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The 11 sins of seafood: Assessing a decade of food fraud reports in the global supply chain

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Abstract: Due to complex, valuable, and often extremely opaque supply chains, seafood is a commodity that has experienced a high prevalence of food fraud throughout the entirety of its logistics network. Fraud detection and prevention require an in-depth understanding of food supply chains and their vulnerabilities and risks so that food business operators, regulators, and other stakeholders can implement practical countermeasures. An analysis of historical criminality within a sector, product, or country is an important component and has not yet been conducted for the seafood sector. This study examines reported seafood fraud incidents from the European Union's Rapid Alert System for Food and Feed, Decernis's Food Fraud Database, HorizonScan, and LexisNexis databases between January 01, 2010 and December 31, 2020. Illegal or unauthorized veterinary residues were found to be the most significant issue of concern, with most reports originating from farmed seafood in Vietnam, China, and India. For internationally traded goods, border inspections revealed a significant frequency of reports with fraudulent or insufficient documentation, indicating that deceptive practices are picked up at import or export but are occurring further down the supply chain. Practices such as species adulteration (excluding veterinary residues), species substitution, fishery substitution, catch method fraud, and illegal, unreported, and unregulated fishing were less prevalent in the databases than evidenced in the scientific literature. The analysis demonstrates significant differences in outcomes depending on source and underlines a requirement for a standardized and rigorous dataset through which food fraud can be scrutinized to ensure enforcement, as well as industry and research resources are directed accurately.

KEYWORDS
Food fraud, seafood supply chain, RASFF, HorizonScan, Food Fraud Database, Nexis

Practical Application: Levels of historic food fraud in a product, sector, supply chain node or geographic location provide an indication of historic criminality,

the methods used and the location of reported frauds. This study provides an overview of historic levels of seafood fraud that can be used to inform seafood fraud prevention and mitigation activities by the food industry, regulators and other stakeholders.

1 INTRODUCTION

Seafood, one of the world's most traded commodities, has complex and valuable supply chains, with an extensive network of actors, a vast array of products and numerous processes that support this food system, including fish feed suppliers, marine fishers and aquaculture farming, processors, wholesalers, middlemen and distributors, retailers, and food service (Fox et al., 2018; Leal et al., 2015; Symes & Phillipson, 2019). Seafood contributes 17% to global protein consumption (FAO, 2020) and is a food source that is important for nutrition and food security (Béné et al., 2016; Costello et al., 2020; Hicks et al., 2019) and employment, income, and livelihoods, particularly in coastal and developing economies (Stacey et al., 2021; Teh & Sumaila, 2013; Worldbank, 2012). According to the Food and Agriculture Organization (FAO), the global production of seafood was estimated at approximately 179 million tons in 2018. Over the last 60 years, global fish consumption has increased significantly above population growth, and production has quadrupled over the last 50 years. Major shifts in seafood production have occurred to meet this increase in demand, and aquaculture now provides over 80 million metric tons of seafood per year, contributing to 46% of total global fish production (FAO, 2020).

As production steps up to meet this rising demand, coexistent with an increase in revenue, so is a potential increase in food fraud motivation (van Ruth et al., 2017), particularly when operating within a supply chain where there is resource scarcity, with a third of global wild fish stocks overexploited (FAO, 2017). The globalization of seafood supply chains has resulted in a network that is valuable but opaque and with a diversity of production methods and species that is unique from other food supply chains (Anderson et al., 2018). As supply chain visibility and oversight decrease, the opportunity for deceptive behavior increases (Everstine, 2017; Lotta & Bogue, 2015).

While there is yet no internationally harmonized legal definition for food fraud, it is broadly described in the literature as the intentional deception of a food product for economic gain (Robson et al., 2021; Spink & Moyer, 2011), achieved through the misrepresentation of food products or associated documentation (Manning & Soon, 2019). Food fraud can be further broken down into specific behaviors to categorize particular types of criminality. Young's Seafood Limited outlined seven sins of seafood, referred to in the Elliott report (Elliott, 2014) that have been expanded upon and used in the literature (Fox et al., 2018), to describe nine fraud types specific to the seafood sector: species substitution, species adulteration, fishery substitution, catch method fraud, undeclared product extension, illegal, unreported, and unregulated (IUU) substitution, chain of custody abuse, modern-day slavery, and animal welfare. This categorization provides a comprehensive typology through which seafood fraud can be analyzed.

Fraud in the seafood supply chain is well documented in the literature, particularly in recent years (Benard-Capelle et al., 2015; Deconinck et al., 2020; Fox et al., 2018; Gordoa et al., 2017; Jacquet & Pauly, 2008; Kroetz et al., 2020; Pardo & Jimenez, 2020; Pramod et al., 2014) and is identified as a current area of vulnerability in the United Kingdom and Scotland (FSA, 2020; FSS, 2020). Criminality in this sector has far-reaching impacts. The true economic cost of food fraud is unknown and difficult to quantify (Cox et al., 2020), but estimates place the cost to the food industry between $10 and $40 billion (GMA, 2010; PWC, 2013) per year, with serious reputational implications for food business operators, illustrated clearly by the erosion of consumer trust following the horsemeat scandal (Brooks et al., 2017). Furthermore, seafood fraud undermines marine conservation efforts (Helyar et al., 2014; Kroetz et al., 2020; Sameera et al., 2021), as product misrepresentation removes the consumer's ability to choose sustainably, with environmental and social implications (Stefanus & Vervaele, 2021). It creates a market for IUU fishing, which has been estimated to have a global economic cost of between $36 and $50 billion per year (Sumaila et al., 2020), including legitimate catch and revenue losses and income and country tax losses. Species substitution and adulteration can present health risks, for example, fish not suitable for human consumption, such as pufferfish (Cohen et al., 2009) or ciguatoxic fish (Friedman et al., 2017) are marketed as edible fish, or fish that are high in levels of mercury, for example, swordfish, or tilefish are marketed as other species. The use of illegal or unauthorized antimicrobials in aquaculture may contribute to an increase in antimicrobial resistance in human pathogens, and prolonged exposure to these drugs through residues in seafood raises health concerns (Hedberg et al., 2018; Okocha et al., 2018). Seafood is one of the top food allergens, and accidental allergenic exposure due to mislabeling of species can lead to severe health problems such as systemic immunological reactions and anaphylaxis (Fernandes et al., 2015).

Understanding where a supply chain is vulnerable is key to strengthening the ability for the timely prevention and detection of fraud, a concept that is increasingly attracting academic and mainstream attention (FSA, 2021; Nestle, 2016; van Ruth et al., 2017; Spink et al., 2017, 2019). By acquiring in-depth knowledge of food supply chains and individual business practices, it becomes easier to reduce or disrupt criminal activity within the food industry (Smith et al., 2017), and food business operators, regulators, and other stakeholders can implement practical prevention and mitigation strategies to "design out crime" by making the environment more difficult for fraudsters to operate in (FSA, 2020). One measure of food fraud vulnerability is the historic level of compliance in a commodity chain, supply chain node, or geographic region, as previous criminality can indicate future risk (van Ruth et al., 2017). Analyzing historic food fraud incidents is an approach that has been used by other authors to gauge the occurrence and trends of fraud in the food industry (Bouzembrak & Marvin, 2016; Beia et al., 2020; Tähkäpää et al., 2015; Zhang & Xue, 2016) and in detail for the beef industry (Robson et al., 2020) and the dairy industry (Montgomery et al., 2020). The seafood industry has not yet been analyzed using this methodology and will provide a useful baseline indicator of the level, location, and method of reported fraud in the sector. Currently, capturing and recording all reported fraud in a harmonized approach is not yet possible, so there is no global central database through which fraud prevalence enquiries can be executed. The literature suggests that food fraud research should therefore include varying data sources relating to fraud to ensure the most comprehensive coverage (Bouzembrak & Marvin, 2016; Manning & Soon, 2019; Montgomery et al., 2020). For the first time, this review uses several databases that document food fraud incidents to inform the research: the European Union's Rapid Alert System for Food and Feed (RASFF), the Food Fraud Database (FFD), HorizonScan, and Nexis to understand the current prevalence of global seafood fraud and how does it breakdown by method, product, sector node, and location? Fraud incidence data from these databases were examined to observe the relationships between these variables to provide the most comprehensive overview ever undertaken.

2 | MATERIALS AND METHODS

2.1 | Data collection

This review uses four databases, outlined in Table 1, along with the search criteria used for each extraction. Searches were conducted between January 01, 2010 and December 31, 2020, a time period that could provide a comprehensive overview of historic trends while maintaining a manageable number of relevant results.

2.2 | Report selection and analysis

Reports were extracted from the four databases, exported into Excel, sorted by chronological order, and reviewed. Duplicate records were removed. For official sources, a record was considered a duplicate on inter- or intra-databases if the same event from the same country occurred on the same day more than once. Due to the limited information from official databases, it was not possible to ascertain whether similar fraud events that occurred over time were replicates. Replicate incidents over time reported through the media were easier to identify, as they contained information such as company name and detailed information about the offence. The following additional inclusion criteria were applied:

- Only records relating to specific incidences of food fraud were downloaded. Examples include data from global official sources, reports on food fraud prosecutions, seizure of goods, or the outcome of food fraud operations. Scientific research, articles on fraud prevention, media investigations, supposition, and general articles about seafood fraud were excluded.
- In the RASFF database, a few entries state that fraud is only suspected. These reports were excluded as there was insufficient detail in the record to ascertain what had occurred.
- Veterinary drug residues were only included if they were prohibited or unauthorized in the country of notification. Legal residues over legal limits were excluded, as these could be unintentional and therefore not fit the criteria for fraud. Where more than one residue has been found in a product, each residue has been recorded as a unique instance.
- Pesticide residues were not included in the analysis, although they could have indicated fraudulent practices in some cases. The data were downloaded and reviewed, and the pesticide residues observed in the data could reasonably be argued to be present in fish due to unintentional, environmental contamination. As suspicion of fraud was excluded in the rest of the analysis, the same criteria were applied for pesticides.

