The Seafood Supply Chain from a Fraudulent Perspective

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REVIEW

The seafood supply chain from a fraudulent perspective

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Abstract

Food fraud is an intentional act for economic gain. It poses a risk to food integrity, the economy, public health and consumers' ethics. Seafood is one commodity which has endured extensive fraudulent activity owing to its increasing consumer demand, resource limitations, high value and complex supply chains. It is essential that these fraudulent opportunities are revealed, the risk is evaluated and countermeasures for mitigation are assigned. This can be achieved through mapping of the seafood supply chains and identifying the vulnerability analysis critical control points (VACCP), which can be exposed, infiltrated and exploited for fraudulent activity. This research systematically maps the seafood supply chain for three key commodities: finfish, shellfish and crustaceans in the United Kingdom. Each chain is comprised of multiple stakeholders across numerous countries producing a diverse range of products distributed globally. For each supply chain the prospect of fraud, with reference to species substitution, fishery substitution, illegal, unreported and unregulated substitution, species adulteration, chain of custody abuse, catch method fraud, undeclared product extension, modern day slavery and animal welfare, has been identified and evaluated. This mapping of the fraudulent opportunities within the supply chains provides a foundation to rank known and emerging risks and to develop a proactive mitigation plan which assigns control measures and responsibility where vulnerabilities exist. Further intelligence gathering and management of VACCPs of the seafood supply chains may deter currently unknown or unexposed fraudulent opportunities.

Keywords Food fraud · Food integrity · HACCP · Seafood supply chain · TACCP · VACCP

1 Introduction

Globally, the food sector plays a significant direct role in human well-being through the provision of authentic food 'fit for human consumption' (European Commission 2002). Inadequacies in food quality, safety, defence and fraud surveillance have been identified as food integrity risks and of increasing sectoral, government and consumer concern (Galimberti et al. 2013). In particular, food fraud, defined as "food which is deliberately placed on the market for financial gain, with the intention of deceiving the consumer", is of heightened concern following recent media coverage of food fraud instances and their consequences (Kamruzzaman et al. 2015; FSA 2016). For the consumer, food fraud can deny their rights to make an informed choice, especially if based on ethical or religious issues (Woolfe and Primrose 2004; Fajardo et al. 2010; Johnson 2014; Ali et al. 2015). In the food industry, food fraud creates economic and sustainability concerns, evident in food businesses which are hit with the cost of recalling products and the subsequent impact on brand reputation (Jacquet and Pauly 2008), and places pressure on small-to-medium sized enterprises to purchase cheaper ingredients in order to compete and sustain their business. Although the intention is for profit and not to cause harm, the availability of potential contaminants and allergens introduces the unknown into the supply chain and can lead to severe illness or death depending on the potency of the materials used and the susceptibility of the consumer (Pascual et al. 2008; Sheth et al. 2010; Triantafyllidis et al. 2010; Spink and Moyer 2011; Chen et al. 2012; Dennis and Kelly 2013; Paiva 2013; Stamatis et al. 2015; Tähkäpää et al. 2015).

In the United Kingdom, the modern day supply chain allows ingredients and products to be sourced and transported among a range of countries and supply chain players for raw materials, processing and retail. These can be supplied

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through individual food companies/importers or from foreign owned entities within a larger multinational company, such as global sourcing between parent and subsidiary (Johnson 2014). Complex supply chains create opportunities for fraudulent activity arising from difficulties in sufficient surveillance (Dennis and Kelly 2013; Manning and Soon 2014). Coupled with rising prices, scarcity of raw ingredients, the competitive nature of the food industry, the constant drive to reduce costs and maximise profits, and the customers desire for variety and access at low cost means that illegal, fraudulent activities and/or products tempt and are sometimes necessary for players in the supply chain in order to sustain their market (Dennis and Kelly 2013; Elliott 2014).

The US Pharmacopeial (USP) Food Fraud Database (USP 2014), reports by Oceana and Consumer Unions (Oceana 2016; Warner et al. 2013; Warner et al. 2016) and scientific publications on food fraud have revealed that fraud is highly prevalent in the seafood supply chain (Hellberg and Morrissey 2011; Moore et al. 2012; Everstine et al. 2013a, b; Galimberti et al. 2013; Hurst et al. 2014; Johnson 2014; Mueller et al. 2015; Stamatis et al. 2015). This has been attributed to the increasing demand and recognition of seafood as a healthy alternative to red meat, the similarity and diversity of seafood species available, the stock limitations and price pressures in the food market (Martinez and Friis 2004; Jacquet and Pauly 2008; Mazzeo et al. 2008; Barbuto et al. 2010; Miller and Mariani 2010; Heyden et al. 2010; Mohanty et al. 2013; Leal et al. 2015; Mueller et al. 2015; Stamatis et al. 2015; Jennings et al. 2016). As consumer demand rises towards the estimated seven-fold increase in seafood production required to meet the predicted global population growth of over 9.8 billion by 2050 (Delgado et al. 2003; United Nations 2015; Jennings et al. 2016), the number of cases of food adulteration and intervention of opportunistic elements in the seafood industry increases (Mohanty et al. 2013). This exploitation in the seafood supply chains is concerning as it poses economic, ethical and food safety consequences (Buck 2010; Johnson 2014). Moreover, the scope and impact of seafood fraud can vary widely. It can occur at every pass of custody in the seafood supply chains, from large-scale multi-national schemes involving importers, to fraudulent activities at individual restaurants or grocery stores. Each aggregator, shipper or wholesaler who collects, blends, or repackages can change the identity, purity and authenticity of the ingredient (Moore et al. 2012). The scientific literature advocates vulnerability assessment as the first step in preventing food fraud (Spink et al. 2014, 2016a). To conduct such an assessment the priority is to identifty each node in the seafood supply chain. A node represents a distinct organisation that is involved in producing and/or delivering the product. They are differentiated based on their unique function in the supply chain. The product flows between nodes from source to consumer to make up the supply chain. Identification of each node will allow food fraud vulnerabilites to be identified, effective control measures assigned and mitigation measures implemented as close as possible to their point of entry. To date there has been limited mapping of the seafood supply chain in correlation with fraudulent opportunities within the scientific literature. The objective of this study is to address this deficiency by systematically mapping the seafood supply chain in the UK and to understand and describe the issues pertaining to seafood fraud at each of the supply chain nodes for subsequent vulnerability analysis of the seafood supply chain.

2 Methodology

A review of the literature and the application of the preliminary step for vulnerability analysis critical control point (VACCP) evaluation, i.e. intelligence gathering, was performed to map the seafood supply chain in the UK and investigate the opportunities for fraud. This involved a search of Web of Science, for articles in the English Language, published between January 1950 and December 2016 and where the full text was available for viewing. Specific key words and the combination of these key words were established to include: (Seafood or Fish or Crustacean) AND ("Supply Chain") AND (map or outline or diagram or picture or "mass balance" or model*). A total of 54 relevant articles were evaluated and formed the basis of the seafood supply chain. This supply chain was reviewed by experts within the UK seafood industry. The search strategy was then amended to include (Seafood or Fish or Crustacean) AND (Food Fraud or Adulteration or Vulnerability). This search retrieved 112 articles which were analysed thematically to understand the vulnerability of the seafood supply chain to fraud.

3 Seafood supply chain

The definition of terms for products when deliberating fraud is of utmost importance. "Seafood" is used to indicate edible aquatic life forms, such as fish, molluscs and crustaceans (Stamatis et al. 2015). "Finfish" is used to describe any animal with a backbone, gills and limbs in the shape of fins. "Crustacean" is an arthropod of the aquatic group Crustacea, such as a crab, lobster or shrimp. "Shellfish" is an aquatic shelled mollusc and crustacean though for regulatory purposes, and the purposes of this review it is often defined as filter feeding molluscs such as clams, mussels and oyster. The seafood supply chain involves eight key stages, including: source; hatchery operations (aquaculture only); nursery operations (aquaculture only); ongrowing techniques / wild; harvesting; processing; market, and consumers. These stages differ slightly for each of the supply chains of finfish (Fig. 1), molluscs (Fig. 2) and crustaceans (Fig. 3).

