug Administration, 2017a). Official food control programmes are not routinely designed to deal with criminal aspects of food fraud. Criminal investigations associated with food fraud are usually the remit of dedicated units in law enforcement agencies. In order to target food fraud effectively at national level, collaboration is required between a range of government agencies, such as food control authorities, customs and excise, and the national police force.

Food fraud is committed when food is illegally placed on the market with the intention of deceiving the customer, usually for financial gain. More simply, it is the act of defrauding food buyers for economic gain. Food fraud involves criminal activity that can include mislabelling, substitution, counterfeiting, misbranding, dilution and adulteration. Food crime involves any criminal conduct that affects the safety or authenticity of food.

Food fraud can result in significant food safety risks where consumers' health is compromised, as occurred with the adulteration of infant formula with melamine in 2008 and the use of lead chromate to enhance the colour of turmeric (Gleason *et al.*, 2014; United States Food and Drug Administration, 2016). Food fraud can also affect the nutritional quality of foods, for example, where milk or fruit juices are diluted with water or sugar solutions. Food fraud can damage consumer trust in the integrity of the food supply as occurred during the horsemeat scandal (above) when lower-value horsemeat was substituted for beef in processed meat products on the market in the European Union (Member Organization). Food fraud can also result in severe economic consequences and can damage national reputations in the global food market.

## 2. FISH FRAUD

Fish fraud is committed when fish[1] is deliberately placed on the market, for financial gain, with the intention of deceiving the consumer. There are many different types of fish fraud (Box 1) that can take place at multiple points along the fish supply chain. This occurs for a number of reasons, from a simple misunderstanding of regulations to deliberate deception of consumers to increase profits, or to laundering illegally harvested fish and the falsification of trade documentation. Misleading claims on fish provenance can deceptively influence consumers' perception that a product is of premium quality. For example, claiming that tuna is caught by pole and line when it is in fact sourced from a purse seine fishery is a form of fish fraud. Fish fraud occurs in a variety of different ways – from intentional mislabelling and species substitution, to "short-weighting" product (overglazing or overbreading). Overglazing occurs more frequently in high-value products, such as scallops or peeled shrimps and prawns. Another example is the undeclared use of water-binding agents to increase the weight of products. Weigh gains of up to 50 percent have been reported when sodium tripolyphosphate (E541) was used in processing Vietnamese pangasius (World Fishing and Aquaculture, 2010). While this additive can legally be added to processed fish at a level of 5 percent in the United States of America and the European Union (Member Organization), overuse can lead to substantial economic gains and the defrauding of consumers. Fish fraud can also include practices such as quality enhancement of fish that alter the appearance of fish so that it is presented as being of a higher quality than it actually is. For example, carbon monoxide can be used to enhance or maintain the colour of fish flesh during frozen storage. The use of carbon monoxide is prohibited in some countries, and such use must be declared on the label.

**Box 1**

**Fish fraud – what's involved?**

Different forms of fish fraud occur in both domestic and international fish marketing chains. The primary motive behind fish fraud is the deception of buyers for economic gain. There are different estimates of the scale of fish fraud as many countries do not have the capacity to monitor fraudulent activities in the marketing chain and do not have developed official food control programmes to regulate fish business operators. Some of the most common forms of fish fraud involve:

- species substitution, where a low-value species replaces a more expensive variety for economic gain, or where a high-value species is presented as a lower-value species for tax evasion purposes;
- mislabelling of fish to conceal the geographical origin of illegally harvested species;
- marketing of counterfeit products, where brand names are fraudulently used;
- undeclared use of food additives such as water-binding agents to deceptively increase the weight of products;
- illegal use of food additives such as carbon monoxide to enhance the visual quality of fish products;
- addition of glaze water to frozen products to increase weight;
- mislabelling of ingredients, such as batter or breadcrumbs, to bulk up the weight of processed products.

Species substitution occurs where low-value or less-desirable fish species are substituted in place of more-expensive varieties. For example, the fraudulent marketing of pangasius as more-valuable white-fleshed species. The flesh of many fish species is similar in appearance, taste and texture. It can be difficult to identify or differentiate species once processed or prepared for consumption and presented with flavouring in sauces or in batter. Species substitution can also occur when a higher-value species is marketed as a lower-value species as a means of avoiding taxation. It can also occur in order to conceal the geographical origin, or to hide an illegally harvested protected species or a species from a protected area.

[1] In this publication, the term fish includes marine fish, freshwater fish, shellfish and crustaceans.

Regardless of the manner in which the fraud occurs, fish fraud is illegal, it can affect public health, it undermines confidence in the market place, and it can have serious consequences for fishery management and the fish industry, in addition to economic, social and environmental costs.

## 3. SCALE AND GLOBAL INCIDENCE OF FISH FRAUD

The fish chain is particularly vulnerable to fraud, as demonstrated by an investigation into food fraud carried out across 57 countries and coordinated by INTERPOL–Europol in 2015 (Europol, 2016). Fish was identified as the third-highest risk category of foods with the potential for fraud. In 2013, the European Parliament identified fish as the second-most likely category of food traded internationally at risk of fraud (European Parliament, 2013). A report to the Congress of the United States of America in 2014 (Johnson, 2014) on food fraud analysed the breakdown of reported incidences by different food categories in two national food fraud databases. In the National Center for Food Protection and Defense Food Fraud Incident Database, the category fish accounted for 31 percent of entries, and in the USP Food Fraud Database between 2008 and 2010 fish accounted for 12 percent of incidences. These data point to a serious problem with fish fraud in the global food marketing chain.