2.3 | Data classification and analysis

The data retrieved from the databases were downloaded into an Excel spreadsheet and organized by

- date,
- reference (RASSF reference number or link to source),
- subject/reason for notifying,
- seafood product (e.g., cod, grouper, crab),
- seafood grouping (crustacean, finfish, mollusc, mixed),
- adulterant (if applicable),
- product country of origin,

TABLE 1 Databases included for fraud data collection

Database	Search criteria
The European Union's Rapid Alert System for Food and Feed: RASFF was established in 1979 to facilitate a prompt and efficient exchange between member states relating to measures taken to respond to serious food and feed food safety risks (European Commission, 2009b) to facilitate collective response measures. Notifications raised on RASFF are posted by food safety authorities in member states, as well as Switzerland, Norway, Lichtenstein, and Iceland through the iRASSF, an online, searchable portal that allows for the interrogation and analysis of food fraud reports (European Commission, 2021).	Bivalve molluscs and products thereof, cephalopods and products thereof, crustaceans and products thereof, dietetic foods, food supplements, fortified foods, fats and oils, feed additives, feed materials and feed premixtures, fish and fish products, gastropods, prepared dishes and snacks, soups, broths, sauces, and condiments (only where seafood is the concern). Hazard Category: fraud/adulteration, poor/insufficient controls, veterinary residues.
Food Fraud Database: Originally founded by the US Pharmacopeia, this subscription-based database is now owned by Decernis and includes over 12,000 food fraud records from the scientific literature, media publications, regulatory reports, judicial records, and trade associations (Decernis, 2021). There are four record types: incident, inference, surveillance (sample/testing within geographic locations), and method (analytical method for authentication or detection).	FFD Searches were completed via a category search of seafood, which included: Incident data for ingredient group: Seafood and seafood products. This includes all fraudulent incidents for seafood recorded on the database, including illegal or unauthorized veterinary residues.
HorizonScan: A subscription-based service owned by the Food and Environment Research Agency (Fera, 2015) and tracks current and historical global food fraud and contamination issues from official sources in 180 countries and 100 independent sources daily.	HorizonScan searches were completed via category and keyword searches, which included: Commodity group: seafood, canned seafood products, fish oil, feed materials—fishmeal, feed materials—crustaceans, frozen ready meals, part cooked chilled ready meals, other prepared foods, soups (chilled), Soup mixes (dry), sauces, other prepared foods, and snack foods. Dashboard: Fraud issues (vulnerability assessment).
Nexis: Nexis is the LexisNexis online news database that includes 40,000 international premium and web news sources, company profiles, legal content and industry information and it is standardized and indexed to be searchable (LexisNexis, 2021).	A keyword search was conducted on the database for using the following search string: (seafood or *fish*) and (fraud or crime). A more comprehensive search string was tested to pick up specific seafood and fraud types, but too many results were retrieved to analyze for the requested chronology, so basic search terms were retained.

Abbreviations: FFD, Food Fraud Database; RASFF, Rapid Alert System for Food and Feed.

- notifying country,
- source (RASFF, HorizonScan, Decernis, or Nexis).

Records were also mapped to the supply chain node where the fraud occurred if it was possible to determine. Due to the brevity of many of the reports, a simple supply chain structure was required to map incidents to basic supply chain nodes. Based on other research papers identifying seafood supply chain actors in aquaculture and wild marine resources (Fox et al., 2018; Leal et al., 2015), the authors constructed a simple supply chain map applicable to all seafood analyzed (finfish, crustaceans and molluscs). The supply chain map is detailed in Figure 4, and the seafood supply chain nodes are outlined below:

- Harvesting of marine resources: point of catch for all fishing methods for wild finfish, crustaceans, molluscs in their natural habitat.
- Aquaculture farming: this includes seed, hatchery and nursery operations, on-growing and harvesting.
- Feed: fishmeal and fish oils for use in aquaculture production.
- Primary processing includes cleaning, gutting, filleting and freezing. Primary processing may happen at sea onboard vessels with processing facilities, or on land at approved processors.
- Secondary processing: the application of value-added processing techniques such as smoking, breading, salting, or other forms of preservation such as irradiation.
- Wholesalers/middlemen and distributors: all forms of forward sale or redistribution, including auction