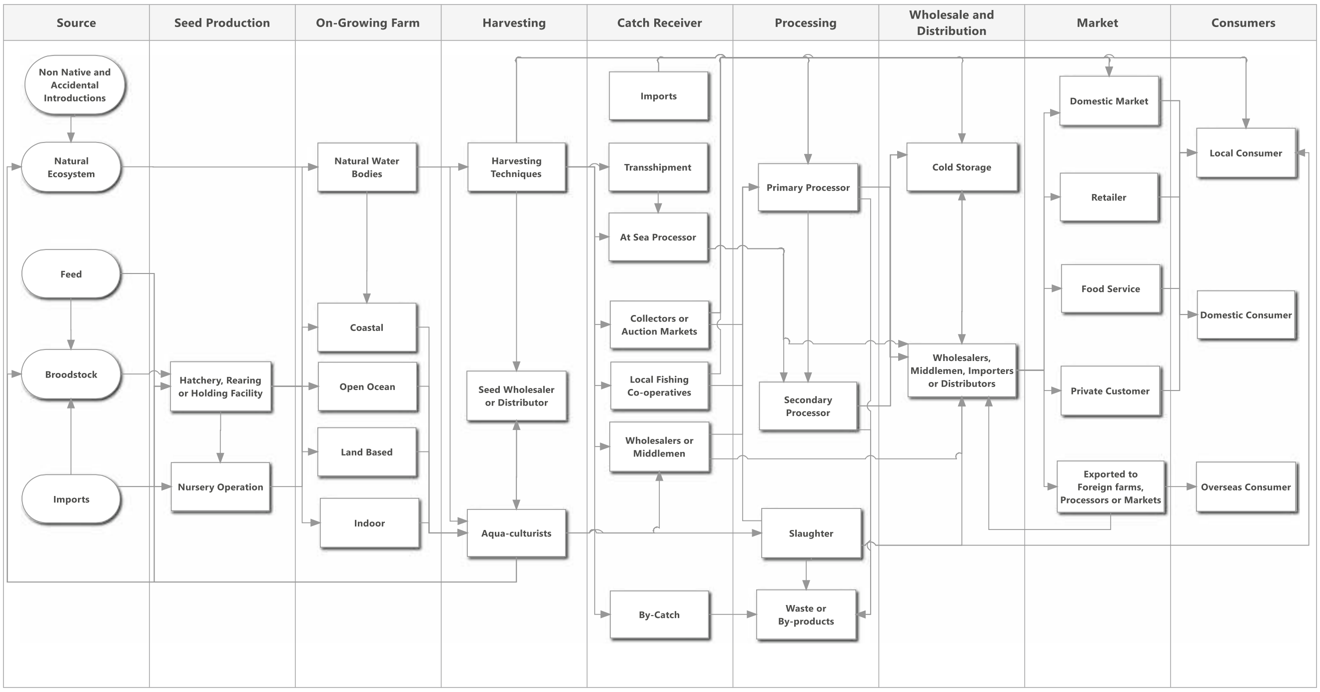

Fig. 1 The finfish supply chain consisting of ten key stages from source to consumption

3.1 Source

Seafood originates from the natural 'wild' ecosystem or aquaculture in the cultivation of aquatic species (Denham et al. 2015; FAO 2016a). In the wild, seafood can be found in habitats, which allow them to reproduce, develop and survive. Finfish (Fig. 1) occupy waterbodies such as lakes, rivers, lagoons, coastal estuaries and the ocean (Purser and Forteath

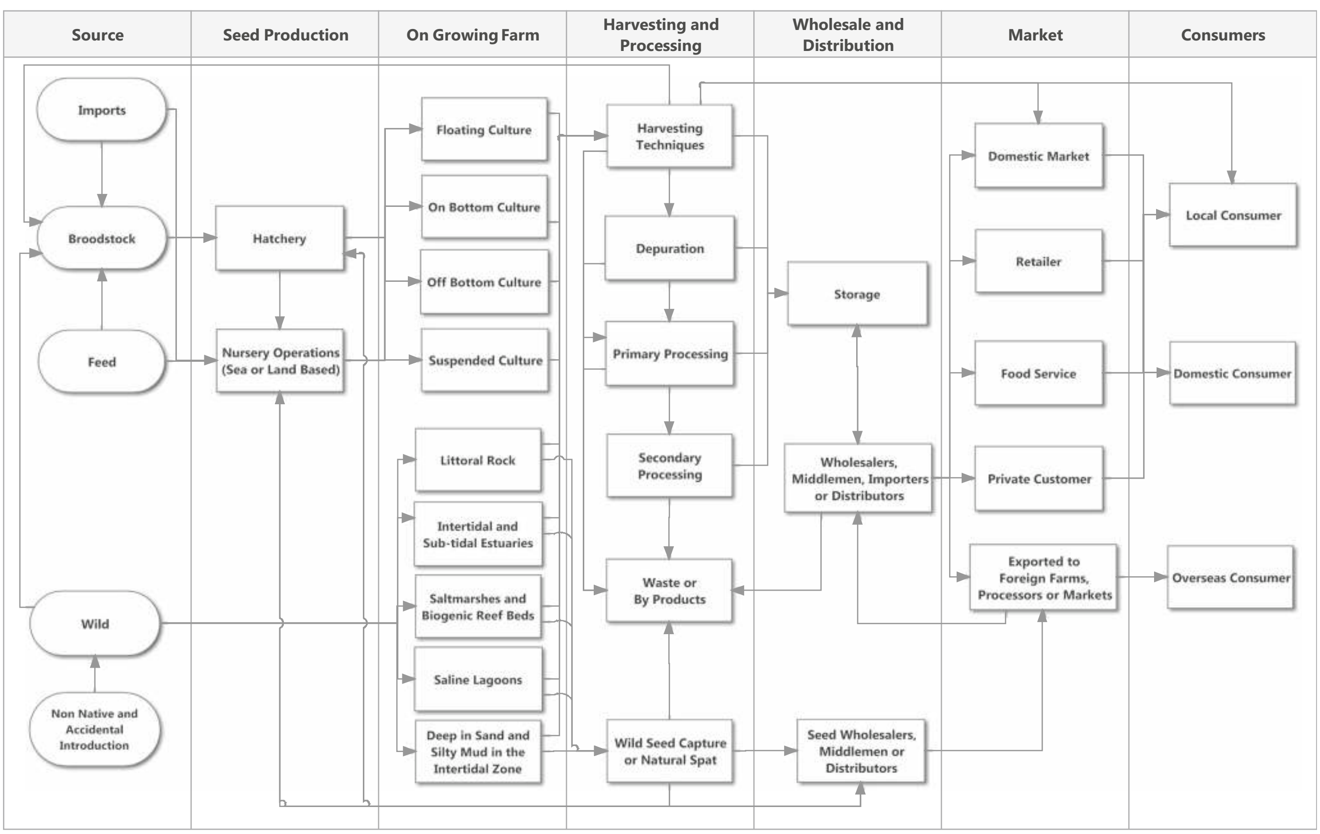

Fig. 2 The shellfish supply chain consisting of seven key stages from source to consumption

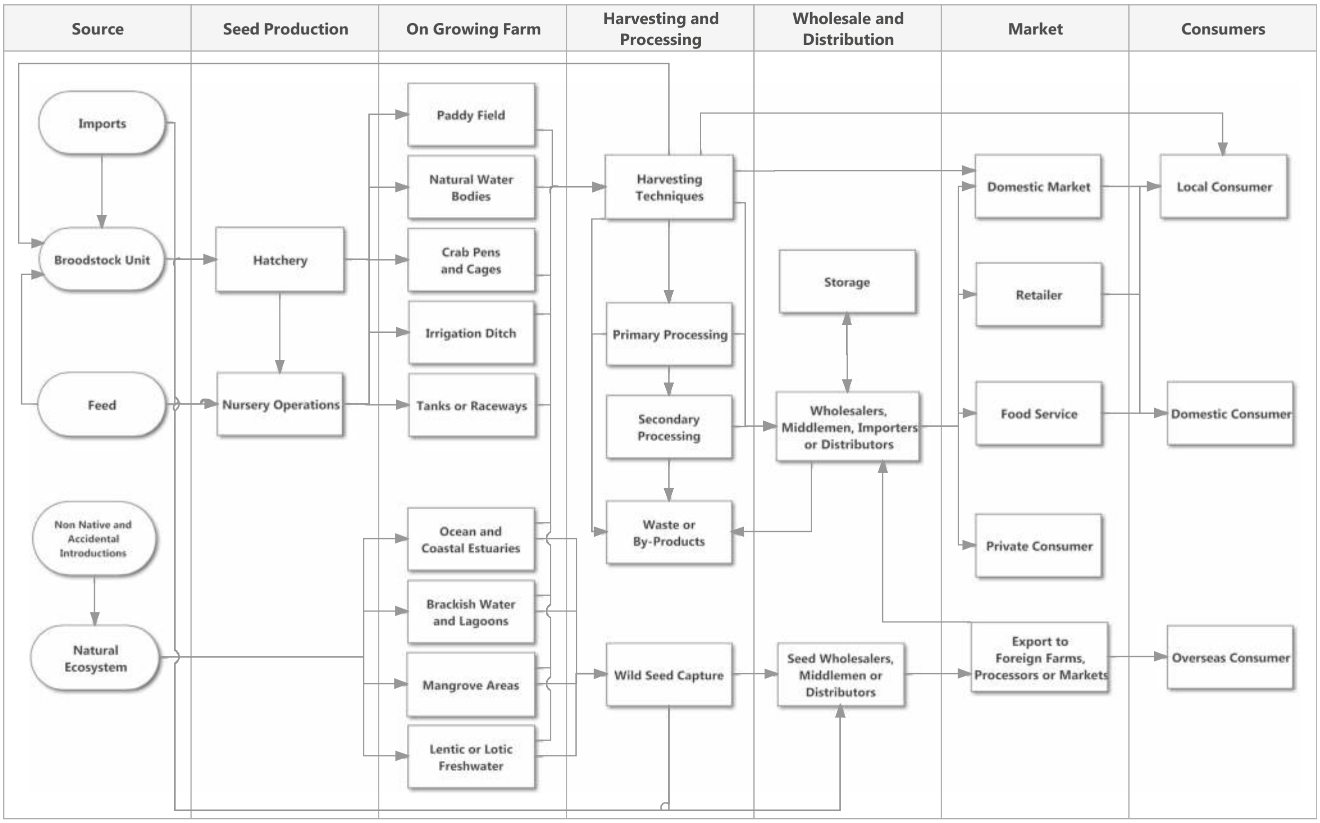

Fig. 3 The crustacean supply chain consisting of seven key stages from source to consumption

2003). Shellfish (Fig. 2) inhabit littoral rock, intertidal estuaries (e.g. rock, mangroves and man-made structures), sub-tidal estuaries (e.g. natural dredge beds), saltmarshes and biogenic reef beds, saline lagoons, and, deep in the sand or silty mud in the intertidal zone (Launey et al. 2002; Sarkis 2007). Crustaceans (Fig. 3) exist in ocean and coastal estuaries, brackish waters and lagoons, mangrove areas and lentic or lotic freshwater (FAO 2016a). In aquaculture, farmers source or purchase the seed, spat, post larvae or juveniles from either their natural habitat or from an ongrowing facility, nationally or internationally. These are transported to a hatchery, nursery or ongrowing facility, depending on their stage of growth. Seed can alternatively be sourced from the commercial production of eggs (Hardy et al. 2000) through the capturing and conditioning of broodstock (natural or artificial spawning) in a broodstock unit (Fernandez and Rodríguez 2003; Seafish 2005; Sarkis 2007). Broodstock may be sourced from capture fisheries or ongrowing facilities of farmers, a middleman or importer (Cuiñas et al. 2014; Parreño-Marchante et al. 2014). The fertilised eggs or viable gametes are obtained and transferred or sold to a hatchery.