While fish fraud is not a new problem, the number of reported cases and incidences in recent years shows an increasing trend in species substitution and mislabelling at a global scale. A major global study published in 2016 found that fish mislabelling occurred at every stage of the fish marketing chain, from the point of landing through to processing, distribution, retail and catering (Oceana, 2016). Cases of fraudulent practices during import and export of fish were also reported. The study reviewed more than 200 published studies on fish fraud from 55 countries worldwide and found that, on average, 20 percent of all fish samples tested were mislabelled. A follow-up investigation of fish labelling in Canadian grocery stores and restaurants found that almost 50 percent of samples tested were mislabelled (Oceana, 2017). Most of the studies reviewed were carried out at the retail and catering stages of the marketing chain. Pardo, Jiménez and Pérez-Villarreal (2016) reviewed published reports from the previous five years of fish fraud where DNA methods were used to identify mislabelling. On average, 30 percent of samples tested were mislabelled, the majority being from the restaurant and takeaway sectors. Many small-scale surveys on fish fraud from different parts of the world have been published in the past decade. All indicate that species substitution and mislabelling are serious problems.

Recent published studies from the United States of America give an indication of the scale of fish fraud. A survey of labelling of red snapper on the United States market using DNA barcoding found that 75 percent of samples were mislabelled (Marko *et al.*, 2004). An investigation into the authenticity of fish in restaurants in three United States regions found that 16.5 percent of fish were mislabelled (Khaksar *et al.*, 2015). A four-year study of the authenticity of fish species sold in sushi restaurants in a large city in the United States of America showed that 47 percent of products were mislabelled (Willette *et al.*, 2017). In 2013, Oceana published a report where DNA barcoding was used to identify the authenticity of fish in the United States of America (Warner *et al.*, 2013). It showed that 33 percent of samples from 21 states were mislabelled. In the study, fish were sampled from retail premises such as restaurants and grocery stores.

In Canada, a study carried out on the authenticity of fish in retail establishments in five metropolitan areas by the Canadian Centre for DNA Barcoding found that 41 percent of samples were mislabelled (Hanner *et al.*, 2011). This study was carried out as part of the Fish Barcode of Life (FISH-BOL) initiative, which seeks to establish a reference database of barcodes derived from the cytochrome c oxidase subunit 1 (CO1) gene to facilitate the rapid, accurate and cost-effective DNA-based identification of fish species (Steinke, Hanner and FISH-BOL, 2011).

The situation in Europe is similar to that in Canada and the United States of America. In 2015, as a follow-up to the horsemeat crisis, the European Commission organized a coordinated control programme across all member states to assess the extent of mislabelling in the white fish market (European Commission, 2015). Almost 4 000 samples were tested in 29 countries, and a 94 percent compliance rate with labelling regulations was found. Many other small surveys have been conducted in individual European countries to assess mislabelling and species substitution. A recent study of labelling non-compliance of imported fishery products carried out by Italian authorities found that 22.5 percent of products were mislabelled (Guardone *et al.*, 2017). The highest level of mislabelling was found in cephalopod-based products (43.8 percent), followed by crustaceans (17 percent) and fish (14 percent), with the highest rate of mislabelling in products imported from China, Viet Nam and Thailand.

A small survey on the prevalence of mislabelling of fish fillets from markets and supermarkets in southern Italy was conducted in 2015 (Tantillo *et al.*, 2015). Overall, 42.8 percent of fillets (sole, plaice, salmon and hake) were mislabelled, with 46.4 percent of plaice fillets being substituted with pangasius. A similar survey of fish fillets on sale at markets and supermarkets showed a high degree of mislabelling (Di Pinto *et al.*, 2015). When tested using DNA barcoding, 82 percent (164 samples out of 200) of fish fillet samples were mislabelled. Mislabelling and species substitution at retail level in Sardinia, Italy, was investigated between 2009 and 2014 (Meloni, Piras and Mazzette, 2015). More than 3 000 labels on fresh fishery products were examined and a 30 percent incidence of non-compliance was detected.

A survey of hake products in Greek and Spanish marketing chains showed that 30 percent of these products were substituted with African fish species (Di Pinto *et al.*, 2015). A study of surimi products manufactured in China, India and Singapore using DNA barcoding showed that low-value species such as sardines and farmed catfish were used (Galal-Khallaf *et al.*, 2016a). In one sample, an endangered species was identified, which warrants further testing on fishery products where classical morphological methods of identification are not effective. An investigation into the levels of labelling accuracy in sushi bars and restaurants across England, the United Kingdom of Great Britain and Northern Ireland, showed a level of 10 percent species substitution of tuna, eel and white-fish species (Vandamme *et al.*, 2016). In a separate survey, DNA barcoding was used to identify fish species in two convenience products, fish fingers and fish sticks. Less than 1.5 percent of fish fingers with species-specific information were mislabelled (Huxley-Jones *et al.*, 2012). A survey of the authenticity of white fish in supermarkets in the United Kingdom of Great Britain and Northern Ireland using DNA barcodes showed a high level of compliance with labelling regulations – 94.34 percent of samples complied with information on labels (Helyar *et al.*, 2014). The authors of the study suggest that the low level of species substitution found was due to a high level of industry and public awareness of fish fraud resulting from enforcement of labelling regulations and media attention.