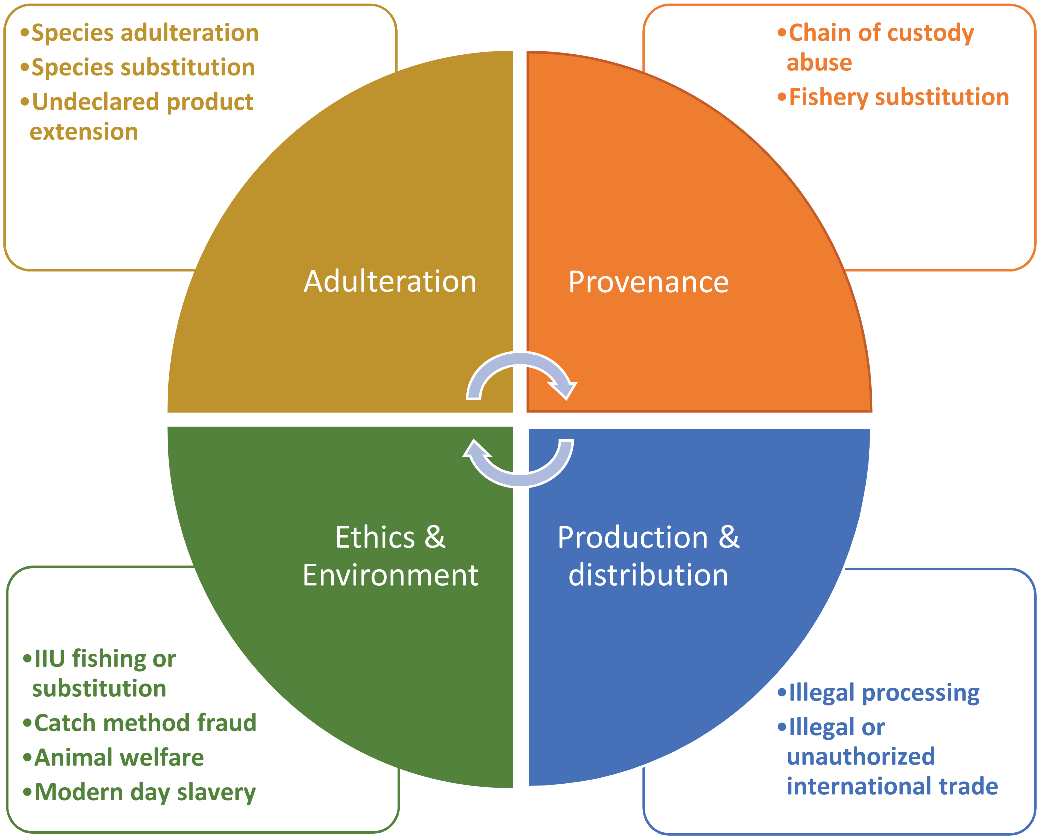

FIGURE 1 The 11 sins of seafood, categorized by area of misrepresentation

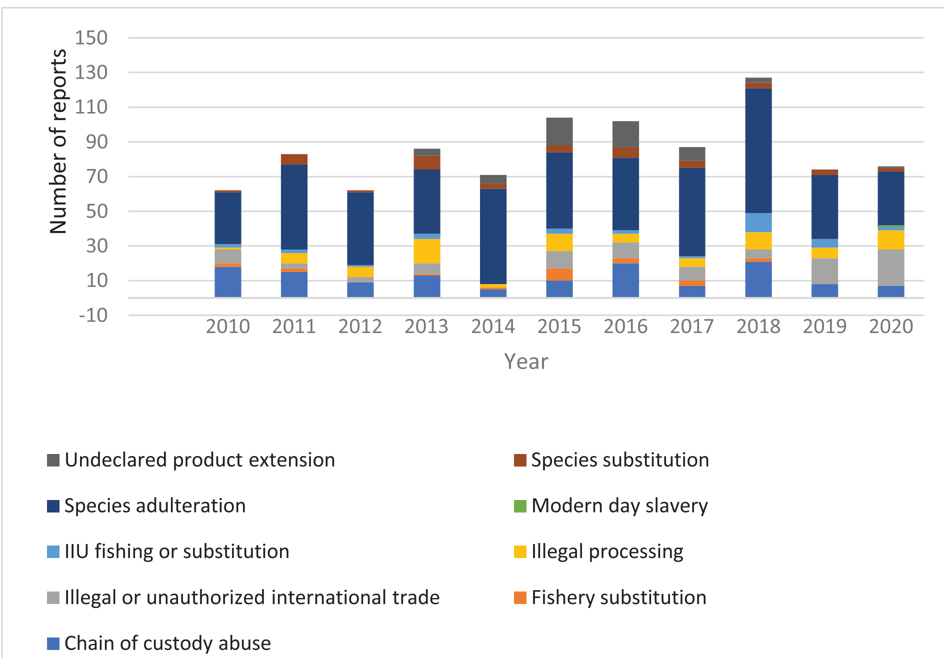

FIGURE 2 Chronology of reported fraud January 01, 2010 to December 31, 2020

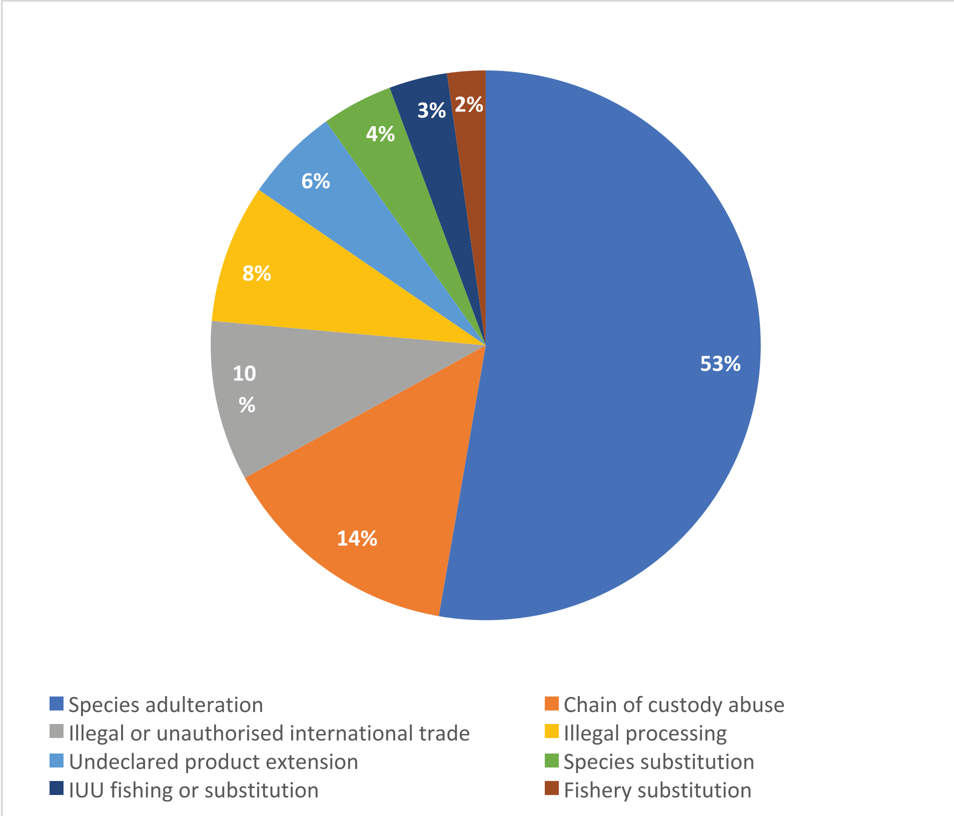

FIGURE 3 Distribution of fraud type by frequency from January 01, 2010 to December 31, 2020

markets, wholesale commercial merchants, and commodity brokers.

- Import/export: international trade of seafood products.
- Retail: consumers facing retail, including supermarkets, fishmongers, and markets.
- Food service: business and companies responsible for any meal provided outside the home, including restaurants, takeaways, pubs, hotels, catering operations, school and hospital cafeterias and meal kits.

Fraud reports were also categorized by fraud type. Due to the wide variety of ways in which fraud can be perpetrated in seafood, it was considered that an industry-specific typology would provide the appropriate depth of analysis, so fraud categories were based on the definitions of "The nine sins of seafood" (Fox et al., 2018), detailed in Table 2. Each record was read individually and classified accordingly.

Reports that could not be classified within existing categories were grouped and reviewed. Two themes emerged: products that were being processed using unauthorized techniques or premises, and international trade contraventions such as smuggling or violations of import or export regulations. There were also several reports from RASFF that only stated "illegal import" or "unauthorized import" without further detail of the offense. Without evidence of fraudulent documentation (where these records could have been classed as chain of custody abuse), there was no corresponding existing category. To accommodate these reports, two further categories were required and added, "illegal processing" and "illegal or unauthorized international trade," and are detailed in Table 3.

In the case of IUU substitution, reports of IUU fishing or illegal harvesting were included even if misrepresentation was not observed. This is a practice that is likely to happen further down the supply chain and is generally not evidenced at harvest.

Figure 1 combines the original nine sins of seafood with the two additional categories to make 11 sins of seafood, organized into four categories: adulteration (which includes species adulteration and substitution and undeclared product extension), provenance (which includes chain of custody abuse and fishery substitution), ethics and environment (which includes IUU fishing or substitution, catch method fraud, animal welfare, and modern-day slavery), and production and distribution (which includes illegal processing and illegal or unauthorized international trade.

Finally, a multiple correspondence analysis (MCA) was conducted on the entire dataset. MCA is a multivariate

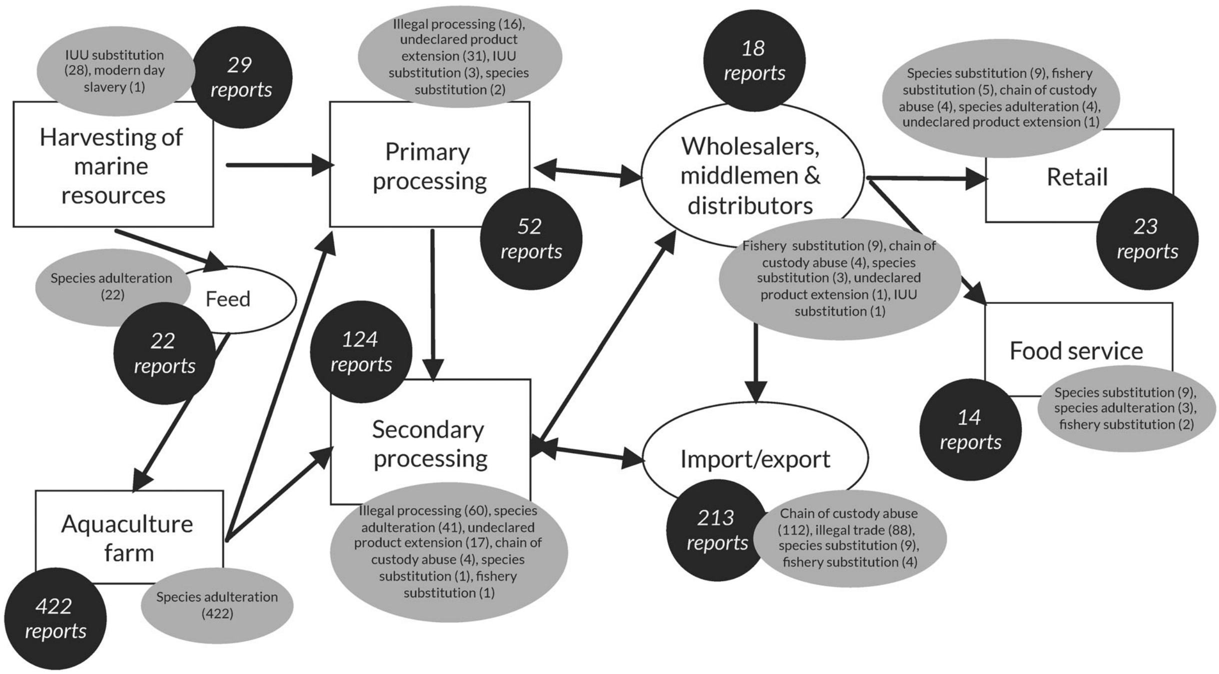

FIGURE 4 Fraud report frequency by supply chain node and fraud type observed at each node

TABLE 2 Food fraud categories as defined by Fox et al. (2018)

Species substitution	The practice of substituting one species for fish for another, usually a higher value fish for a cheaper alternative and refers to inter- and intraspecies substitution. This practice may also occur because of other motivations, for example, to evade tariffs due to resource scarcity, or to conceal IUU fishing activity.
Fishery substitution	A product from one fishery is misrepresented as the product of another (usually superior) fishery, as particular areas of capture represent a point of difference.
Illegal, unreported, and unregulated (IUU) substitution	IUU substitution facilitates the entry and concealment of IUU products into legitimate supply chains by misrepresenting species, fishery, or country of origin, which may be protected. It includes catch that is procured without a license, fishing with prohibited gear, fishing over quota, underreporting of catch, fishing of prohibited species, and fishing in a closed area.
Species adulteration	Processed products that include the addition of a lower value or more abundant nondeclared species, or include materials of unauthorized or prohibited origin, for example, veterinary products, pesticides, colorants or preservatives.
Chain of custody abuse	Fraudulently representing or omitting the chronological documentation of the ownership or control of the product that allows for the traceability of product from the harvesting or procurement of raw materials to processing and packaging, retail, and distribution.
Catch method fraud	Mislabeling of fishing production or harvesting method to achieve price premium or increase consumer desirability.
Undeclared product extension	Increasing product value by making a product appear heavier, for example, overglazing or over breading to increase weight or the use of undeclared water binding agents to increase weight.
Modern-day slavery	The offences of human trafficking and slavery, servitude, forced or compulsory labor at any point in the seafood supply chain, including fishermen, workers in seafood processing plants, and employees of the aquaculture industry,
Animal welfare	Misrepresentation of the requirements for aquatic welfare, including environment, diet, stocking conditions and appropriate disease management.

TABLE 3 Additional fraud types added by authors

Illegal processing	Processing seafood products in unapproved premises or using unauthorized techniques.
Illegal or unauthorized international trade	Smuggling, contravention of import and export regulations.

analysis technique to analyze categorical data to explore relationships between variables through data visualization (Greenacre & Blasius, 2006). Using the MCA function in XLSTAT software, the technique was applied to explore associations between area of origin, supply chain node, and fraud type and identify the most correlated variables within a given dimension.