3.2 Hatchery operations

At the hatchery, artificial fertilisation of the viable gametes from the broodstock is performed *in-vitro* (Hardy et al. 2000). Eggs fertilised naturally and those collected from the wild or farms, are allowed to hatch with the offspring, fed and maintained at optimum conditions through the early life stages until a sufficient size is reached to commence nursery operations or to be shipped on order to the growers (Fernandez and Rodríguez 2003; Purser and Forteath 2003; Sarkis 2007). Hatchery systems can range from specialised, small, unsophisticated units to large, sophisticated and environmentally controlled installations, together with maturation units. Some hatcheries are integrated with nursery and grow-out facilities (FAO 2016a). Hatchery operations may also occur at sea. In this case, the seed is captured from the wild in spat collectors, strung from longlines below the water surface and are allowed to hatch and grow there until they are ready to enter the nursery phase (Gosling 2003; Launey et al. 2002). Occasionally, the nursing of hatchery produced post larvae can be impractical and unnecessary, so the farmers skip the nursery stage and transfer or sell directly to the treated grow out facilities (FAO 2016a).

3.3 Nursery operations

Nursery operations commence following the direct sale or transfer from hatchery operations or wild capture (Purser and Forteath 2003). The seafood is fed and maintained at optimum conditions until they reach an adequate size and have adapted for survival in ongrowing facilities. Implemented systems are dependent on the species and farmer. For finfish (Fig. 1), the operations mimic their natural habitat, comprising treated fresh, brackish, marine or man-made waterbodies (Purser and Forteath 2003). For shellfish (Fig. 2), the spats are carefully resettled on: on-bottom culture in the intertidal zone directly on the beach; off-bottom culture in mesh or screen enclosures, either intertidally or sub-tidally; suspended in deep water from longlines and rafts; in inland ponds or tanks involving upweller and downweller systems, or; floating culture on trays in raft systems (Gosling 2003; BCSGA 2016). In crustacean aquaculture (Fig. 3), the nursery operations may include indoor or outdoor nurseries in the form of treated earthen ponds, impoundment nets, pens or small enclosures in the earthen department of grow-out ponds, paddy fields, or, greenhouse, concrete or lined raceways which prevent their escape (Seafish 2002). Moreover, nursery rearing may involve a two-stage system of cement tanks or fine mesh cages for intensive rearing before transfer to earthen ponds or paddy fields (FAO 2016a).

3.4 Ongrowing techniques

In the wild, once finfish, crustaceans or shellfish achieve fertilisation and the resultant eggs hatch, the juveniles or spat reside in a habitat with adequate conditions for survival. In aquaculture, the species is transferred or sold from the nursery operations to an ongrowing facility for growth to a marketable size. Alternatively, the juveniles may be directly transported from wild capture or purchased from farms to ongrowing production systems. For finfish (Fig. 1), the ongrowing sites comprise ocean, coastal, on land or indoor systems. In the ocean, floating cages enclose and submerge the finfish at different levels (Purser and Forteath 2003). At the coast, lagoons or brackish water bodies are adapted to allow fish to enter but prevent escape. On land, the finfish can be reared in a pond, tank or raceway and supplied with water in a continuous flow system (Hardy et al. 2000; Fernandez and Rodríguez 2003) or in indoor tanks using recirculating water systems (FAO 2016a). In shellfish ongrowing operations (Fig. 2), on-bottom, off-bottom, floating or suspension culture are utilised (Launey et al. 2002). On-bottom culture involves seeding in a suitable substrate in designated plots, including ponds, coastal lagoons and estuaries. Off-bottom culture involves rack and bag culture, where the shellfish are placed in plastic bags, baskets or tumblers supported off the ground. Floating culture involves the rearing of shellfish sub-tidally on covered rafts structures supported by floats in groups called parks. These rafts hold three ropes for collecting seed, growing shellfish and marketable shellfish. This allows continuous production. Suspension culture comprises growing the shellfish from floats or subtidal longlines in deeper subtidal waters and can take the form of tray culture or lantern net culture. The longline culture can be adapted to allow the shellfish to be set on strands of rope stretched above the ground with pegs. Alternatively, the shellfish may be ear-hung in pairs and attached to vertical and horizontal lines in shallow water lease areas. The Bouchet technique is another suspension culture method comprising wooden poles separated in rows and protruding above the seabed in the intertidal region for spat settlement and ongrowing (BCSGA 2016; FAO 2016a). In crustacean ongrowing (Fig. 3) ponds, net pens in small lakes and reservoirs, paddy fields and irrigation ditches are used (Seafish 2005; FAO 2016a). These ongrowing facilities are stocked with crustaceans brought in by the tidal water or by auto stocking with farmed crustaceans. In some cases, the species are capable of maintaining self-sustaining populations and this system only needs stocked once e.g. crawfish. Those reared in a super-intensive greenhouse raceway system use no water exchange (only the replacement of evaporation losses) or discharge whereas those raised in an irrigation ditch have an area of dry land with an artificial supply of water (FAO 2016a).

3.5 Harvesting techniques

Once the seafood reaches marketable size, they are harvested. The method implemented is dependent on the species and the ongrowing system. Wild finfish are harvested by fishermen (Fig. 1) hauling the fish from the water using netting, angling or trapping methods. The catch are placed in dedicated fish boxes whilst by-catch is discarded at sea, where legally permissible to do so (Ringsberg and Mirzabeiki 2014; Gordon and Hussain 2015). Finfish reared in indoor tanks, are graded and transferred to holding tanks before transport to the processing facility. Floating cages are simply lifted out of the water and the stock removed. Land based systems, including tanks, pens, ponds or cages, typically undergo water lowering followed by sweep nets and vacuum pumping (Purser and Forteath 2003). Shellfish in their natural habitat or those cultured on on-bottom culture, are typically harvested by scuba divers or dredging. Shellfish produced in bags or planted on substrate are excavated by rake or hand and collected in mesh bags. Mechanical harvesting, including suction, elevator dredges or a tractor equipped with a lateral conveyor belt, may be used to dig and grade the shellfish (Gosling 2003). Shellfish reared on raft culture are either harvested using a crane to raise the ropes to the boat or by sinking floats under the raft to catch the shellfish once the culture ropes are cut. Those produced from suspended culture using craft of various types are often fitted with mechanical winches which remove and transfer the shellfish to a trailer or inboard containers. Shellfish grown on longlines are harvested by vessels fitted with mini-cranes which raise the heavy shellfish laden longline to a hydraulic stripper to remove and pass the shellfish into a revolving drum for cleaning, de-clumping and sorting into transporting or wholesale sacks ready for landing (Launey et al. 2002). Any weak or damaged shells are discarded (Fig. 2). Re-watering on the substrate in the intertidal zone may be required to excrete mud, grit and sand and to allow recovery from the dredging stress. Crustaceans harvested from the wild or aquaculture involves either trap (creeling) or trawl capture. Baited traps in various forms of cages and baskets are placed in designated areas, inland or along the shore, to catch a wide variety of crustacean species. After capture, the crustaceans are manhandled, removed and placed in a container for sorting and processing before storage (Fig. 3) (Seafish 2005). In trawl capture, cone-shaped nets or pots are towed by boats on the bottom or mid water and hauled up into the vessel where the catch is removed and placed in a container for on-board sorting and processing before storage. When legally permitted, any undersized seafood or by-catch are immediately returned to the sea. Smaller vessels either store their catch in boxes or cages and land daily or underwater until collection from the buyer. Larger vessels store their catch alive in vivier tanks on-board the vessel and land their catch after several days of fishing. Some vessels may have catch handling, packing and freezing capabilities to allow these processes to occur at sea before landing or delivery to a mother ship which lands combined catches from different vessels (Fig. 3) (Farmery et al. 2015).

3.6 Handling and processing

Once the finfish, crustaceans and shellfish have been harvested they are either destined for restocking for angling purposes, aquaculture, animal feed or human consumption. Those species which are destined for angling or aquaculture purposes are checked for quality and disease, before careful transportation to the desired facility (FAO 2016a). Those for human consumption enter a diverse and complex stream of commerce, involving many actors and transit between countries for various stages of processing, combination of lots, and sale of products to customers and consumers (Bakhrankova et al. 2014; Borit and Santos 2015). From this point onwards, seafood from the wild and aquaculture sub-sectors compete in the same market. Seafood is sold live or slaughtered as fresh and value added products.