A comprehensive retail survey in France sampled 371 fresh and frozen fish fillets and fish meals labelled as containing 55 commercial fish species (Bénard-Capelle *et al.*, 2015). The incidence of species substitution in this study was 3.7 percent. No cases of mislabelling were detected in the frozen fillets or in industrially prepared meals. Mislabelling was detected in fishmongers and restaurants, where five species (bluefin tuna, cod, yellowfin tuna, sole and seabream) were substituted with cheaper species. In 2011, the Food Safety Authority of Ireland carried of a national survey of the authenticity of fish marketed in restaurants, takeaways and retail premises (Food Safety Authority of Ireland, 2011). Products were subjected to DNA testing, and about one-fifth of the products tested were found to be mislabelled. All but one of the non-compliant samples were sold as cod, but were actually found to contain pollock, smelt or other cheaper fish species. Almost three-quarters of the smoked fish products sampled were mislabelled, most of which were purchased in takeaways. The Food Safety Authority of Ireland issued a warning to the seafood sector that fish labelling regulations would be strictly enforced, and prosecutions followed. Fish authenticity monitoring is now part of the routine national food surveillance programme in Ireland and no cases of mislabelling have been detected since 2012 (Food Safety Authority of Ireland, 2016).

In South America, DNA barcoding was used in a study in Brazil to detect a high level (more than 70 percent) of fish mislabelling and species substitution (de Brito *et al.*, 2015). In 2017, the Federal Government of Brazil adopted DNA barcoding as the standard method for the enforcement of regulations for processed fish products (Carvalho *et al.*, 2017).

Incidences of species substitution have also been reported from Africa. A study of fish species substitution and misnaming in South Africa showed that, out of 149 fish samples collected from restaurants and retailers in three provinces, 18 percent of samples were mislabelled (Cawthorn *et al.*, 2015). An investigation was conducted into the utility of DNA barcoding for both the identification of a variety of commercial fish in South Africa and for estimating the prevalence of species substitution and fraud prevailing in this market. Results showed that 9 percent of samples from wholesalers and 31 percent from retailers were identified as different species to the ones indicated at the point of sale (Cawthorn *et al.*, 2015). In a study of the authenticity of fish fillets on the Egyptian market, a high level of species substitution was detected, with Nile perch fillets being substituted with imported pangasius (Galal-Khallaf *et al.*, 2014). A novel study on the composition of aquaculture feeds was carried out in Egypt using DNA meta-barcoding, where about 46 percent of all fish species detected were either overfished or their stocks were in decline (Galal-Khallaf *et al.*, 2016b).

Investigations in Asia using DNA barcoding have also reported incidences of mislabelling of fish. In a pioneering forensic fish survey conducted in Malaysia in 2016, 16 percent of raw, frozen or commercially processed fish were found to be mislabelled (Chin Chin *et al.*, 2016). Studies in China using DNA barcoding have also revealed widespread mislabelling of fish on the national market (Xiong *et al.*, 2016a, 2016c). A study on the authenticity of fish maws (dried, salted swim bladders) on the Chinese market found that 53.2 percent were mislabelled and commercial species substituted with low-value species (Wen *et al.*, 2015). Similarly, an investigation of the authenticity of fish imported into Taiwan Province of China showed that 70 percent of samples were mislabelled (Chang *et al.*, 2016).

An Indian survey of the authenticity of fresh and processed fish from the domestic market also used DNA barcoding (Nagalakshmi *et al.*, 2016). Its results showed that 22 percent of samples were mislabelled. Another study used DNA barcoding to identify shark species from dried fins, confiscated from a vessel fishing illegally in Australian waters (Holmes, Steinke and Ward, 2009). It found that the fins were from 27 different shark and ray species, some belonging to endangered species. A DNA analysis of fish in retail markets and fish ports in Indonesia utilizing both the CO1 and the nuclear rhodopsin gene fragment revealed mislabelling of some species and the finding of substitution with endangered species (Abdullah and Rehbein, 2017).

The scale of mislabelling and species substitution in the global fish marketing chain is a cause for concern and occurs in many different countries. Traditional identification of fish species is compromised when fish are processed as fillets and read-to-eat products. Today, DNA barcoding is a well-established method for definitively identifying fish to species level and it provides a science-based system for linking scientific nomenclature with approved common fish names. There is a pressing need for this method to be internationally recognized and to be used to strengthen official food control programmes as a system to combat fraud, mislabelling and species substitution in fish value chains.

## 4. PUBLIC HEALTH ASPECTS OF FISH FRAUD

Although many of the fish fraud incidents discussed in this review do not pose an immediate risk to public health, some cases have resulted in actual or potential harm to consumers' health. Public health is endangered when fish species that are toxic are substituted for non-toxic species. Public health is also put at risk when farmed species from polluted watercourses are substituted for marine fish.