3 | RESULTS AND DISCUSSION

3.1 | Overview and chronological analysis

A large number (934) of records were selected from the four databases, with 497 records retrieved from RASFF, 312 from HorizonScan, 83 from FFD, and 42 from Nexis, after duplicates were removed. Figure 2 shows trends of reported fraud from the databases. The number of reported frauds fluctuated throughout the period, but peaks were observed in 2015, 2016, and 2018. Increases in 2015 and 2016 were driven by a rise in reporting of undeclared product extension by the Czech Republic, with product being of a lower fish content than declared on the packaging. In 2016, there was also a significant increase in reports relating to chain of custody abuse, but without a specific trend of fraud type or country of origin. The largest number of reports were published in 2018. This increase was mainly due to reports relating to species adulteration (n = 72). Sixty-nine percent (n = 50) of these reports were due to the presence of unauthorized or illegal veterinary residues, but there was also an increased reporting on the presence of nitrates that year (n = 12) due to a coordinated action through Opson VII on fraudulently treated tuna (Europol, 2019).

Following an initial review of report frequency across the databases over the time period, the data were analyzed by fraud type (3.2), supply chain node (3.3), seafood product (3.4), and country of origin (3.5) to provide a comprehensive analysis of fraud prevalence according to these variables as well as their associations (3.6).

3.2 | Fraud type

Categorizing fraud incidents into fraud type provides a useful overview of the breadth of seafood fraud and the likely geographic location or supply chain node that those fraud types may reside, as well as an indication of enforcement focus by notifying countries. The fraud types observed in the data are detailed in Table 4, by supply chain node, seafood species, country of origin, notifying country, and source. Nine out of the 11 fraud types defined were present, and catch method fraud and animal welfare were not represented in the data. Figure 3 shows the distribution of fraud types by frequency. Modern-day slavery is not displayed in this chart as it represents less than 1% of reports.

3.2.1 | Most prevalent fraud type: Species adulteration

The most prevalent fraud type in the data was species adulteration, accounting for 52% of all records (n = 492). The presence of illegal or unauthorized veterinary residues accounted for 86% (n = 422) of these records and was most frequently observed in products originating from Asia. Table 5 shows the top 10 residues by frequency of reports.

There were significant differences in the residues present according to seafood type. The most frequent residues observed in crustaceans were nitrofurans (n = 110) and chloramphenicol (n = 36). For finfish, the most prevalent residues were malachite green (n = 66), fluoroquinolones (n = 34), and nitrofurans (n = 32) and in molluscs, chloramphenicol (n = 25). Similar trends by seafood type were reflected in a previous analysis of veterinary residues in seafood between 2000 and 2009 (Love et al., 2011).

The volume of reports due to illegal or unauthorized veterinary residues indicates that residues in aquaculture products, particularly from Asia, remain an ongoing problem. The intensification of aquaculture, the fastest growing animal food producing sector, has increased dependence on antibiotics. These are used prophylactically and therapeutically for disease prevention and treatment, as well as for enhancing growth promotion. The unregulated use of antibiotics in aquaculture poses health risks to both humans and animals. Their use is associated with the growth and development of antimicrobial resistance along the food chain, which may lead to infections resistant to antibiotic treatment (Nobrega et al., 2020). The toxic properties of individual antibiotic residues in seafood products can include disruption of normal intestinal flora, drug hypersensitivity reactions, and carcinogenic, mutagenic, and teratogenic effects (EFSA, 2014, 2015; Okocha et al., 2018; Serra-Compte et al., 2017; Srivastava et al., 2004).

TABLE 4 Fraud type by supply chain node, seafood species, country of origin, notifying country, and source

Fraud type	Supply chain node	Seafood species (top 5)	Country of origin (top 5)	Notifying country (top 5)	Source
Species adulteration	Aquaculture farming ($n = 422$), secondary processing ($n = 41$), feed ($n = 22$), retail ($n = 4$), food service ($n = 3$)	Prawns/shrimps ($n = 156$), tilapia ($n = 52$), catfish ($n = 49$), eel ($n = 30$), mixed/undefined ($n = 26$)	Vietnam ($n = 157$), India ($n = 89$), China ($n = 85$), Bangladesh ($n = 14$), Spain ($n = 11$)	USA ($n = 90$), Japan ($n = 88$), Germany ($n = 35$), Belgium ($n = 34$), UK ($n = 33$)	RASSF ($n = 251$), HorizonScan ($n = 197$), FFD ($n = 27$), Nexis ($n = 17$)
Chain of custody abuse	Import/export ($n = 112$), retail ($n = 4$), wholesale and distribution ($n = 4$) secondary processing ($n = 4$), unknown ($n = 9$)	Mixed/undefined ($n = 33$), prawns/shrimp ($n = 9$), tuna ($n = 9$), tilapia, hake, squid ($n = 6$)	China ($n = 23$), Ecuador ($n = 11$), Senegal ($n = 8$), Morocco ($n = 6$), South Africa ($n = 6$)	Spain ($n = 25$), Italy ($n = 23$), UK ($n = 16$), Cyprus ($n = 11$), Portugal ($n = 11$)	RASFF ($n = 114$), FFD ($n = 10$), HorizonScan ($n = 5$), Nexis ($n = 4$)
Illegal or unauthorized international trade	All reports for this fraud type occurred at import/export	Mixed/undefined ($n = 34$), catfish ($n = 21$), salmon ($n = 5$), prawns/shrimp ($n = 4$), tuna ($n = 3$)	Ghana ($n = 18$), Nigeria ($n = 12$), Vietnam ($n = 10$), China ($n = 7$), Canada ($n = 4$)	UK ($n = 28$), USA ($n = 18$), Norway ($n = 7$), Spain ($n = 7$), Sweden ($n = 7$)	RASFF ($n = 61$), HorizonScan ($n = 24$), FFD ($n = 2$), Nexis ($n = 1$)
Illegal processing	Secondary processing ($n = 60$), primary processing ($n = 16$)	Mixed/undefined ($n = 15$), squid ($n = 14$), anchovy ($n = 12$), crayfish ($n = 8$), tuna ($n = 4$)	China ($n = 18$), Vietnam ($n = 13$), UK ($n = 8$), Thailand ($n = 5$), Denmark ($n = 3$)	USA ($n = 12$), Germany ($n = 11$), Italy ($n = 10$), Spain ($n = 9$), UK ($n = 9$)	RASFF ($n = 56$), HorizonScan ($n = 20$)
IUU fishing or substitution	Harvesting ($n = 28$), primary processing ($n = 3$), wholesale and distribution ($n = 1$)	Clams ($n = 8$), Mixed/undefined ($n = 5$), tuna ($n = 4$), oysters ($n = 3$), mussels, cockles, eels ($n = 2$)	USA ($n = 6$), Spain ($n = 5$), Ireland ($n = 4$), Portugal ($n = 3$), UK ($n = 3$)	Spain ($n = 8$), USA ($n = 7$), Ireland ($n = 4$), Portugal ($n = 4$), UK ($n = 3$)	RASFF ($n = 12$), HorizonScan ($n = 10$), Nexis ($n = 7$), FFD ($n = 3$)

(Continues)

TABLE 4 (Continued)

Fraud type	Supply chain node	Seafood species (top 5)	Country of origin (top 5)	Notifying country (top 5)	Source
Undeclared product extension	Primary processing ($n = 31$), secondary processing ($n = 17$), wholesale and distribution ($n = 1$), retail ($n = 1$)	Cod ($n = 14$), mixed/undefined ($n = 8$), prawns/shrimp ($n = 8$), tilapia ($n = 5$), herring ($n = 4$)	China ($n = 17$), Poland ($n = 9$), Czech Republic ($n = 7$), Vietnam ($n = 7$), USA ($n = 3$)	Czech Republic ($n = 42$), China ($n = 3$), Bangladesh, Brazil, Cambodia, UK, USA ($n = 1$)	HorizonScan ($n = 47$), FFD ($n = 4$), Nexis ($n = 1$)
Species substitution	Food service ($n = 9$), retail ($n = 9$), import/export ($n = 9$), wholesale and distribution ($n = 3$), primary processing ($n = 2$), secondary processing ($n = 1$)	Cod ($n = 5$), mixed/undefined ($n = 4$), snapper ($n = 4$), monkfish ($n = 3$), crab, grouper, halibut, octopus, skate ($n = 2$),	USA ($n = 8$), UK ($n = 7$), China ($n = 2$), Indonesia, Japan, Mexico ($n = 2$)	USA ($n = 20$), UK ($n = 8$), Germany ($n = 2$), Japan ($n = 2$), China, France, Ireland, Italy, Mexico, Taiwan ($n = 1$)	FFD ($n = 22$), HorizonScan ($n = 7$), Nexis ($n = 7$), RASFF ($n = 3$)
Fishery substitution	Wholesale and distribution ($n = 9$), retail ($n = 5$), import/export ($n = 4$), food service ($n = 2$), secondary processing ($n = 1$)	Prawns/shrimps ($n = 7$), crab ($n = 4$), salmon ($n = 3$), eel, haddock, sardine, seabass, tuna, walleye ($n = 1$)	UK ($n = 2$), China ($n = 2$), Chile, Greece, India, Malta, Mexico, Taiwan, Thailand, Vietnam ($n = 1$)	USA ($n = 13$), UK ($n = 2$), Japan ($n = 2$), Australia, Canada, Italy, Spain ($n = 1$)	FFD ($n = 15$), Nexis ($n = 4$), HorizonScan ($n = 2$)
Modern-day slavery	Harvesting ($n = 1$)	Unspecified ($n = 1$)	Taiwan ($n = 1$)	USA ($n = 1$)	Nexis ($n = 1$)

Abbreviation: IUU, illegal, unreported, and unregulated.