In the case of wild finfish (Fig. 1) fishermen may undertake gutting at sea and vessels may have handling, packing and freezing capabilities. The catch is transported to a private or public landing in several fishing ports and piers, directly or via a mother-ship. On landing, fish boxes are moved to the quay were the fish is either auctioned in batches or sold individually or as specified in a sales agreement to collectors, auction markets, wholesalers, factory agents, processors, retailers and the final consumer (Fig. 1). For minimal spoiling the head remains but the fish is gutted (if desired), washed, chilled, graded and packed on ice. At this stage, disposition of catch into fresh or frozen markets will depend upon the intended customer demands. Alternatively, fish may progress on for primary processing where they are filleted (often boneless), matched with orders which indicate specific quality demands and sent for outbound transport either as fresh or frozen fillets. Customers can be secondary processors, wholesalers, retailers, restaurants and private customers, nationally or internationally and the order can vary from one to several fish or fish boxes (Fig. 1) (Mai et al. 2011; Donnelly and Olsen 2012; Cuiñas et al. 2014; Parreño-Marchante et al. 2014; FAO 2016a). Marketable shellfish (Fig. 2) is typically washed, cleaned and sorted by the farmer and transported live in the shell to the processing and packing plant. Primary processing includes washing, grading, declumping and debyssing before packaging into bags. Shellfish are routed to depuration plants (if required), fresh markets or sold or transferred for further processing both nationally and internationally. Depuration is required for shellfish harvested in areas with unsatisfactory results and classification in the sanitary survey and on-going strategic water sampling programs (Fig. 2) (Launey et al. 2002; Gosling 2003; BCSGA 2016; FAO 2016a).

Crustaceans (Fig. 3) of commercial significance can be delivered into the food chain as live or raw product, fresh, frozen or cooked. Crustaceans are typically washed, cleaned and weighed immediately after harvest. Those to be sold as live produce are stored in holding tanks, transported and kept moist. In some instances, their limbs are tied to reduce movement and ice bags employed to maintain a low temperature and mortality rate. The live products are typically transported directly to aquarium tanks in restaurants or chilled to a temperature in which they become in-active before export. Those that are intended to be sold fresh, are typically killed in a mixture of water and ice at the pond bank and washed. Crustaceans sold fresh must not be kept on ice for more than three days whereas those frozen must be quick-frozen at -10°C and stored at -18°C or below. Those to be processed are transported in insulated tanks to processing sites where they are cleaned and sorted into various grades to match market and export requirements (Seafish 2005).

Secondary processors implement value-added processing such as breading, battering, smoking, salting or other value added processing and preservation techniques to achieve a store ready product (Denham et al. 2015). Processors require a reliable source of the desired species to meet production and market demands. Such sources may include various auction markets, suppliers and imports of both fresh and frozen seafood. Others may have tighter bonds to the fishermen and farmers through ownership, proprietary unloading facilities or direct purchase (Jensen et al. 2010).

Waste can now derive a value. It is increasingly used in alternative product streams to enhance the efficiency and profitability of a production system. The edible and non-edible parts (e.g. meat, internal organs, blood, and soft tissues) of the slaughtered seafood animal are often sold and used as raw materials for manufacturing novel products such as, fish meal for aquaculture and agriculture, bait, pet food, liquid fertiliser, a source of lactic acid or plastic production, edible products including fish sauce, fish oil, calcium and protein powder, sale of dried fish heads to African markets and sale of fish frames for production of flavour in other fish products. This presents a separate, but linked supply chain (Denham et al. 2015; James et al. 2015).

Following processing, the seafood is stored in cold storage and distributed to customers for national consumption or exported to foreign markets or processors (FAO 2016a). Distributors typically serve as intermediates between processors and sellers, with exporters and importers also acting as distributors (Christensen et al. 2011; FAO 2016a).

3.7 Market

A variety of global customers purchase the seafood produced nationally and internationally. These customers can receive fish at landings or directly from primary processors, secondary processors or wholesalers. Customers include; auction markets, wholesalers, consumers, international or national retail chains and food service companies (Asioli et al. 2014; Avadí et al. 2014). Collectors and auction markets are used for the first hand sales where there is high potential for batch mixing from several fishermen, which is then split among buyers (Jensen et al. 2010). Wholesaler commercial merchants purchase product in bulk from producers, wholesale marketers, primary processors, secondary processors and importers who subsequently subdivide the products and supply retailers and food service establishments nationally and internationally (Kobayashi et al. 2004). Retailers display the store ready product to the consumers in the desired storage cabinets, or as fresh fillet products were the consumer chooses the desired fish before packaging (Kobayashi et al. 2004). These retailers are increasingly dominated by large, centrally managed retailers such as supermarket chains and web-based retailers (Chen 2013). The foodservice customer buy the fish, prepare it and sell it to the end consumer as a component of meals (FAO 2016a). Seafood production is similar for foreign seafood products, with one exception, these products enter the imported country's supply chain through an importer and then move on to a distributor who supplies seafood to landings, wholesalers or processors as either a live, raw, semi-processed or final product for farming, processing or supply to customers and consumers nationally or export internationally (FAO 2016a). The most valuable species that are cultured in the UK are exported (e.g. shellfish and salmon), along with lower value, high volume but nutritious species that are not favoured by UK consumers (e.g. mackerel and herring). These seafood may be exported post-harvest, after primary processing, or following secondary processing as a store ready product. Moreover, seafood may pass through one or more intermediary countries for post-harvest processing and subsequent re-export (Pramod et al. 2014; FAO 2016a).

3.8 Consumers

Consumers mark the end of the seafood supply chain. Local consumers purchase directly from the fisher or farmer. Domestic consumers purchase their seafood from retailers and food service outlets. Foreign consumers purchase their seafood exported from the UK (Kobayashi et al. 2004; FAO 2016a).

By the end of the seafood supply chain, the custody of the product has involved many actors between the fisher, aquaculturist and final consumer. Commonly, these include brokers, traders, wholesalers, distributors and other middlemen, often distant from the consumer and the markets they supply (Schell et al. 2012; Pramod et al. 2014). Each actor carries out diverse and variable operations and functions to achieve a complex range of products distributed nationally and internationally. This global and complex nature of the supply chain has been identified as a risk factor for increased fraudulent opportunity (Warner et al. 2013; Elliott 2014; Foodfraud.org 2016). It is therefore imperative to address this risk by identifying and understanding the types of food fraud and the vulnerable nodes in the supply chain for their occurrence (Table 1). Subsequently, mitigation strategies can be implemented as close as possible to the node of entry (Spink et al. 2016a).

4 Seafood fraud

Seafood fraud is the practice of misleading consumers about their seafood for financial gain. The literature indicates that the seafood supply chain is vulnerable to nine types of fraud, mirroring Young's Seafood Limited's nine sins of seafood (Young's Seafood 2016) which were acknowledged in the Elliott Report (2014). They include; species substitution, fishery substitution, illegal, unreported and unregulated (IUU) substitution; species adulteration, chain of custody abuse; catch method fraud, undeclared product extension, modern day slavery and animal welfare (Fig. 4).

4.1 Species substitution

Species substitution occurs when a superior, high-value species is substituted by an inferior, lower-value species, for example cod by whiting. Inter and intra species substitutions are implemented for economic gain, to satisfy the market demand that cannot be met through legal routes and to evade border controls and high tariffs associated with a particular species (Asensio et al. 2008; Jacquet and Pauly 2008; Ramussen and Morrissey 2008; Mohanty et al. 2013; Johnson 2014; Jennings et al. 2016; Nmfs.noaa.gov 2016). As an example, mislabelling Asian catfish as grouper allowed Sterling Seafood Co-operation to evade over $60million in federal

Table 1 Food fraud vulnerabilities and mitigation strategies at nodes in the seafood supply chain

Node in the Supply Chain	Description	Practices	Purpose	Responsibility
	Illegal, unregulated and under reported substitution ***Consequence:*** *Fishery Sustainability and Economic Deception*			
Source	Illegal capture of the broodstock or seed from the wild and the use of unlicensed or unapproved farmer, capture fisher or vessel	Traceability (origin, health certificates, license details) and Production records	Product Veracity	Internally –Supply chain player
Seed Production	Unlicensed or unapproved hatchery or nursery operations	Verification by Inspection and Auditing – including sub-contractors	System Effectiveness	Regulatory, food quality and safety schemes and customer
Harvesting	Exploit quotas and catches undersized fish; harvesting in areas closed for harvest, illegal harvesting methods, misreporting of catch as lower value species, unlicensed vessels or farms; transhipments to flags of convenience	Import and export controls, random sampling and analytical testing	Product Veracity and System Effectiveness	Regulatory and border controls
Processing	Mixing of legally and illegally sourced fish to meet production demand and increase profits	Delivery checks, acceptance criteria	Product Veracity	Customer
Wholesalers, Middlemen and distributors	Illegal seafood is laundered into the supply chain	Supplier Approval procedures	Product Veracity	Customer
	Species Substitution ***Consequence:*** *Economic deception, Consumer rights and public health threat*			
Harvesting	Fishers or farmers mislabel the seafood	Traceability and production records including any species testing	Product Veracity	Internally - Supply chain players
Processing	Reduces or eliminates the morphological traits used to identify the species allowing superior species to be substituted with inferior species	Food Management System and records	Product Veracity	Internally – Supply chain players
Storage	Intervention and substitution of higher value species with lower value species	Verification by Inspection, Auditing and random sampling with analytical methods	Product Veracity and System Effectiveness	Regulatory, Quality assurance or food safety scheme, customer
Wholesale, middlemen and distributors	Price takers who purchase seafood of a lesser price or intervene whilst in their care to sell as their higher value relatives	Delivery checks, acceptance criteria, analytical testing, supplier approval and mock traceability exercises	Product Veracity and System Effectiveness	Customer
Market - Retailers - Food Service	Mislabel and sell low quality fish as their superior relatives especially in the sale of processed or ready to eat meals which lack the morphological traits	Import and export controls and random sampling and species testing	Product Veracity and System Effectiveness	Regulatory and border controls
	Species Adulteration ***Consequence:*** *Public Health threat, consumer rights and economic deception*			
Seed Production	The use of banned or higher than prescribed additive to achieve superior production of seed	Traceability and Production records	Product Veracity	Internally – supply chain player
On-growing Operations	The use of undeclared, banned or higher than allowed additives to achieve superior growth and quality	Food Management System	Product Veracity	Processor
Processing	The use of non-declared additives or species to a primary processed material to extend the product or introduce a raw material of dubious or prohibited origin, boost appearance and quality	Verification by Inspection including random analytical testing	Product Veracity and System Effectiveness	Regulatory, Food quality or safety schemes, Customers
Wholesale, middlemen and distributors	The use of undeclared or banned additives to extend shelf-life and boost quality	Import and export controls including random sampling and analytical testing	Product Veracity and System Effectiveness	Regulatory and border control
Market - Collector and auction markets	The use of undeclared or banned additives to extend shelf-life and boost quality	Delivery checks, supplier approval and mock traceability exercises	Product Veracity and System Effectiveness	Customer
		Request traceability information and whistleblowing	Product Veracity and System Effectiveness	Consumer
	Modern Day Slavery ***Consequence:*** *Consumer rights and economic deception*			
Source	Employee's rights, wage and working conditions are below the legal requirement. If this activity goes undetected, it deceives the consumer and the reduced expenditure allows financial gain. It is	Employee Policy and Procedure	Product Veracity and System Effectiveness	Supply chain player
Seed production	exacerbated when seafood travels through intermediary countries and is challenging to track.	Contingency Plans, with approved companies for sub-contracted work	Product Veracity and System Effectiveness	Supply chain player
On-growing Operations		Verification by Inspection and Auditing	Product Veracity and System Effectiveness	Regulatory, third party certification scheme or customer
Harvesting Processing Storage		Delivery checks and supplier approval requiring verification of ethical trade	Product Veracity and System Effectiveness	Customer
Wholesale, middlemen and distributors Market		Mock traceability exercises to track the product and verify its routes through regulated and approved companies	System Effectiveness	Customer, regulatory and third party auditors