Naturally toxic fish species that cause serious forms of food poisoning and that can sometimes cause fatalities include some species of puffer fish, scombroid fish, escolar or oilfish, and ciguatoxic fish species. Puffer fish toxicity results from the ingestion of tetrodotoxin, which causes paralysis and death (Box 2). Some scombroid species such as tuna can cause histamine poisoning, which results in allergic reactions in sensitive individuals (FAO/WHO, 2013). Some species of escolar or oilfish contain waxy esters, which are indigestible and cause gastrointestinal disorders such as keriorrhoea (anal leakage and oily orange diarrhoea). These species belong to the family Gempylidae, and the waxy esters are referred to as gempylotoxins. Ciguatera fish poisoning is caused by eating certain reef fish from tropical and subtropical climates that contain naturally occurring ciguatoxins (Friedman *et al.*, 2008). The link between mislabelling and food safety is also illustrated when aquaculture species are substituted for wild-caught species. Farmed fish may have a higher incidence of contamination with environmental contaminants, such as heavy metals. Residues of antibiotics in farmed species may also pose a risk to consumer health, emphasizing the link between species authentication and food safety.

**Box 2**

**Food safety consequences of mislabelling fish: puffer fish fatalities in Bangladesh**

Some species of puffer fish (*Lagocephalus sceleratus*) contain tetrodotoxins, which are powerful neurotoxins that can cause fatalities. Death is caused by muscular paralysis, respiratory depression and circulatory failure. In recent years, there have reports of fatalities associated the consumption of puffer fish in Bangladesh resulting from unscrupulous marketing of toxic fish in communities that would have no knowledge about the risks to health from puffer fish. In 2008, inland populations in Bangladesh unknowingly purchased cheap puffer fish at local markets, which gave rise to 3 outbreaks with 141 cases and 17 deaths.[1] A similar outbreak occurred in in Khulna, involving 37 cases with 8 fatalities in 2002.[2] In 2016, five people in an inland community in Sylhet died from eating puffer fish.[3]

[1] Islam, Q.T., Razzak, M.A., Islam, M.A., Bari, M.I., Basher, A., Chowdhury, F.R., Sayeduzzaman, A.B.M., Ahasan, H.A.M.N., Faiz, M.A., Arakawa, O., Yotsu-Yamashita, M., Kuch, U. & Mebs, D. 2011. Puffer fish poisoning in Bangladesh: clinical and toxicological results from large outbreaks in 2008. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, 105(2): 74–80. https://doi.org/10.1016/j.trstmh.2010.10.002
[2] Ahasan, H.A.M.N., Mamun, A.A., Karim, S.R., Bakar, M.A., Gazi, E.A. & Bala, C.S. 2004. Paralytic complications of puffer fish (tetrodotoxin) poisoning. *Singapore Medical Journal*, 45(2): 73–74.
[3] International Society for Infection Diseases. 2016. Tetrodotoxin poisoning, puffer fish - Bangladesh: (Sylhet) fatal. [Cited 23 February 2018]. http://www.promedmail.org/direct.php?id=20161207.4679425

The puffer fish fatalities in Bangladesh (Box 2) are a result of a combination of ignorance, unscrupulous marketing by intermediaries in the fish market chain and species substitution. These factors are compounded by weak food control systems, absence of regulations and poor consumer awareness of the consequences of fish fraud. Using DNA barcoding, a number of studies identified toxic species found to be substituted for commercial fish species. In a study of ethnic fish on the Italian market in 2015, samples labelled as squid were identified as toxic species of puffer fish (Armani *et al.*, 2015). In 2007, two cases of puffer fish poisoning occurred in the United States of America after the consumption of fish incorrectly labelled as monkfish (Cohen *et al.*, 2009). In a study of fish fillets in commercial trade in Italy, 32 percent of samples tested were mislabelled (Filonzi *et al.*, 2010). Findings included Mediterranean grouper being substituted with Nile tilapia, gurnard substituted with Nile perch, and halibut with pangasius. All of these cases amount to economic fraud with risks to public health from environmental contaminants. The substitution of gindara or sablefish with escolar was identified in a study of fish authenticity on the market in the Philippines (Maralit *et al.*, 2013), again demonstrating the food safety risks of species substitution. Pardo, Jiménez and Pérez-Villarreal (2016) discussed the food safety implications of species mislabelling on public health and concluded that the consequences could be extremely hazardous. Red snapper was found to be substituted with tilefish in a study carried out in 2013 of the authenticity of fish on the retail market in the United States of America (Warner *et al.*, 2013). Tilefish are listed by the United States Food and Drug Administration (USFDA) as a species for young children and pregnant women to avoid because of high mercury levels (United States Food and Drug Administration, 2017b).

## 5. DNA BARCODING

The definitive identification of fish to species level using traditional morphological methods is difficult, if not impossible, when fish are processed into fillets, ready-to-eat breaded or battered products, or highly processed in pre-prepared fish meals. Traditional methods of species identification are of little value when assessing the species content of fish feed or products such as surimi. The usual morphological characteristics such as head, tail and skin used in identification are partially or completely lost in processing. With the advent of molecular identification methods, such as DNA barcoding and next-generation sequencing, the possibility exists for far greater transparency in the fish marketing chain. Fish traceability is key to combating fish fraud, enforcing food safety regulations and ensuring high standards of sustainable fisheries management. Traceability is also critical for ensuring the quality of fish products and minimizing health risks for consumers.