TABLE 5 Top 10 veterinary residues by frequency of reports

Veterinary residue	Crustacean	Finfish	Mollusc	Mixed/ undefined	Total
Nitrofurans	110	32	4	2	148
Chloramphenicol	36	23	25	4	88
Malachite, leucomalachite, and brilliant green	6	66			72
Fluoroquinolones	14	34		2	50
Sulphonamides	1	23			24
Crystal violet	1	10			11
Trimethoprim		10			10
Mebendazole		6			6
Tetracyclines	4	1			5
Ivermectin		3			3

Other forms of species adulteration included the presence of ruminant DNA in fishmeal ($n = 20$), the use of substances such as nitrates, bleach, citric acid, phosphate, and hydrogen peroxide to mask spoiling or increase the perception of freshness ($n = 18$), unauthorized flavorings, additives, colorants, and dyes ($n = 12$), the use of chemicals including formaldehyde, formalin, ammonia and polyphosphates for preservation ($n = 8$), adulteration of product with another species ($n = 5$), unauthorized pesticides in fishmeal ($n = 4$), the use of unauthorized vitamins ($n = 2$), and one report with an unknown adulterant.

3.2.2 | Second most prevalent fraud type: Chain of custody abuse

Chain of custody abuse accounted for 14% ($n = 133$) of reports. A total of 115 reports were due to health marks or certificates that were absent, improper, or fraudulent. Eight reports were for the misrepresentation of expired products or tampering with expiration dates. Mislabeling of brand or certification accounted for four reports, and there were five reports of products for which the product origin was unclear. There was one report for unlabeled irradiation.

The frequency of reports relating to chain of custody abuse at import/export indicates that deceptive behavior is most frequently revealed at border checks, and fraudulent or missing health certification or inadequate sampling, testing, or inspection upon import were found to be the most common offences. Products with fraudulent documentation are likely to conceal other frauds (Pramod et al., 2014), for example, the import of restricted or prohibited products, import/export from/to a nonapproved country, false declarations of standards or hygiene, or the facilitation of IUU catch into legitimate supply chains (FSA, 2020; FSS, 2020). These types of fraud are surfaced at border checks due to the mandatory frequency of sampling and scrutiny of documents that are not necessarily present in other parts of the supply chain.

3.2.3 | Third most prevalent fraud type: Illegal or unauthorized international trade

Eighty-eight reports were due to illegal or unauthorized international trade, 76 at import and 12 at export. Import contraventions included unauthorized or illegal import ($n = 50$), inadequate sampling, testing or inspection upon import ($n = 20$), smuggling ($n = 3$), imports from a nonapproved country ($n = 2$), and import of previously refused food ($n = 1$).

Twenty-four percent of import contraventions were due to US imports of catfish from Vietnam that were packed and distributed without being reinspected at import. However, most reports occurred in 2017, when new legislation transferred inspections of catfish from the US Food and Drug Administration to the US Department of Agriculture's Food Safety and Inspection Service, and may just reflect resultant changes in import reinspection requirements, rather than an increase in prevalence over time.

Export contraventions included unauthorized placing on the market ($n = 8$), exporting products unfit for human consumption ($n = 2$), not meeting export requirements ($n = 1$), and falsifying export certificates. Four of these reports were due to the authorized placing of Baltic salmon from Sweden, which was under EU export restrictions, due to unsafe levels of dioxins (EC, 2016).

3.2.4 | Fourth most prevalent fraud type: Illegal processing

There were 76 reports of illegal processing. Thirty-three reports originated from products produced in an unapproved establishment or by an unauthorized operator.

Unauthorized operators accounted for 19% of illegal processing reports, and a third of all reports were due to unauthorized freezer vessels for squid from China reported by Portugal and Spain. Chinese squid fishing is internationally contentious, with China accounting for approximately 70% of all catch and evidence of distant water fishing fleets engaging in illegal fishing and damage to ecosystems (Park et al., 2020). To help restore squid populations, China agreed to a 3-month ban of squid fishing in 2021 in parts of the Atlantic and Pacific oceans, where overfishing has meant stocks are close to collapse (Godfrey, 2021).

Twenty-five reports were due to unauthorized irradiation or irradiation in an unauthorized facility from a variety of countries, notified by EU member states. Irradiation does not present a public health risk, but to be legally placed on the EU market, products must be irradiated legally in the state of origin in an approved facility and correctly labeled (EC, 1999). Eleven reports referred to products not in compliance with HACCP regulation, three reports of improper production, two reports for seafood produced without inspection, one report of inadequate testing, and one report of unauthorized repackaging.

3.2.5 | Fifth most prevalent fraud type: Undeclared product extension

Fifty-two reports were associated with undeclared product extension. Thirty-seven of these were due to lower than declared fish content, six reports for underweighting, four reports of added gelatin, two reports of undeclared added water, two reports of more fat than declared, and one report of overglazing. Most of the reports associated with fish content originated from the Czech Agriculture and Inspection Authority, following inspections in domestic retail of imported products. Reports of dual food quality followed reporting of fish fingers sold under the same name and with the same branding and packaging in the Czech Republic with differing fish content and value for money than those sold in Germany. Although an investigation by the EU's Joint Research Committee did not 'reveal any consistent pattern of product differentiation for particular geographical regions', a provision on dual quality has been added to the EU directive on unfair commercial practices, applicable from May 2022 (EPRS, 2020). However, this is a useful example of reporting bias, where interest and therefore scrutiny of a particular issue has driven up enforcement activity and consequently fraud reports and is not necessarily reflective of the global distribution of this fraud type.

3.2.6 | Sixth most prevalent fraud type: Species substitution

There were 39 reports of species substitution. Nineteen reports were for the substitution of one white fish for another (likely to be an inexpensive or more readily available alternative). This type of substitution is well evidenced in the literature, particularly among species that are similar in appearance, taste, texture, or in processed fish (FAO, 2018). Species substitution was most prevalent in the United States ($n = 8$) and the United Kingdom ($n = 7$). These countries also had the highest percentage of their total incidents categorized as species substitution, accounting for 27% and 26%, respectively. Japan had the highest proportion of total reports categorized as species substitution at 29% but a lower number of actual reports ($n = 2$). For all three countries, the practice was identified at the top end of the supply chain in wholesale and distribution, retail and food service, often through regulatory checks.

The replacement of cod and snapper with other species was the most common substitution. The substitution of other species for cod occurred in five reports where it was replaced with catfish (including pangasius), haddock, and Vietnamese river cobbler. The substitution of other species for snapper occurred in four reports and included sea bream, cheaper snapper and perch. There were two reports each of grouper being replaced with catfish and turbot with halibut.

Several reports indicated extensive fraud. The Universal Group, a wholesaler in the United States, labeled over 2.5 million pounds of catfish as grouper worth over $5.5 million, among other offences. In 2013, species substitution in food service in Japan saw luxury hotel chains mislabeling multiple menu items, including high end seafood, a scandal that was estimated to have affected 78,000 diners. In the United Kingdom in 2014, 390,000 packs of Japanese seabass were falsely labeled as a different species of seabass and distributed to a large UK supermarket. A 2018 investigation by the US New York State Office of the Attorney General in 155 supermarkets revealed widespread substitution of sole, red snapper, and grouper.

These data illustrate some of the potential public health risks posed by species substitution. There were three reports of monkfish substitution with pufferfish from China, Senegal, and Gambia, and one report of 10 tons of fake jellyfish produced and distributed in China in 2015 by combining sodium alginate, calcium chloride, and aluminum sulphate. Snapper substitution in New York had higher mercury levels than the desired species, and Vietnamese catfish sold as grouper in the United States tested positive for malachite green and enrofloxacin.

3.2.7 | Seventh most prevalent fraud type: Illegal, unregulated, and unreported fishing or substitution

There were 32 reports associated with IUU fishing or substitution. Seventeen reports were regarding the illegal harvesting of molluscs and included clams ($n = 8$), oysters ($n = 3$), mussels ($n = 2$), cockles ($n = 2$), razor clams ($n = 1$), and undefined bivalve mollusc (1). Ten reports were attributed to IUU catches of finfish, and four of these reports were for illegal bluefin tuna. Other species included grouper, trout, salmon, pikeperch, catfish, and glass eels. The remaining five products were related to undefined or mixed IUU fishing.

A significant peak was observed in 2018 ($n = 11$), partially due to an increase in reporting of illegally caught bluefin tuna from Operation Tarantelo, coordinated by Europol, which resulted in 79 arrests and the seizure of more than 80,000 kg of illicit bluefin tuna (Europol, 2017).

3.2.8 | Eighth most prevalent fraud type: Fishery substitution

There were 21 reports of fishery substitution. The most common reason for fishery substitution was the misdeclaration of the country of origin to increase marketability ($n = 17$), as particular areas of capture can represent increased demand and revenue opportunity (Claret et al., 2012). The most prevalent reason for fishery substitution was the mislabeling of foreign prawns or shrimps as domestic ($n = 7$). Six of these reports were Asian or Mexican prawns labeled as US domestic product, and one report referred to Thai prawns labeled as Australian. Products were also declared wild caught when they were farm raised. In total, there were six reports of farm products declared as wild, including foreign farm raised shrimp sold as wild caught in the United States ($n = 4$), Mediterranean seabass from aquaculture plants in Greece ($n = 1$), and farmed salmon sold as locally caught Welsh salmon ($n = 1$). Consumer preference and willingness to pay for sustainable seafood attributes such as country of origin, eco-certification, and information on catch method are well documented (Del Giudice et al., 2018; Zander & Feucht, 2018), as is the perception of value for wild versus farmed fish (Claret et al., 2012; Menozzi et al., 2020). This price premium means that financial incentives exist for fraudsters to seek fraudulent gain by making false provenance claims.

Fishery substitution was used as a vehicle to launder unsuitable products. For example, illegal bluefin tuna caught in Malta was illegally imported using documents from legal fishing and authorized farms, and Vietnamese prawns were sold using a Malaysian certificate of origin to facilitate import into the United States. There was a significant prosecution in Scotland in 2017 for Sea-Pac, a salmon company that fraudulently used labels from another fishery that had been approved for export to Russia, Lithuania, and Estonia.