Table 1 (continued)

Animal Welfare ***Consequence:*** *Economic deception and consumers rights*				
Seed Production and Ongrowing Operations		Traceability, production and storage records	Product Veracity	Supply chain players
Harvesting and Storage	Animals may be subject to conditions which threaten their welfare such as unnecessary pain, injury or suffering or experience unacceptable environments, feeding regime and space	Verification by inspection and auditing	Product Veracity and System Effectiveness	Regulatory, Third party certification scheme, customer
Wholesale, middlemen and distributors to Market		Delivery checks, acceptance criteria and supplier approval	Product Veracity and System Effectiveness	Customer
Fishery Substitution ***Consequence:*** *Economic deception, consumers rights and public health threat*				
Harvesting	Fishers or farmers lie about the origin of the seafood on landing	Traceability, production and distribution records including license details	Product Veracity	Supply chain players
Processing	Mislabel the origin to that of a superior reputation	Food management system and records	Product Veracity	Processor
Wholesale, middlemen and distributors	Intervene, mislabel, advertise and/or sell the seafood to that of a superior value or one which will allows evasion of border controls	Verification by inspection, auditing and analytical methods	Product Veracity and System Effectiveness	Regulatory, food quality and safety schemes, Customer
		Import and export controls including random sampling and analytical testing	Product Veracity and System Effectiveness	Border Control and regulatory
Market - Food Service	Mislabelling or advertising of catch or farm origin to one of a superior reputation	Delivery checks, acceptance criteria, supplier approval and mock traceability exercises	Product Veracity and System Effectiveness	Customer
Chain of Custody Abuse ***Consequence:*** *Economic deception, consumers rights*				
Harvesting	Mixing of product with certificates or origin or documentation during transhipment and the falsification of traceability information	Traceability, production and storage records	Product Veracity	Supply chain player
Processing	Labelling and advertising a product with a premium credence claim of consumer value issues	Food Integrity Management System and records	Product Veracity	Processor
Storage	The mixing of product without certificates of origin or traceability documentation during storage	Verification by Inspection, auditing and mock traceability exercises	Product Veracity and System Effectiveness	Regulatory, Third party auditors or customer
Wholesale, middlemen and distributors	Advertising a product with a premium claim of consumer value issues and mixing product without certification and traceability documentation	Delivery checks, supplier approval and mock traceability exercises with 100% reconciliation	Product Veracity and System Effectiveness	Customer
Market Retailers and Food Service	Advertising and labelling product with credence claims of consumer value	Import and export controls, random sampling and analytical testing	Product Veracity and System Effectiveness	Regulatory and border controls
Catch Method Fraud ***Consequence:*** *Economic deception and consumer's rights*				
Harvesting	Mislabelling the type of production or harvesting method	Licencing, traceability and production records	Product Veracity	Internally – Supply Chain player
Wholesale, middlemen and distributors		Inspection, auditing and random analytical testing	Product Veracity and System Effectiveness	Regulatory, food quality or safety schemes, customer
Market - Collectors and auction - Food Service		Supplier approval, delivery checks, acceptance criteria, approved suppliers list including random analytical testing	Product Veracity and System Effectiveness	Customer
		Request traceability documentation and whistleblowing	System Effectiveness	Consumer
Undeclared product Extension ***Consequence:*** *Economic deception, consumers rights*				
Processing	The use of technology to misrepresent and increase the perceived weight of the seafood content, thus increasing its value	Traceability, production, analytical testing records	Product Veracity	Supply Chain Player
		Verification by inspection auditing and analytical tests	Product Veracity and System Effectiveness	Regulatory, food quality and safety schemes, Customer
		Delivery checks, approved suppliers list and testing	Product Veracity and System Effectiveness	Customer

Table 1 identifies and explains the nodes in the seafood supply chain at which each type of seafood fraud can occur. The current practices for mitigation, purpose and responsibility are also assigned in order to contribute to Food Fraud Mitigation

Fig. 4 The nine sins of seafood involves three separate categories: adulteration including species substitution, adulteration and undeclared product extension; provenance comprising of fishery substitution and chain of custody abuse and ethical trade consisting of illegal, unregulated and under reported substitution, catch method fraud and animal welfare

tariffs and sell over $500,000 of the misbranded fish at four times its typical price (Warner et al. 2013; Lou 2015). Similarly, Lou (2015) revealed how one forensic scientist at the National Oceanographic Atmospheric Administration (NOAA) has seen more than 2,000 disguised catfish fillets and an increasing number of mislabelled species approaching half a million pounds per shipment over his 18 years. Conversely, NOAA has fewer than 100 inspectors throughout the US coastline, a number which continues to decline with diminishing federal funding. Thus only 1% of imported seafood in the US is reportedly inspected for mislabelling, despite the fact that 90% of the imported fish originates from countries with inferior regulations, such as Thailand, Indonesia, China and Vietnam (Lou 2015). It is therefore unsurprising that seafood substitution is reported to be widespread within the global marketplace (Roos et al. 2007; Triantafyllidis et al. 2010; Mohanty et al. 2013; Stamatis et al. 2015; Warner et al. 2016) at rates ranging from 25-50% in broad retail market surveys (Jacquet and Pauly 2008; Wong and Hanner 2008; Buck 2010; Heyden et al. 2010; Hanner et al. 2011; Hellberg and Morrissey 2011; Cawthorn et al. 2012; Warner et al. 2013) and 25-60% in commonly substituted species such as red snapper, wild salmon and Atlantic cod (Marko et al. 2004; Consumer Reports 2006; Miller and Mariani 2010). Oceana released the most comprehensive review of publications on seafood mislabelling. They examined over 200 peer-reviewed journal articles, popular media sources and public documents from governments and NGOs covering 55 countries and over 25,000 samples on every continent except Antarctica (Warner et al. 2016). The review concluded that nearly one in every five samples tested worldwide was mislabelled. Moreover, fraud was found at every level of the seafood supply chain. However the majority of studies (80%) were conducted at the retail level, such as restaurants and grocery stores. In addition, the published research tends to be low in the hierarchy of scientific evidence in terms of how the sampling was undertaken, the sample numbers recruited and the rationale for such investigations. Thus the level of confidence and validity of these figures are questionable and resultant figures reflect the sampling population rather than the entire population. Similarly, a court case requires enforcement officers to proactively recognise and identify the latest seafood fraud in order to bring a batch of species to forensics. An inaccurate suspicion results in wasted lab time and refunds to the importer. In addition, some mislabelling may result from human error in identifying fish or their origin rather than fraud. Nevertheless, the literature indicates substitution exists within the seafood supply chain. This is facilitated by the fact that seafood is a highly traded commodity with a very diverse range of closely related and visually similar species which undergo procedures and processing, reducing or eliminating the morphological traits used for identification, such as heading, filleting or value-added processing (Pineiro et al. 2001; Marko et al. 2004; Chen et al. 2012; Mohanty et al. 2013; Jennings et al. 2016; Tagliavia et al. 2016). This coupled with the fact that seafood has become a limited resource and experiences price pressures, provides a substantial market for substitution and mislabeling within the industry (Jacquet and Pauly 2008; Miller and Mariani 2010; Heyden et al. 2010; Chen et al. 2012; Galal-Khallaf et al. 2014; Hurst et al. 2014; Mueller et al. 2015; Stamatis et al. 2015; Warner et al. 2016).