Today, DNA barcoding based on short sequences from the mitochondrial CO1 region is now a reliable method for definitively identifying fish to species level (Box 3). This method needs to be standardized and accredited before its use in official food control laboratories becomes a matter of routine. The Joint Research Centre of the European Commission concluded in its report on deterring illegal activities in the fisheries sector that "despite enormous technological progress, particularly in the field of DNA analysis, the routine application of modern molecular techniques for fisheries control and traceability is far from being fully established" (Martinsohn, 2011).

An example of why DNA analysis is urgently required to authenticate ecolabelling and certification labels, such as those of the Marine Stewardship Council (MSC), was demonstrated by study of fish products labelled as Patagonian toothfish and marketed as "Chilean sea bass". Using DNA testing, 8 percent of the fish with the MSC certification labels were in fact other species (Marko, Nance and Guynn, 2011). This analytical technique was also used to identify processed fins from internationally endangered shark species (Fields *et al.*, 2015). This study also reported that the DNA minibarcoding method was also successfully used to identify fins in processed shark fin soup. A recent survey of mislabelling of tuna in the Spanish marketing chain carried out over a one-year period and using DNA barcoding found species substitution began at suppliers, with 40 percent of observed cases, increasing to 58 percent at fishmongers and 62 percent at restaurants (Gordoa *et al.*, 2017). Increasing numbers of consumers are purchasing food products via e-commerce platforms, where there is a higher risk of deception by species substitution. A recent investigation using DNA barcoding of fishery products sold online in China found that 85 percent of the samples identified by DNA barcoding were mislabelled (Xiong *et al.*, 2016b).

**Box 3**

**Barcoding for the identification of fish fraud**

For fish identification, DNA barcoding works by using a short genetic sequence of mitochondrial DNA to identify the fish as belonging to a particular species. Subjecting fish and fishery products to DNA analysis is a definitive method for identification of fish down to species level. This is a very useful technique for testing the authenticity of fish and can be used on both raw and cooked products. Once a fish has been subjected to processing with the removal of morphological features such as the skin, head and tail, it becomes extremely difficult to differentiate between species by visual inspection alone. Today, DNA analysis, referred to as barcoding, is now a well-established method for authenticity testing of fish species. Initially developed by Hebert *et al.* (2003),[1] it involves the identification of fish species by analysing short nucleotide sequences and comparing the results with reference sequences in online public databases. Such DNA analysis has been used very successfully to identify mislabelling or species substitution at different stages of the fish marketing chain in many different parts of the world.

The gene region which is most frequently used as the standard barcode for fish is the mitochondrial cytochrome oxidase subunit 1 (CO1) region. The advantages of using mitochondrial DNA is that it is relatively heat-resistant, and it has a high level of recovery compared with nuclear DNA as there are greater quantities of mitochondrial DNA in the cell. Barcoding uses species-specific, short genetic sequences from the CO1 to distinguish between fish species. The Brazilian government has recently adopted this barcoding system as part of its regulatory food control programme for testing the authenticity of fish.[2] Shokralla *et al.* (2015)[3] successfully applied a DNA minibarcoding system for the identification of processed fishery products. The versatility of this system was recently demonstrated in a study that differentiated between species of fish used in the manufacture of surimi from five different countries.[4]

The United States Food and Drug Administration has published an online database where DNA sequences can be compared with standard sequences for fish identification – the Reference Standard Sequence Library for Seafood Identification.[5] Other online databases are also used, such as GenBank,[6] and FISH-BOL.[7]

[1] Hebert, P.D.N., Cywinska, A., Ball, S.L. & deWaard, J.R. 2003. Biological identifications through DNA barcodes. *Proceedings of the Royal Society of London B: Biological Sciences*, 270(1512): 313–321. https://doi.org/10.1098/rspb.2002.2218
[2] Carvalho, D.C., Guedes, D., da Gloria Trindade, M., Coelho, R.M.S. & de Lima Araujo, P.H. 2017. Nationwide Brazilian governmental forensic programme reveals seafood mislabelling trends and rates using DNA barcoding. *Fisheries Research*, 191: 30–35. https://doi.org/10.1016/j.fishres.2017.02.021
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[4] Galal-Khallaf, A., Ardura, A., Borrell, Y.J. & Garcia-Vazquez, E. 2016. Towards more sustainable surimi? PCR-cloning approach for DNA barcoding reveals the use of species of low trophic level and aquaculture in Asian surimi. *Food Control*, 61: 62–69. https://doi.org/10.1016/j.foodcont.2015.09.027
[5] United States Food and Drug Administration. 2017. *Reference Standard Sequence Library for Seafood Identification (RSSL)* [online]. [Cited 23 February 2018]. https://www.fda.gov/food/foodscienceresearch/dnaseafoodidentification/ucm238880.htm
[6] National Center for Biotechnology Information. 2017. *GenBank overview* [online]. [Cited 23 February 2018]. https://www.ncbi.nlm.nih.gov/genbank/
[7] International Barcode of Life Project. 2018. *Fish barcode of life (FISH-BOL)* [online]. [Cited 23 February 2018]. http://www.fishbol.org/

In order to combat fish fraud, the fish industry should require a certificate of analysis based on DNA barcoding with every business transaction. This system is now routine in the European meat sector, where supermarkets and meat processors will only purchase batches of processed meat upon presentation of a laboratory certificate guaranteeing the authenticity of the meat products.