3.2.9 | Ninth most prevalent fraud type: Modern-day slavery

There was one report for modern-day slavery in 2020, which referred to a withhold release order issued against a Taiwanese-owned fishing vessel where the United States Customs and Border Protection observed indicators of forced labor, including debt bondage, excessive overtime, and restriction of movement.

3.2.10 | Less prevalent fraud types

Although there is robust evidence of seafood mislabeling in the literature (Kroetz et al., 2020), certain fraud types were less evident than expected in the data. Species adulteration (excluding veterinary residues accounted for only 7% of all reports), species substitution accounted for 4%, and fishery substitution accounted for 2%. There were only 32 reports of IUU fishing or substitution, averaging three reports per year, even though this practice represents up to 26 million tons of fish caught annually (FAO, 2021) and is estimated to cause economic harm of approximately \$36 and \$50 billion annually (Sumaila et al., 2020). Notably, only one report of modern slavery occurred in this dataset, despite a wealth of evidence of the practice in fishing from academia, the media, and international organizations (GLAA, 2020; Global Slavery Index, 2018; McDowell et al., 2015; MRCI, 2017; SOCA, 2013; Tickler et al., 2018). There is undoubtedly more data that this research could have drawn upon to reveal further reports, and as previously discussed, much of this fraud is concealed through fraudulent documentation. Nonetheless, the four databases utilized are commonly employed by industry, government, and academia to assess food fraud vulnerability and risk in food supply chains. These results suggest that further insights are necessary to accurately reflect certain seafood fraud categories.

Catch method fraud and animal welfare fraud types were absent. Analytical techniques to identify catch method fraud are still relatively emergent (Black et al., 2017), and where fish have been filleted or processed, any visible signs to indicate trawl fishing are likely to have been removed (Holmyard, 2017). This makes it difficult to determine the catch method by inspection or sampling and therefore to identify fraudulent claims regarding sustainable fishing.

Legislation enabling the enforcement of marine animal welfare is currently limited (Levenda, 2013), as the regulatory framework is less stringent than that of other production animals (Gismervik et al., 2020). However, an increasing appetite for assessing and addressing aquatic animal welfare issues has moved it up the public agenda (Metcalfe, 2010), and as certification schemes and retailers begin to include welfare standards in their accreditation of seafood (ASC, 2020; BAP, 2020; Fletcher, 2021; RSPCA, 2020), the documented misrepresentation of marine welfare standards may increase.

3.3 | Supply chain node trends

Figure 4 maps out the report frequency by supply chain node (at which point in the supply chain that the fraud is considered to have taken place) and by the type of fraud observed at each node. For 17 reports, there was insufficient information to determine where the fraud had occurred.

Due to the high prevalence of reports regarding illegal or unauthorized veterinary residues, aquaculture farming was found to be the most vulnerable supply chain node, with 422 reports. There were 213 reports at import and export; the most common offences were fraudulent or missing health certificates ($n = 110$) and illegal or unauthorized imports ($n = 50$), which included offences such as the attempted import or smuggling of prohibited products. As discussed in Section 3.2 (chain of custody abuse), products with fraudulent export documentation may be concealing violations that are occurring further down the supply chain and are simply identified at border checks due to enhanced scrutiny at customs. However, as the fraudulent export credentials may be used to facilitate substandard produce into the legitimate importing supply chain, it is considered that this area of the supply chain is also vulnerable to misrepresentation where fraud has been perpetrated to facilitate trade.

Processing was the third most vulnerable area of the supply chain ($n = 176$), with more reports in secondary processing than in primary processing. Processing is well recognized in the literature as a vulnerable area of the supply chain, as it provides ample opportunity to mix other components, such as cheaper fish or bulking ingredients. These are hard to detect when morphological traits have been removed and other textures and flavors are introduced through processing (FAO, 2018; Fox et al., 2018).

Harvesting of marine resources was the fourth most vulnerable area of the supply chain, with 28 reports of IIU fishing or substitution and one report of modern-day slavery. As discussed earlier, it is considered likely that fraud occurring at this point is not proportionately reflected in the databases selected.

Retail, ($n = 23$), wholesalers, middlemen and distributors ($n = 18$), and food service ($n = 14$) had a similar report frequency, and reports at this end of the supply chain were more commonly associated with the misrepresentation of product or origin. Examples include low value fish labeled as high value species, farmed fish marketed as wild, and imported seafood labeled as domestic, practices that are well evidenced in the literature at this end of the supply chain (Christiansen et al., 2018; Erin & John, 2019; Kappel & Schroder, 2016).

Twenty-two reports were associated with feed. Four reports were due to the presence of pesticides (hexachlorobenzene and β-hexachlorocyclohexane). Both compounds are banned and associated with adverse health outcomes (NCBI, 2021; Rubini et al., 2021). Eighteen reports were due to the presence of ruminant DNA; the use of ruminant meat and bone meal is not permitted in aquaculture to prevent the transmission of transmissible spongiform encephalopathies (Nesic et al., 2019).

The analysis revealed several successful prosecutions in the United States under the Lacey Act between 2011 and 2020 of large-scale, complex seafood frauds spanning multiple supply chain nodes, companies and fraud types, reflecting the complexity of both the seafood supply chain, and the incorporation of food fraud into the legitimate supply chain. Most of these cases involved imported fish (the United States imports 90% of its seafood), resulting from increased demand and an associated higher price for domestic seafood (Pramod et al., 2014).

However, as acknowledged in other research (Joenpera et al., 2022; Lord et al., 2021), the prevalence of fraud in one area reflects not only the incidence of fraud but also the level of monitoring and law enforcement. Notably, the results in this section show that veterinary residues in aquaculture farming and chain of custody abuse and illegal or unauthorized international trade at import and export are the most frequently reported. The overwhelming majority of these particular incidents are picked up at border control where products are subject to mandatory monitoring, and the results will therefore be reflective of enforcement focus as well as incidence.

3.4 | Seafood product trends

In total, there were 72 unique seafood species identified in fraud reports. In 151 reports, the seafood product was mixed or not detailed, for example, “white fish or mixed seafood”.

Figure 5 shows the top 20 species by incidence, which accounted for 68% of all reports. For crustaceans, most reports were related to prawns/shrimps ($n = 187$), followed by crayfish ($n = 24$), crab ($n = 18$), and lobster ($n = 8$).

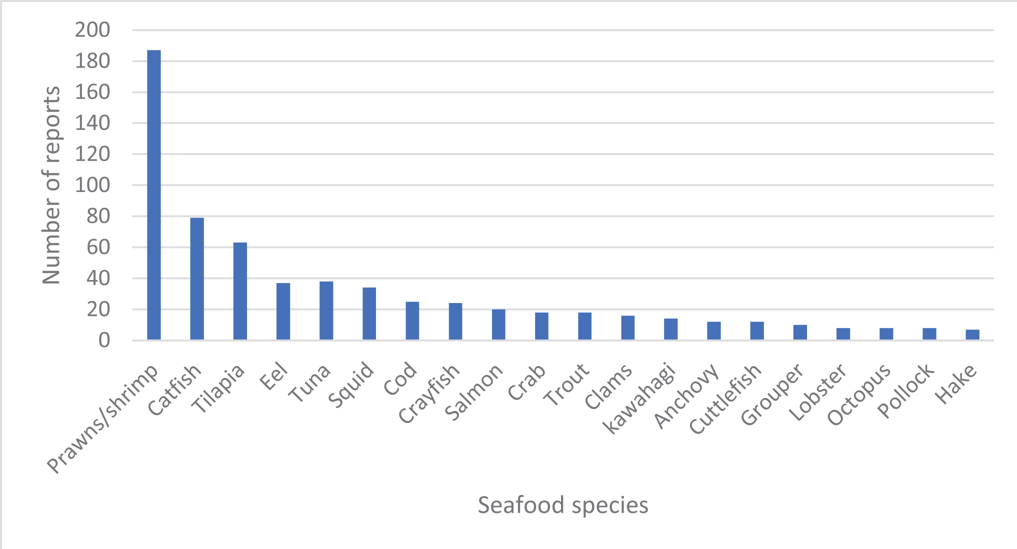

FIGURE 5 Top 20 seafood species by report frequency January 01, 2010–December 31, 2020

Finfish accounted for over half the dataset ($n = 521$), and the main species identified were catfish ($n = 79$), tilapia ($n = 63$), tuna ($n = 38$), eel ($n = 37$), cod ($n = 25$), salmon ($n = 20$), trout ($n = 18$), kawahagi ($n = 14$), anchovy ($n = 12$), and grouper ($n = 10$).

Molluscs accounted for 94 reports. Squid accounted for the greatest number of reports ($n = 34$), followed by clams ($n = 16$), cuttlefish ($n = 12$), octopus ($n = 8$), mussels ($n = 4$), oysters ($n = 4$), scallops ($n = 4$), abalone ($n = 3$), cockles ($n = 2$), and razor clams ($n = 1$).

3.5 | Country of origin trends

Fraudulent products originated from 80 unique countries, and 19 reports had an unknown country of origin. The heat map in Figure 6 shows the global spread of reported seafood fraud by frequency. The greatest concentration is in Asia ($n = 556$), with the highest number of reports originating from Vietnam ($n = 194$), China ($n = 155$), and India ($n = 93$). Ninety-seven percent of reports were picked up from border checks, while the remaining 3% of reports were due to domestic enforcement, mostly in response to the use of authorized preservatives such as formaldehyde, formalin, and ammonia.

In Europe ($n = 164$), the greatest number of reports originated from the United Kingdom ($n = 29$) and Spain (21). Forty-seven percent of reports were self-notified and were the result of domestic enforcement for various reasons, including regulatory testing, action to stop illegal harvesting of shellfish, and Europol operations.