Worryingly, seafood substitution poses a significant public health threat associated with the exposure to allergenic foods and fish with high toxicity and contaminants in the substituted species (Pascual et al. 2008; Sheth et al. 2010; Triantafyllidis et al. 2010; Chen et al. 2012; Stamatis et al. 2015). One such case involved pufferfish, (*Lagocephalus scleratus*) which contains a potentially deadly neurotoxin, tetrodotoxin, being mislabeled as monkfish to lower the cost of production and evade import and other restrictions (Johnson 2014). However, this mislabeled pufferfish caused paralysis of the respiratory muscles and death in a number of consumers (Noguchi and Arakawa 2008; Islam et al. 2011; Curll 2015; Luekasemsuk et al. 2015). Disturbingly, more than half (58%) of samples substituted for other seafood are with species that pose health risks to consumers (Warner et al. 2016). Consequently, consumers could be unwittingly eating fish that could make them sick. Recent media reports revealed; “Fried Cabbage sold as crispy seaweed” “Crab substituted with seafood sticks”, “Reformed whitefish with very little or no scampi sold as scampi, ” “82% of the 200 grouper, perch and sword fish samples tested in Italy mislabeled,” (Whitworth 2016), “In Brazil, 55% of “shark” were actually large tooth sawfish”, “98% of the 69 Bluefin tuna tested in Brussels restaurants were another species”, “In 2015, a German study found about half of the samples sold as “sole” to be lower value fish upon testing”, “In 2015, a Santa Monica restaurant was charged for selling the endangered sei whale as fatty tuna” (Warner et al. 2016) and, “Restaurant busted for passing off Escolar for white tuna” (Weinsier 2016).

Species substitution can occur at numerous stages throughout the seafood supply chain (Table 1), particularly prevalent in the chain of higher priced fish. It has been associated with fishers who mislabel the seafood and, more commonly, after they are purchased from the fishers by ‘price-takers’. The price for certain fish can be high due to resource scarcity. Therefore distributors, retailers and other final seafood customers (such as fish mongers) often buy fish of a lesser price and illegally sell these fish as their higher value relatives for the sake of increased profits (Jacquet and Pauly 2008). In particular, foodservice companies, e.g. restaurants and takeaways, have been associated with species substitution (Filonzi et al. 2010; Hanner et al. 2011; Miller et al. 2012; Lamendin et al. 2014; Stamatis et al. 2015; Jennings et al. 2016; Warner et al. 2016). In these outlets, the act can go undetected as the prepared dishes lack morphological characters, there is less stringent labelling and the inspections by food control authorities typically focus on samples taken from storage rather than the prepared dishes (Hurst et al. 2014; Kappel and Schroder 2015). Similarly, the availability of processed fish products such as fillets, fish fingers, and other processed foods eliminate the diagnostic traits creating additional opportunities (Mohanty et al. 2013). Moreover, as primary and secondary processed fish is increasingly used as raw materials for novel products, such as protein powder, the modern day supply chain is becoming increasingly opaque and complex and introducing significant challenges to traceability and food safety. This is especially concerning as species substitution at one point along the supply chain can pose health risks that are far-reaching in terms of allergy and toxicity and are potentially untraceable.

4.2 Fishery substitution

Fishery substitution is the substitution of a product from a fishery with a “bad” or inferior reputation to a “good” reputation (Elliott 2014). For example, substituting North Sea Cod for Icelandic Cod which has a better reputation for sustainability and can sell for a superior price or, shellfish harvested from a ‘Class C’ or closed site may be reported as a ‘Class A’ bed to avoid deputation or destruction of stock. This poses a particular public health risk as the substituted shellfish is from polluted waterbodies with high levels of *E. coli.* Fishery Substitution is prohibited in European Regulation, which requires the catch area (if caught) or country of origin (if farmed/cultivated) to be specified (European Commission 2000; European Commission 2001). Its consequences incorporate not only economic deception, industry issues and impacts to consumer rights, but also a public health risk associated with disease, contaminants or toxicity related to the seafood's origin which may go unchecked due to mislabelling. For example, Fukushima (2016) reported an incident were potentially radiation tainted seafood, from the 2011 earthquake and tsunami, was smuggled from Fukushima, Japan into China. The report described how 5,000 tonnes of expensive seafood such as king crabs and scallops, worth a total of 230 million yuan ($34.7million USD) had been illegally imported by a company based in Shandong province and sold across the country over 2 years. Fishery substitution can occur at numerous points along the seafood supply chain similar to species substitution. It can be implemented by the fishers who mislabel the seafood, but more commonly after purchase by distributors, middlemen and food service companies. This method of fraud is commonly used to avoid foreign duties when foreign producers may ship seafood products en route to the UK through a third country to avoid import duties and regulatory controls (e.g. import alerts) by labelling the product's country of origin as the third country.

4.3 Illegal, unreported and unregulated (IUU) substitution

Illegal, unreported and unregulated substitution includes seafood which has been farmed or caught over quota or in areas closed for harvest, the harvesting of undersized fish, the illegal setting of traps, the misreporting of catch as lower value species (e.g. pink salmon reported as chum salmon) and the use of unlicensed vessels or farms (Borit and Olsen 2012; Pramod et al. 2014). This fraudulent activity allows brokers to enhance profits and amalgamate supplies from different sources to achieve their orders in a fully exploited and limited resource market (Gayo and Hale 2007; Pramod et al. 2014). It has been described as "of serious and increasing concern" (FAO 2001; Borit and Olsen 2012), with 10% of the total value of fish and fish product imports to the European Union estimated to originate from IUU fishing (Borit and Olsen 2012). IUU fishing is facilitated by nations that provide flags of convenience, relaxed import and export regulations, the thousands of fishing boats which employ fishing practices that would be illegal in their home nations and the lack of transparency and traceability when supplies are consolidated during trans-shipping and sold at sea. Consequently, even products carrying a traceability package, may potentially derive from mixed shipments with mixed species fished by a mix of licensed and blacklisted vessels (Jacquet and Pauly 2008; Borit and Olsen 2012). These traceability issues are exacerbated when companies own fishing vessels in another country and register it under a different national company or flag (Pramod et al. 2014). Additionally, the global nature of the supply chain where products are transported through one or more intermediary countries for post-harvest processing and subsequent re-export provides multiple opportunities for the mixing of legally and illegally sourced fish, where the illegals are essentially 'laundered' in the processing countries and subsequently enter international trade as a 'legal' product of the exporting nation (Pramod et al. 2014). For example, many Russian vessels are reported to illegally overharvest crab or capture crab by vessels without a quota share or license. They then transship these catches to flags of convenience or switch off their vehicle management system and land the illegal crab in Japan or Korea, were it is processed and consumed, or provided with counterfeit Certificates of Origin and Health. The crab is then shipped to China for repackaging (sometimes including re-processing), where it may be mixed with legal crab, before export. The fraud goes undetected due to false documentation, repacking and obfuscation of traceability (Pramod et al. 2014). Since 2001, the European Union has introduced legal provisions and funded research aimed at tracing seafood and mitigating against IUU fishing. In 2008, they enhanced legislation and stipulated catch documentation requirements for all imported and exported seafood, a third country carding process that imposes import restrictions on countries that are not actively addressing IUU fishing, and, penalties for EU nationals who engage or support IUU fishing around the world. Additional provisions went into effect in 2012 and 2014 which required even more stringent traceability and mandatory labelling requirements from catch or harvest to the retail level. A preliminary analysis of studies on seafood fraud carried out before and after this legislation has indicated that rates of fraud have decreased (Warner et al. 2016). While these provisions have increased fisheries' control and transparency of seafood information, the limitations of the data prevent any definitive conclusion and certain weaknesses in the scope, implementation and information available to consumers means the opportunity for IUU fishing remain. For example, certain seafood are exempt from provisions: most processed or prepared food (i.e. cooked, steamed, breaded, fried or marinated), several types of aquatic invertebrates (e.g. jelly fish) and canned seafood. Also excluded from the legislation is the food service sector of the supply chain (e.g. restaurants, takeaway, schools and catering enterprises). These are all points in the seafood supply chain where fraud incidents are prevalent (Warner et al. 2016). In addition, some studies did not show markedly lower mislabeling rates even in places and for products covered by EU provisions.

Ultimately, IUU supplies can enter the seafood supply chain where there is a lack of transparency and accountability.

These gaps in the system occur at sea during fishing, harvesting or trans-shipment operations, where the fisherman's activities are restricted by quotas and other regulations and, where monitoring and surveillance remain inadequate; in ports at landing, where systems to document catch landings are often non-transparent, and; in onshore distribution chains and market countries, where the seafood is mixed in crates incorporating fish from different vessels and catches. This is exacerbated in distribution chains and countries which lack effective traceability and proof of origin systems, such as China, Japan and Canada which are major seafood exporters and importers (Jacquet and Pauly 2008; Borit and Olsen 2012). The sustained opportunity for IUU substitution is particularly concerning in the seafood industry as it depletes global stocks, destroys marine habitats, distorts competition, and threatens communities that depend on seafood for food and the livelihoods of legitimate fishermen (Borit and Olsen 2012; Pramod et al. 2014).

4.4 Species adulteration

Species adulteration is the addition of a non-declared, non-specified species to a primary processed raw material, e.g. adding a lower value species such as Coley or Saithe to high value frozen block of Atlantic Cod or the wrong types of prawn to adulterate and extend a scampi core. The motivation for this type of seafood fraud is exploitation of the considerable price difference between different species, or to introduce a raw material of dubious or prohibited origin into the supply chain. Seafood can be adulterated with additives and chemicals such as fertilizers, pesticides, antibiotics, hormones, veterinary drugs, colorants and preservatives to increase either production or food quality or 'hide' other types of seafood fraud (Zhang and Cai 2006; Mohanty et al. 2013; Ortega et al. 2014; Rahman et al. 2016). The presence of these compounds may have detrimental effects on human health (Mohanty et al. 2013). For example, Malachite green (and methylene blue) are not permitted veterinary treatments but are reportedly used illegally as effective and low cost anti-fungal agents in fresh water systems (Mohanty et al. 2013; Ortega et al. 2014). Prolonged consumption can cause inflammation, ulceration and necrosis of the linings of the mouth, throat and gastrointestinal tract and may cause cancers and other conditions e.g. childhood asthma and skin diseases with chronic exposure (Wooster et al. 2005; Tang et al. 2009; Rahman et al. 2016). In Italy, bleaching seafood in a mixture of water and hydrogen peroxide to make fish seem whiter, fresher and more attractive to the consumer has been reported, yet it's a violation of EU law (TheLocal 2016).