While DNA barcoding using the mitochondrial CO1 unit has been established as a reliable method to identify fish to species level, it has certain drawbacks for use in the identification of geographical origin of fish species (Box 4). However, DNA analysis based on next-generation sequencing and other advanced genetic techniques have been proposed to identify the origin or provenance of fish catches. These methods need further development before use in routine official food control programmes. Advanced DNA analysis has been used successfully to identify the river of origin of wild-caught salmon (Horreo, Machado-Schiaffino and García-Vázquez, 2017). Advanced methods that allow simultaneous testing of fish species and provenance have been developed by the FishPopTrace project (European Commission, 2018b).

**Box 4**

**Using DNA analysis to determine the geographical origin of fish**

The definitive scientific determination of the origin of fish is crucial in fisheries management and in preventing illegal, unreported and unregulated (IUU) fishing. The current system is open to abuse, some countries have limited enforcement capabilities, and traceability records can be falsified. In recent years, research has been under way to assess whether there are sufficient genetic differences between populations of fish from different geographical areas. The theory behind this research is that different genetic traceability markers can be identified in fish from different geographical regions based on the adaptability of fish to environmental differences such as water temperature, nutrients and salinity. The adaptation of fish to different environments will be reflected in their genetic code, which can be detected using new advanced DNA analyses, such as next-generation sequencing (whole genome sequencing). One the specific sequences for “local adaptation” have been identified, these can be used to definitively determine the geographical origin of fish.

An international project, FishPopTrace, funded under the 7th Framework Programme of the European Union (Member Organization), investigated the use of next-generation sequencing for product traceability and policy-related monitoring, control and surveillance in the fisheries sector.[1] Under this project, rapid and forensically robust DNA markers were developed to discriminate between cod populations from Canada, North Sea, Baltic Sea and Northeast Arctic regions. This work identified a number of single-nucleotide polymorphisms in populations from different geographical regions, and generated distinct population DNA signatures.[2] By compiling these signatures in databases, the researchers produced a set of DNA fingerprints that enabled the tracing of the origin of the products tested. While this research shows promise for definitively identifying the geographical origin of fish species, more work needs to be done to refine methods for use in the regulatory enforcement of the fish chain.

[1] European Commission. 2018. *About FishPopTrace* [online]. [Cited 23 February 2018]. https://fishpoptrace.jrc.ec.europa.eu/

[2] European Commission. 2014. How fish DNA tests can trace illegal catches. In: *Horizon 2020* [online]. [Cited 23 February 2018]. https://ec.europa.eu/programmes/horizon2020/en/news/how-fish-dna-tests-can-trace-illegal-catches

While DNA barcoding is a rapid and reliable method for the identification of fish species for combating fish fraud and an ideal tool for regulatory control purposes, developing countries may need technical assistance to integrate this system into their food control structures. The adoption of these methods requires technical expertise and a high level of food laboratory capacity. There is also a need to standardize and accredit methodologies, and to harmonize DNA databases for confirmation of barcodes. Clark (2015) discusses the status of DNA barcoding for fish identification and challenges for integrating this technology into national food control programmes. The field of molecular diagnostics for authentication of fish is a rapidly developing area. A handheld genetic sensor has been successfully employed for the field identification of grouper, and it compared favourably with standards laboratory methods (Ulrich *et al.*, 2015).

## 6. ILLEGAL, UNREPORTED AND UNREGULATED FISHING AND FISH FRAUD

Illegal, unreported and unregulated fishing (IUU) contributes to fish fraud in that IUU fish catches are illegally marketed and laundered through the legitimate fish marketing chain. This leads to deceptive marketing practices with respect to the geographical origin of catches through mislabelling, species substitution, falsification of documentation, and endangering consumers' health. On a wider scale, sustainable fishing practices are undermined, fish stocks are threatened, and both food and economic security in developing countries are put at risk. The extent of IUU fisheries globally has been estimated to be somewhere between USD 10 billion and USD 23 billion annually, representing between 11 million and 26 million tonnes (Agnew *et al.*, 2009). Developing countries are most at risk because of the absence of appropriate regulations and poor enforcement policy. Many governments are putting increased efforts on enhanced regulatory measures to prevent fish catches from IUU fisheries from entering the fish marketing chain.

Major international initiatives include the FAO Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (Box 5), the comprehensive framework established in the United States of America on IUU fishing and seafood fraud (National Ocean Council Committee on Illegal, Unreported and Unregulated [IUU] Fishing and Seafood Fraud, 2018), and the framework regulations of the European Union (Member Organization) to prevent, deter and eliminate IUU fisheries (European Commission, 2016). All of these initiatives place a major emphasis on prohibiting landings and market access, strengthening enforcement of regulations, enhanced traceability and catch documentation systems, and improving communication and information sharing.