In Africa ($n = 87$), countries with the highest number of reports were Ghana ($n = 20$) and Nigeria ($n = 15$). Eighty-six reports originated from border checks, and one report from Africa was from domestic enforcement, resulting from city council action in Uganda to stop local markets using formaldehyde to preserve beef and fish.

Fifty-nine reports originated from North America. A large percentage of these were self-notified (45%) and were the result of prosecutions for large-scale species and fishery substitution, domestic detection of veterinary residues, and shellfish originating from an unapproved source.

Thirty-two reports originated from South America, and all reports were the result of border checks.

There were six reports from the Middle East and two reports from Australia. All reports were from border checks.

3.6 | Associations between fraud type, supply chain node, seafood product, and country of origin

A multiple correspondence analysis (MCA) was conducted on all variables to observe common associations between fraud type, supply chain node, seafood product, and country of origin.

The first two dimensions of the MCA are plotted in Figure 7, which displays a symmetric observation plot and reveals three distinct groups. The plots show clear associations of fraud types with supply chain node, seafood species, and country of origin. Group A clearly reveals associations between Asia and the use of illegal or unauthorized veterinary residues in shrimp farming, with most reports in this group originating from India and

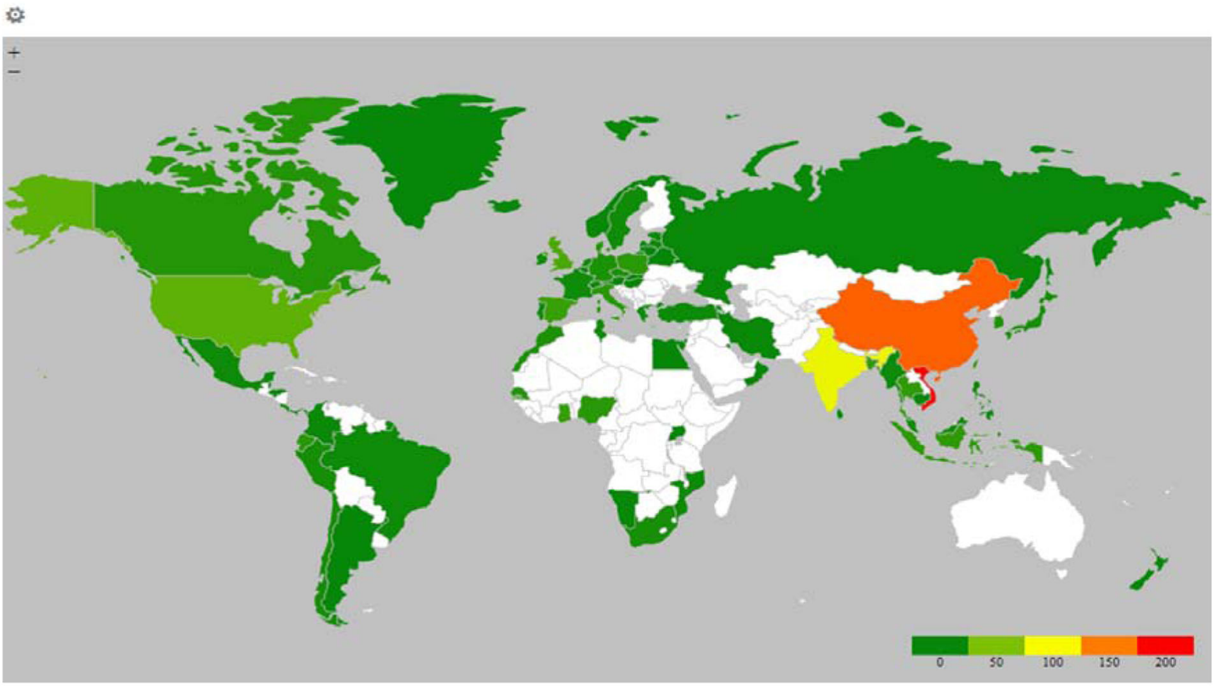

FIGURE 6 Geographic heat map of global reported seafood fraud by product country of origin

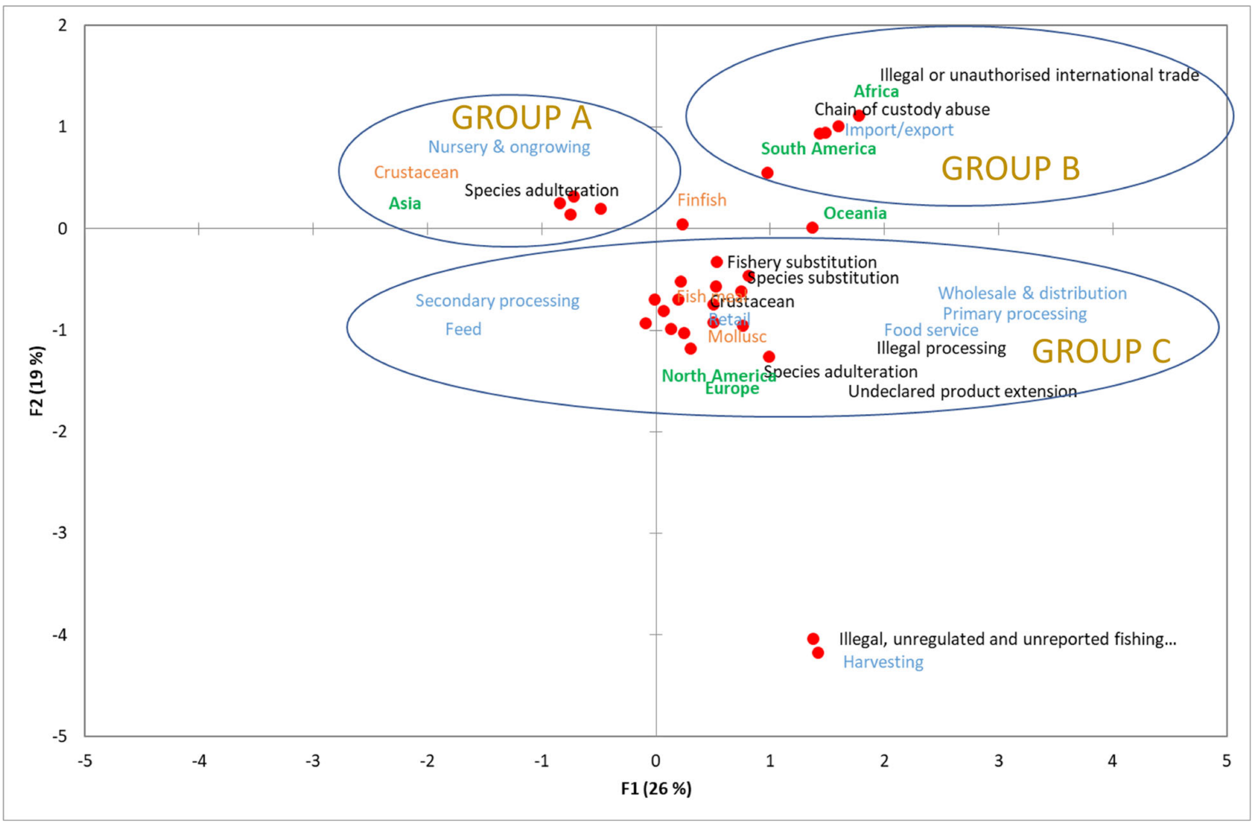

FIGURE 7 First two dimensions of a multiple correspondence analysis of the dataset by report frequency. Black labeling indicates fraud type, blue indicates supply chain node, orange indicates seafood type, and green indicates origin

Vietnam. There were slight differences in the residues reported, which is probably reflective of both access to veterinary products and species farmed (Rico et al., 2013), as well as export markets, as most reports were picked up from border checks. In the EU, legislation on residues of veterinary medicines and contaminants is harmonized through Council Directive 96/23/EC (European Commission, 1993) and Regulation 37/2010/EU (European Commission, 2009a) and has resulted in high levels of compliance, reflected in the relatively low levels of veterinary reports in European countries of this study ($n = 16$). International standards are set by the Joint Food and Agriculture Organization of the United Nations and the World Health Organization Codex Alimentarius Commission (CODEX, 2018), and although there are efforts to harmonize maximum residue limits (MRLs) of veterinary drugs globally, permitted MRLs among countries may still differ significantly, depending on local regulation (Okocha et al., 2018). Developing countries in particular may face difficulty in meeting the current food safety standards of developed importing countries, so continued vigilance is necessary until a globally harmonized approach on the use of veterinary drugs is adopted. There was a significant drop in the dataset of illegal or unauthorized residue presence in 2019 and 2020, mostly attributed to reductions from Vietnam and India, which could indicate increased efforts toward compliance in importing standards. Group B shows correlations at import and export of illegal and unauthorized international trade and chain of custody abuse, with products originating from Africa and South America. African reports were most commonly from Ghana and Nigeria, and many of these reports were related to the illegal import of smoked and dried fish products. There is significant market demand for these products from ethnic communities living in Europe (Asiedu et al., 2018). However, the illegal importation of fish that have been smoked using traditional methods can present a public health risk due to unsafe levels of polycyclic aromatic hydrocarbons (PAHs), which are carcinogenic and genotoxic (Chaber & Cunningham, 2016; IAFI, 2017). Products may therefore be illegally imported to bypass European regulation as they do not meet European thresholds for PAH levels and so can no longer be exported to Europe (EC, 2011). Illegal import of such fish may also occur to bypass taxes and tariffs or conceal IUU fishing activity (EJF, 2020). Reports from South America were more strongly correlated with the chain of custody abuse at import and export than any other fraud type.