Species adulteration has been reported throughout the supply chain, particularly on the farm during primary production, processing and handling stages and during transport (Gale and Buzby 2009; Mohanty et al. 2013; Ortega et al. 2014).

4.5 Chain of custody abuse

Chain of custody is the chronological documentation which states the seizure, custody, control, transfer, analysis and disposition of evidence. This documentation is required as part of traceability procedures and certification processes (e.g. eco-labels or Marine Council Stewardship certification) (Borit and Olsen 2012; Miret-Pastor et al. 2014; Pramod et al. 2014). The falsification of this documentation allows financial gain from premium "credence claims" of "consumer value issues" such as, farming systems, species, and provenance claims on the packaging of seafood of a lesser purported value (Mohanty et al. 2013; Pramod et al. 2014; Curll 2015). There is a sustained opportunity for chain of custody abuse due to the global and complex nature of the seafood chain, comprised of many actors and activities ranging from fishers and aqua-culturists, transhipments, distributors, warehouse owners, wholesalers, retailers, brokers, large trading companies in different countries, and, others, all capable of abusing and tampering with the traceability documentation (Pramod et al. 2014). This has overwhelmed regulatory authorities and made sharing of information through the supply chain inconsistent and difficult (Yasuda and Bowen 2006). Even information on coastal harvesting environments is largely unaddressed, with the exception of shellfish. Import health authorities, food safety officers or customs authorities do not have full access to information pertaining to the origins, trans-shipment points and activities associated with the product. This limited communication between regulatory authorities at multiple independent inspection points allows less precise information about the background of the products further along the chain, with the end consumer knowing very little (Pramod et al. 2014; Yasuda and Bowen 2006). Record keeping can be time-consuming, challenging and beyond the skills of the individuals involved relying on methods and technologies that have remain unchanged for decades. Consequently, the ability to effectively and reliably trace consignments of seafood throughout all supply chains in a consistent manner is challenging (Charlebois et al. 2014; Ringsberg 2014; Leal et al. 2015; D'Amico et al. 2016). Incidences of chain of custody abuse have been reported. For example Chien-hua and Chung (2016) reported how a Kaohsiung seafood firm sold NT$700m (US $21.83million) of expired products in the past three years to restaurants and traditional markets in Taiwan by removing expiry dates from packaging and re-shelling old shrimp to mask the freshness. In another report by Chen and Chao-fu (2016) over 51 tonnes of expired, unlabelled and frozen soft-shell shrimp, squid and lumpfish were seized from two companies by Kaohsiung authorities.

4.6 Catch method fraud

Catch method fraud involves the mislabelling or advertising of the type of production or harvesting method to increase the financial return. For example, line caught fish attract a higher market value than trawled fish so may be mislabelled to achieve a higher market price. Likewise, the consumer views the 'wild' species as a superior standard than the farmed species, attracting a higher price. A UK study involving 100 samples from retailers, identified that 15% of 'wild' salmon, 11% of 'wild' sea bream and 10% of 'wild' sea bass were actually farmed and not wild as claimed (Jacquet and Pauly 2008). This fraudulent activity is commonly performed at the processing and manufacturing supply chain stages by agents, middlemen or final retail customer before sale to the consumer.

4.7 Undeclared product extension

Undeclared product extension involves the use of technology by processors to increase the perceived weight of the seafood content and thus the economic return. Typical practices include: over treating, (e.g. over-breading or over-glazing), soaking fish in a brine solution, injecting undeclared chemical additives to increase the muscles water holding capacity, or injection of fish by-products (minced up and blended) back into the fillet to bring up the weight (Jennings et al. 2016). Undeclared product extension has been reported as a common practice, which may pose a public health threat (Nmfs.noaa.gov 2016). For example, in China there have been reports of the injection of gelatin like chemicals, derived from animal skins and bones, into prawns and shrimp. The chemicals resemble their natural colour and increase the weight by 20-30% and allow wholesalers to increase their price. This subjects the consumer to uncertain health threats associated with long-term ingestion of unknown chemicals and industrial substances in this economic fraud (Wu et al. 2013).

4.8 Modern Day Slavery

Modern day slavery is a crime which describes a situation when someone is forced to work by ownership or control of an 'employer' through mental or physical threat or abuse, dehumanised when treated as a commodity or physically constrained on freedom of movement (Antislavery.org 2016; Modern Slavery Act 2015). It is illegal in all countries throughout the world. Food produced using high standards of human welfare is considered a quality attribute by consumers, enhancing brand reputation, competitive advantage and price premium. Therefore, fraudulent claims and undetected modern day slavery in the food supply chain deceives the consumer and allows financial gain from the reduced expenditure on wages and health and safety procedures. Worryingly, the scale of hidden human exploitation is significant and involves thousands of people internationally, some supply chains of which are known to support UK consumption (Elliott 2014). In particular, the seafood supply chain has been accused of exhibiting modern day slavery and exposure of employees to a greater risk of injury, death and human right abuses compared to other jobs (Ratner et al. 2014; Couper et al. 2015; Jennings et al. 2016). For instance, Roberts et al. (2010), reported 1039 fatalities from 1948 to 2008 on UK fishing vessels which were unstable, overloaded and unseaworthy. Another report described how 23 out of 38 illegal immigrants from China died in Morecambe Bay in 2004 when drowned by a rising tide whilst collecting cockles (*Cerastoderma edule,* Cardiidae) due to an employer motivated by avarice and minimal regard for employee safety (Jennings et al. 2016). In 2012, the UK Serious and Organised Crime Agency (SOCA) reported 74 potential victims of illegal, bonded and forced labour in fisheries (SOCA 2013) through abuse of an immigration concession (transit visas) for seamen to facilitate the potential victims' entry into the UK. A subsequent report noted that fishermen continue to find employment in the UK via agencies in the Philippines and Ghana, but are not paid the originally contracted wages and experience poor working conditions on arrival (National Crime Agency 2014). Furthermore, raids by SOCA in both England and Scotland have led to at least 50 exploited fishermen being freed from fishing boats. The aquaculture sector has been described as a safer occupation than working in wild capture, but the relative fatality rates are still high with 5 fatal accidents from 2003 to 2013 in the Scottish aquaculture industry (Health and Safety Executive 2014). The complex and internationalised nature of the seafood supply chains makes it particularly difficult to track a component to an end product of a particular producer, and hence, challenging to certify social welfare and ethics (Antislavery.org 2016). Abuse of human welfare is more likely to occur when customers give their supplier a large order with a short turn around beyond their capacity, forcing the supplier to subcontract work to factories or workers that are not regulated by the same standards. When buyers negotiate such low prices there is an increased likelihood of suppliers to reduce the price it pays for materials, production and wages, encouraging the use of forced labour. Consequently, a number of government and independent initiatives have developed standards to promote responsible supply chain activities, particularly, labour rights, health and safety, the environment and business ethics (Modern Slavery Act 2015; Ethical Trading Initiative 2016; Jennings et al. 2016; Marine Stewardship Council 2016; Seafish 2016). Ultimately, companies should assume responsibility and actively ensure no forced labour has been used throughout the supply chain of their retail products.

4.9 Animal welfare

Food authenticity experts have revealed a "new unconventional fraud" relating to the sale of food with valuable animal welfare marketing claims, such as "Animal Friendly" (Curll 2015; ScienceDaily 2016). For many consumers, animal welfare is an important aspect relating to their food choice. This offers an opportunity for competitive advantage and increased market value. However, it can be challenging to standardise and prove a seafood product has experienced all the requirements for welfare, including a suitable environment and diet, to exhibit normal behaviour patterns and be housed with or apart from other animals, and to be protected from unnecessary pain, injury, suffering and disease (Jennings et al. 2016). Therefore animal welfare of seafood can be undermined at any stage in the supply chain from primary production to its slaughter.

In the wild capture fisheries, welfare becomes an issue from the moment the fish encounter the fishing gear. Animals either die as a consequence of the harvesting process (Metcalfe 2009) or, enter the fishing vessel alive, especially in the case of high-value fish and where flesh quality is of primary concern. The time to death can vary from minutes to hours to days and each animal can experience different gear specific trauma (Jennings et al. 2016). During harvesting, some fish may escape or be discarded at sea. For those not already dead, they may subsequently die from trauma or predation, while others may recover and survive (Jennings et al. 2016). Though nothing is known about sub-lethal effects on growth, predation and reproduction of these fish.

In aquaculture, welfare is an issue throughout the supply chain, to the point of slaughter. Stocking density, water quality, diet, feeding techniques, husbandry practices and management procedures all affect welfare prior to death (Boujard et al. 2002; Ashley 2007; Jennings et al. 2016). Recently, more humane slaughter methods have been utilised for fish. For example, automated percussive systems or electric stunning systems have been developed to stun fish immediately allowing them to die without regaining consciousness (Robb and Kestin 2002; Lines et al. 2003; Jennings et al. 2016). As with fish, crustaceans, are thought to encounter uncomfortable experiences during their capture and death, particularly during their live storage and transport. Similar techniques, such as electric stunning prior to processing have been used to reduce unnecessary abuse to their welfare (Elwood et al. 2009; Neil 2010; Roth and Oines 2010; Jennings et al. 2016).