**Box 5**

**FAO Port State Measures Agreement**

The FAO Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing was adopted by the FAO Conference in 2009 and entered into force in June 2016.[1] Its main objective is to prevent, deter and eliminate IUU fishing by preventing vessels engaged in IUU fishing from using ports and landing their catches. In this way, the Agreement reduces the incentive of such vessels to continue to operate while it also blocks fishery products derived from IUU fishing from reaching national and international markets. The Agreement lays down a minimum set of standard measures for port states to apply when foreign vessels seek entry into their ports or while they are in their ports.

The effective implementation of the Agreement will prevent opportunities for fish fraud, in addition to contributing to the long-term conservation and sustainable use of living marine resources and marine ecosystems. The provisions of the Agreement apply to fishing vessels seeking entry into a designated port of a state that is other than their flag state. The application of the measures set out in the Agreement aims to harmonize port state measures, enhance regional and international cooperation, and prevent the entry of IUU-caught fish into national and international markets.

Port state measures are requirements for foreign fishing vessels to comply with as a condition for use of ports within the port state. These would typically include: requirements related to prior notification of port entry, use of designated ports, restrictions on port entry and landing or transshipment of fish, restrictions on supplies and services, documentation requirements and port inspections, as well as related measures, such as IUU vessel listing, trade-related measures and sanctions.

[1] FAO. 2017. *Port State Measures Agreement* [online]. [Cited 23 February 2018]. http://www.fao.org/fishery/psm/agreement/en

The effective implementation of all of these measures will reduce the opportunities for fraudulent practices at the harvesting and landing segments of the fish marketing chain.

## 7. MITIGATION OF FISH FRAUD AT NATIONAL LEVEL

In most countries around the world, no single government agency is responsible for regulating fish fraud, and no single food law directly addresses all aspects of fish fraud (Box 6). Responsibilities are usually shared across official food regulatory authorities, border protection agencies, customs import authorities and specialist agencies within the national police force. Combating fish fraud at national level involves a number of key mandatory steps and close collaboration between different agencies of government. To meet the current demands of the global fish marketing chain to combat fish fraud, an effective science-based fish traceability system must be able to identify the fish species, the geographical origin, and to distinguish between wild-capture and farmed products. The system must also be able to identify fresh and frozen fish, and the many different forms of processed fish that are currently traded.

**Box 6**

**Drivers of fish fraud**

The primary driver of fish fraud is economic gain for the perpetrators. Some of the most common examples of fish fraud are substitution of lower-value species for more expensive varieties and mislabelling illegally caught fish for laundering through the legitimate fish marketing chain. Other factors that contribute to fish fraud are:

- the globalization of the fish chain and the consequently longer supply lines that provide greater opportunities for fraudulent activities;
- the low risk of detection of species substitution by food control authorities that lack dedicated official food control programmes targeting food fraud;
- a lack of harmonization between common fish names applied at national and scientific naming level (some species have the same common names);
- weak import controls where modern accredited methods of fish species identification using DNA barcoding are not routinely used;
- poor coordination at national level between food control authorities and other agencies of state that have responsibilities for criminal investigation and tax evasion;
- traceability programmes relying on paper certificates and documents that can be easily falsified;
- the absence of an internationally agreed regulatory definition of “food fraud”;
- many food control laboratories lack the capacity to use next-generation sequencing for the identification of the geographical origin of fish;
- lack of awareness by fish business operators – need to introduce fish and fishery product authenticity testing based on DNA barcoding as a matter of routine for all industry transactions (similar to the red-meat sector as a result of the horsemeat crisis);
- fish catch certificates not being required as a matter of routine for all business transactions;
- the absence of food fraud threat and vulnerability assessments by food business operators;
- the continued downward pressure on prices in the fish marketing chain;
- poor food laboratory capacity to support official food control programmes, and absence of analytical methodology to detect food fraud, species substitution and adulteration.

### Establishing an agreed list of fish names

One of the principal challenges in tackling fish fraud is that of establishing an agreed list of common names that are linked to scientific nomenclature. This is an essential first step for national governments in introducing official fish fraud control programmes. Many countries have established such lists, for example, the USFDA has published its Seafood List, which contains a list of common names, market names and scientific names that are mandatory for commercial trade (United States Food and Drug Administration, 2018). The Canadian Food Inspection Agency has also published its Fish List (Canadian Food Inspection Agency, 2012). Regulations in the European Union (Member Organization) require all its member countries to draw and publish a list of commercial designations and scientific names for fish and aquaculture products in commercial trade (European Union, 2013). Many countries have harmonized their commercial fish species lists with the FishBase Information System or FAO's Aquatic Sciences and Fisheries Information System database (FAO, 2018a). One of the main problems in establishing an agreed list of fish names is that different species may have the same common name in different countries, or the same species may have different names in the same language in different regions in the same country (Martinez, James and Loréal, 2005). The challenges of creating an agreed fish list for international trade were discussed by the Codex Committee on Fish and Fishery Products in 2003 (Codex Alimentarius Commission, 2003).