Group C concerns five fraud types: species substitution, species adulteration, fishery substitution, illegal processing and undeclared product extension, strongly associated with Europe and North America, focused at the top end of the supply chain. In Europe, species and fishery substitution and species adulteration accounted for 51% of all reports and was identified at secondary processing, food service and retail, with most reports relating to high value products including cod, scampi, and lobster, adulterated or substituted for lower value products. Illegal processing also featured in this grouping, primarily due to unauthorized irradiation and undeclared product extension. In North America, the most common fraud types were species substitution and species adulteration, most often found in wholesale and distribution, retail and food service. Species substitution included squid labeled as octopus, tilapia, and pangasius for sole, cheaper seafood for lobster, African perch as grouper and snapper, and foreign crab as domestic blue crab. There is a high demand in the United States for domestically produced blue crab and therefore a significant financial incentive to deceive through species and fishery substitution. There were three reports of significant fraud in 2015 concerning blue crab with a combined retail value of millions of dollars. It was observed that 2013 and 2014 had significant declines in the domestic blue crab harvest, dropping to less than half the harvest of 2012 (CBF, 2014), causing increased prices and underutilized demand—an ideal environment for fraud. In addition, picking meat from crabs is highly labor intensive, so the incentive to buy prepared crab meat is raised. Similarly, domestic shrimp is in high demand, and there were two reports of significant frauds where Asian farmed product was used as a substitute.

4 | METHODOLOGICAL CONSIDERATIONS

4.1 | Differences between data sources

The FFD and HorizonScan provide data from a variety of sources, so fraud types by source were compared between RASFF, which only includes regulatory notifications, and Nexis, which contains only news stories. Table 6 shows the fraud types revealed in the data, which trended differently, according to the source. This reflects in part the individual strengths of each dataset and emphasizes the requirement to link data on food fraud from a wide variety of sources to maximize the information and intelligence available, but it also reveals where there are gaps.

For both datasets, species adulteration was the fraud type with the highest frequency, although for RASFF, 88% of these reports were attributed to veterinary residues, whereas for Nexis, they only accounted for 22%, with more stories (52%) focused on nitrates in tuna. RASFF picked up several reports relating to illegal or unauthorized international trade, which accounted for only 2% of stories reported in the media. Illegal processing was also picked

TABLE 6 Percentage of the total number of reports on Rapid Alert System for Food and Feed (RASFF) and Nexis by fraud type

Fraud type	Nexis	RASFF
Chain of custody abuse	9.5	22.9
Fishery substitution	9.5	0.0
Illegal or unauthorized international trade	2.4	12.3
Illegal processing	0.0	11.3
IUU fishing or substitution	16.7	2.4
Modern-day slavery	2.4	0.0
Species adulteration	40.5	50.5
Species substitution	16.7	0.6
Undeclared product extension	2.4	0.0

Abbreviation: IUU, illegal, unreported, and unregulated.

up by RASFF (11% of stories) but was not reflected in the Nexis dataset. Nexis picked up several stories on species substitution (17% of total), whereas this accounted for less than 1% of RASFF notifications. Similarly, IUU substitution was picked up in the media (17% of stories) but only accounted for 2% of RASFF reports. The media picked up some reports on fishery substitution (10%), but it was not revealed in RASFF reports.

Notably, there was a very low frequency of reports for species substitution, IUU substitution, fishery substitution, and undeclared product extension in the RASFF dataset. These practices are less likely to be picked up by visual inspection, particularly with processed fish products, and there is a requirement to increase and enhance analytical methods by regulatory authorities for fishery products to verify products and their associated certification along the seafood supply chain to deter mislabeling (Guardone et al., 2017; D'Amico et al., 2018).

Similarly, species adulteration from veterinary residues, a significant area of concern, has not been proportionally reflected in the media stories. The media plays an important role in exposing a wider range of incidents, a concept that is acknowledged in other studies (Zhu et al., 2019). However, as journalists determine which issues are given salience or frame them by highlighting certain realities while marginalizing others (Cobb & Elder, 1983; McCombs & Shaw, 1972), it is argued that content is "socially rather than objectively constructed" (Manning & Soon, 2019) and should be interpreted with caution. Additionally, in certain geographies, the state limits the ability of the media to operate freely (RSF, 2016), and press censorship may mean that stories are suppressed.

4.2 | Limitations

Much food fraud goes unreported, and it lacks a natural break-out point, as consumers or food businesses may be unaware that they have been deceived. To evade detection, fraudsters find new flaws and weaknesses in control measures using varying and complex techniques (van Ruth et al., 2017). Like other corporate crimes, food fraud is often found concealed within legitimate food business actors and supply chains and embedded within the food system (Lord et al., 2017). Therefore, a considerable proportion of food-related criminality will not be reflected in food fraud databases or media reports, and accurately assessing the real extent is extremely challenging.

Food fraud databases may not distinguish deliberate acts from unintentional acts. There are over 30,000 fish species, and even slight differences in appearance are speciated (Anderson et al., 2018). If species that are morphologically similar are caught together, then they may be incorrectly tagged. Equally, products may be mixed up during processing, and if trade names are used rather than the scientific name, such as 'snapper', then ambiguity in product naming may lead to incorrect labeling (Barendse & Francis, 2015; Meloni et al., 2015; Mitchell et al., 2019). Identifying motives, such as significant price differentiation or the inclusion of illegally caught species in mislabeled products, would help determine if mislabeling is deceptive or accidental (Miller et al., 2012).

Over half of the records in this study are from RASFF. While the obligatory participation of member states makes it a unique information asset, several limitations are observed. Most RASFF reports originate from border inspection reports when food is declined, so certain fraud types may not be exposed. One food fraud incident may result in multiple reports on RASFF, particularly when exported to different countries within the EU, and details such as producer name or importer are not included in RASFF reports, which makes it challenging to identify notifications from the same incident (D'Amico et al., 2018). Differing regulatory approaches and levels of engagement with RASSF between countries may impact the overall representation of the data (Kowalska & Manning, 2021). In line with previous research on RASFF notifications (Kowalska & Manning, 2021; Taylor et al., 2013), this study found the United Kingdom, Spain, Germany, Italy, and Belgium to be the most frequent notifiers. This means an increased representation from these countries in the overall dataset, and data may therefore be influenced by their individual regulatory agendas. Purposive sampling rather than probability-based sampling makes it challenging to identify trends within the database reflective of an overall fraud picture, and products subject to more frequent checks will drive up results. This, in turn, gains attention and further drives up analytical testing, but the actual prevalence of fraud for that commodity may not have increased. Consequently, fraud occurring in other areas may be overlooked as enforcement and research resources are redirected elsewhere. Kowalska and

Manning (2021) examined notifications relating to mycotoxins within RASFF, and their research confirmed that purposive sampling does influence the dataset. Finally, the size of individual consignments is not detailed, which makes it difficult to understand the scale of the frauds reported on the database (Bouzembrak & Marvin, 2016).

Previous research has recommended enhancing RASFF data with other international databases and media reports (Bouzembrak & Marvin, 2016; Montgomery et al., 2020; Ulberth, 2020) to improve data quality. This study attempts to bridge this gap by including other food fraud databases (HorizonScan and the Food Fraud Database) and media coverage (Lexis Nexis).

5 | FUTURE PROSPECTS

This study analyzes data on reported fraud to December 2020, so the impacts of the COVID-19 crisis and EU exit are not reflected in this dataset. The pandemic has had significant impacts across production, consumption, and distribution in food supply chains (Chenarides et al., 2021; Garnett et al., 2020; Hobbs, 2020). In the seafood sector, measures such as trade restrictions, the closure of food service establishments, the reduction of transport services and the cessation of tourism have triggered huge impacts at every node in the seafood supply chain at a local and global scale. For European seafood producers (particularly UK-based exporters), EU exit has placed significant pressure on businesses, which have faced delays and nontariff barriers to Europe, resulting from the new customs and export certification requirements of the EU exit trade agreement (UK Parliament, 2021). It remains to be seen whether these are short-term issues and whether the seafood supply chain is robust and flexible enough to ride it out (Symes & Phillipson, 2019), but certainly, for the foreseeable future, UK seafood companies that rely on exports to Europe or European companies importing to the United Kingdom are likely to be facing additional economic pressure, particularly for lower value exports who have smaller margins. The external pressures of COVID-19 and EU exit, particularly when combined, are likely to increase the risk of food fraud, and further analysis comparing food fraud reports before, during and after this period would provide useful insight.

6 | CONCLUSION

This study presents a number of novel contributions to the analysis of seafood fraud. It provides a global comparison, assessing food fraud trends across 80 countries and 72 seafood species. It also provides an analysis of the types of fraud that exist within the seafood supply chain and the supply chain nodes that are more vulnerable to criminality. The presence of illegal or unauthorized veterinary residues from Asia was the most significant issue reported within the four datasets and represents an ongoing concern for imported seafood. Aquaculture was therefore found to be the most vulnerable area of the seafood supply chain. Import and export are the next most vulnerable, with a substantial proportion of reports due to inadequate or fraudulent health certification. Products with fraudulent documentation, or even just the required levels of traceability, may be indicative of disreputable operators seeking to import products that do not meet the conditions of the importing country and conceal a variety of deceptive practices, such as the seafood fraud types discussed in this study. A multiple correspondence analysis revealed clear associations of fraud types with supply chain node, seafood species, and country of origin, with three distinct geographical groupings.

This study illustrates the variety of data and differences in the reporting of food fraud and underlines the necessity for better recording of fraud cases, as has been acknowledged in previous research. As much food fraud is also unreported, a more in-depth understanding of current vulnerabilities in the seafood supply chain is required to identify future points of deception and assist prevention and mitigation activities.

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AUTHOR CONTRIBUTIONS

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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