**Mandatory labelling requirements**

The second key step in tackling fish fraud is the introduction of mandatory labelling requirements for fish and fishery products. The European Union (Member Organization) has some of the most comprehensive food regulations governing the labelling of fish and fishery products. The basic principle underlying its regulations on food labelling information is that it should not mislead consumers, particularly with respect to the characteristics of the food. The information provided must be honest and accurate with respect to the identity, properties, composition, quantity, durability, country of origin or place of provenance, and method of manufacture or production. Regulation (EU) 1169/2011 (European Union, 2014) sets out the general labelling rule for provision of information for consumers, and Regulation (EU) 1379/2013 (European Union, 2013) sets out rules on the mandatory and voluntary information to be provided for prepacked and non-prepacked fishery and aquaculture products. Article 35 of this regulation specifies the following mandatory indications:

- commercial and scientific name of the species;
- production method ("… caught …" or "… caught in freshwater …" or "… farmed …");
- area where the product was caught or farmed (using the FAO Major Fishing Areas [FAO, 2018b]);
- category of fishing gear used;
- whether the product has been defrosted (with limited exceptions);
- date of minimum durability – where appropriate.

In addition to the above, prepacked fishery and aquaculture products marketed in the European Union (Member Organization) must also display all the relevant information specified in Articles 9 and 10 of Regulation (EU) 1169/2011 on the provision of food information to consumers.

This type of fish labelling information is necessary to ensure an effective food control system to combat fish fraud and for full traceability from the point of catch to consumption. Information on the geographical catch area and area where fish is farmed must make reference to one of the 12 FAO Major Fishing Areas that are important for controlling IUU fishing.

**Strengthening official food controls**

The third key step in tackling fish fraud is to strengthen official food control systems with: the introduction of regulations to combat fish fraud; the introduction of monitoring and surveillance programmes for assessing the degree of compliance with fish labelling regulations; the development of laboratory detection methods based on DNA barcoding; and the enforcement of regulations in the event of the detection of non-compliance. In order to implement effective food control programmes and to mitigate fish fraud, food control authorities need to authenticate and validate traceability systems based on a documentary paper trail.

**Strengthening industry food safety management systems**

The fish industry needs to put systems in place to protect against the risk of fraudulent activities in the food chain. When assessing risks during the development of food safety management systems based on the principles of Hazard Analysis and Critical Control Points (HACCP), the risk of being defrauded in the supply chain needs to be factored in management systems. The fish industry needs to conduct a vulnerability and threat assessment to evaluate the likelihood of fraud and to put a mechanism in place to authenticate and validate traceability documentation. Guidelines for the industry on how to develop and implement a Threat Assessment and Critical Control Points (TACCP) system to enhance controls to mitigate against fraud and other threats have been developed by authorities in the United Kingdom of Great Britain and Northern Ireland (British Standards Institution, 2014). The industry needs to introduce systems for fish fraud vulnerability assessment based on risk assessment and vulnerability analysis. The recommendation is for the industry to adopt a two-stage approach: first to undertake vulnerability assessments to identify potential sources of fish fraud within its supply chains; and second, to prioritize control measures to minimize the chances of receiving fraudulent or adulterated ingredients, raw materials or products (PricewaterhouseCoopers, 2018; Ruth, Huisman and Luning, 2017). Supplier traceability, supported by laboratory certification of fish species based on DNA barcode analysis, should be a key element of fish fraud vulnerability assessment.

**Role of the Codex Alimentarius Commission**

At its meeting in February 2017, the Codex Committee on Food Import and Export Inspection and Certification Systems discussed the authenticity of food and need for new methodologies and Codex guidelines to help authorities to address the dramatic increase in food fraud (Codex Alimentarius Commission, 2017). The Codex Alimentarius Commission, in association with member countries, should develop international principles and guidelines designed to identify, manage and mitigate fraudulent practices in food trade. The industry requires guidance on how to assure the authenticity of food by minimizing vulnerability to, and mitigating the consequences, of food fraud.

## 8. CONCLUSIONS

The numbers of reports and reviews published in both the scientific literature and the popular media in the past decade provide adequate documentary evidence that fish fraud through mislabelling and species substitution is a widespread problem in both national and international markets for fish and fishery products. While the scale of the problem has been investigated and reported in developed countries, much less is known about fish fraud in developing countries. There is a major expansion of e-commerce and online food sales, which present major opportunities for fraudulent trade in fish. In order to combat fish fraud, improved traceability systems are required that can reliably track fish from the point of harvest to the consumer's plate. Current traceability systems rely on a paper trail that documents such data as the geographical origin, species, and registration details of vessels. Experience from previous food fraud incidents, such as the European horsemeat scandal, shows that such documentation can be falsified.

What is required is a traceability system that is science-based and verified by independent scientific analytical methodologies to trace fish and fishery products throughout the marketing chain. Food control authorities require definitive analytical tools for the identification of fish species based on molecular DNA techniques. There is a need for harmonization and standardization of analytical techniques and for universal access to a standard database with relevant data on CO1 primers based on scientific names. Greater cooperation between food control authorities and law enforcement agencies is required in order to combat the criminal activities involved in fish fraud. Food regulations need to be strengthened and penalties made proportionate to criminal infringements. Fish labelling regulations need to provide sufficient data for consumers to be able to make informed choices about the products they purchase. The introduction of new analytical technology for fish species identification means that food inspectors and laboratory staff will need to be adequately trained. Food inspectors will also need to be trained in the investigation of fraud.

The fishery sector also need to upgrade its food control systems to take account of risks of fraud in their supply and marketing chains. A structured system for fish fraud vulnerability assessment needs to be developed and integrated into routine food quality and safety management programmes.

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