Ultimately, seafood species from aquaculture or wild fisheries may be exposed to unnecessary pain through their environment, capture, harvest, transport and slaughter. Similarly, welfare claims may be used as a tactical marketing ploy to gain from the good publicity of the labelling. For example, Brown (2005) exposed one distinct case were canned tuna was labelled as 'dolphin-safe' despite the fact that the species, skipjack tuna, is not implicated in the dolphin by-catch problem. This is misleading to the consumer and relates to current concerns regarding transparent labelling. Ultimately, the current regulation is limiting in terms of how fish are handled or killed or what constitutes as acceptable animal welfare standards and labelling. The current trends in public attitudes to human and animal welfare suggest that these issues relating to seafood welfare are likely to become more visible in the UK. Moreover, it is evident that active certification schemes are targeting such ethical issues (Jennings et al. 2016).

5 Current status

Seafood fraud remains a serious problem. Every node in the supply chain offers an opportunity for one or more of the nine sins of seafood (Table 1). Each of these sins encompass economic, sustainability, consumer choice and/or public health consequences. It is imperative these fraudulent opportunities are considered in food management procedures. The increasing complexity of the supply chain requires more robust measures in terms of auditing, traceability and testing in order to protect the supply chain and its consumers (Folinas et al. 2006; Ringsberg 2014; Lidskog et al. 2015; Black et al. 2016). The United Kingdom (UK) has recognised these food fraud issues. To date in the UK there have been limited high profile media reports, research publications and public health incidents related to seafood fraud. Nonetheless, there is a strong commitment from the industry and government to improve the integrity and assurance of food supply networks and a determination to protect UK consumers. This commitment is reinforced by the government funded review of the food supply chain which states that "UK consumers have access to perhaps the safest food in the world" and provides recommendations for the UK government to address Food Fraud (Elliott 2014; Spink et al. 2016b). Likewise, the European Commission has been addressing Food Fraud within the Food Integrity focus areas (European Parliament 2013). The Commission has instigated preventative initiatives, including the Food Fraud Network of Government agencies sharing information and intelligence on incidents, the expansion of the Rapid Alert System for Food and Feed (RASSF) for food recall to include "adulteration and fraud" and a 12 million Euro Food Integrity Project (Spink et al. 2016b). In addition, there is a range of industry and non-government activities relating to food fraud continuing to surface such as GFSI and BRC which require food fraud vulnerability assessment as part of their food management standards. However, there is no room for complacency. The implementation of these networks and increased focus on fraudulent opportunities and inspection of practices has uncovered incidences in other meat sectors such as the poultry sector in the UK with the recent unveiling of events occurring within the 2 Sisters Food Group. Therefore, although the UK reputation is promising, it does not mean seafood fraud does not exist in the supply chain. It may be the result of data limitations and insufficient testing. Moreover, the opportunities, which continue to exist, mean the UK supply is still vulnerable to food fraud and its consequences, particularly economic costs. It is therefore imperative to construct and instigate a mitigation plan which deters food fraud to protect the UK's reputation for food safety and to promote the interests of honest and hardworking food businesses (Elliott 2014).

6 Food fraud mitigation

In order to mitigate food fraud there is a need to examine motivation and opportunity. The factors that influence fraudulent opportunity have included, pressure, differentiated into personal (individual e.g. financial or social pressure), employment (corporate or management derived pressure) and external pressure (business or stakeholder pressure to incur financial return, social environmental and market price pressure) (Gbegi and Adebisi 2013; Kleboth et al. 2016); opportunity to commit fraud, influenced by the extent of formal control systems (countermeasures) and/or the potential for weaknesses or gaps in the business network (Gbegi and Adebisi 2013; Tähkäpää et al. 2015; Kleboth et al. 2016; Manning et al. 2016); rationalisation, the ability of the individual to assess their behaviour as acceptable, if excusable to themselves or others (Gbegi and Adebisi 2013; Kleboth et al. 2016; Manning et al. 2016; TiFSiP 2016), the lack of a strong deterrent i.e. penalties (Tähkäpää et al. 2015; Manning et al. 2016; TiFSiP 2016); capability, the power or ability to undertake the fraud (Wolfe and Hermanson 2004; Gbegi and Adebisi 2013), the motivation or benefit of undertaking the fraud (e.g. guaranteed economic benefit) (Canter 2000; Williams 2001; Dennis and Kelly 2013; Smith and Laing 2013; Spink et al. 2013; Elliott 2014; Spink et al. 2014; Tähkäpää et al. 2015; Manning et al. 2016), and the personal integrity or category of offender (Canter 2000; Williams 2001; Smith and Laing 2013; Spink et al. 2013, 2014; Manning et al. 2016). A number of academics have attempted to construct models to illustrate these factors. Spink and Moyer (2011) used the crime triangle consisting of the victim, the guardian and the hurdle gaps as the three elements of fraud. Gbegi and Adebisi (2013) defined the factors for fraud using the fraud triangle consisting of pressure, opportunity and rationalisation. Wolfe and Hermanson (2004) suggested the fraud diamond model consisting of capability, opportunity, realisation and pressure. Gbegi and Adebisi (2013) modified this to capability, opportunity, rationalisation and pressure and Kleboth et al. (2016) advanced this again to capability, opportunity, motivation and personal integrity. The overarching theme revealed from this literature is that fraud takes place because the dishonest minority exploit process and system vulnerabilities. Therefore, good practice involves reducing the number of opportunities this dishonest minority can exploit (TiFSiP 2016; Spink et al. 2016a). Similarly, the literature proposes various methods to achieve this. These fall under the themes of 'practices', 'evidence', 'awareness and targeted education' and 'governance'. These factors, models and mitigation strategies suggested in the literature have informed the basis of the

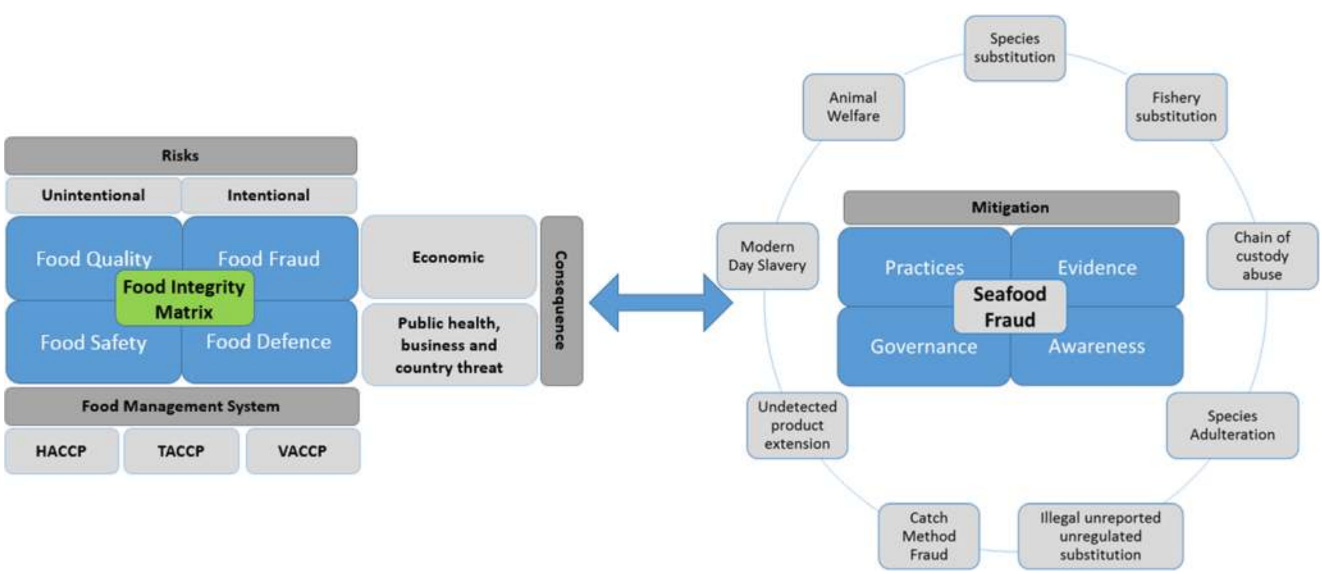

Fig. 5 The food integrity matrix interlinked to the nine sins of seafood fraud and key categories for mitigation. Food integrity is threatened by four elements; unintentional food quality and safety issues and intentional food defense and fraud incidents. These are stand-alone entities by definition but interlink as they create uncertainties to each of the other elements. A food integrity management system consisting of HACCP, VACCP and TACCP will help identify the critical control points to assure food integrity. The matrix is integrated with the nine sins of seafood and the key categories of practices, evidence gathering, awareness and governance crucial for mitigation

conceptual model to address seafood fraud developed in this study (Fig. 5).

6.1 Practices

Food fraud can be prevented by making food production, manufacture, retail and food service environments hostile and difficult for the offender to operate in (NFCU 2016). In order to achieve this, practices, also known as countermeasures, are assigned to the production process and supply chain for detection and deterrence. In order to assign practices a risk-based approach is advocated by private label owners (e.g. BRC, IFS and FSSC 22000), international institutions (e.g. FAO) and EU legislation (European Commission 2007 (No. 834/2007); EU Regulation 178/2002; European Union 2014). This risk-based approach is advantageous as it concentrates resources on the critical points in the food chain, which pose the highest risk (FAO 2016b; Kleboth et al. 2016). However, this approach has also been criticised for its reactive nature, focusing on historic or existing knowledge. The literature expresses the need to predict important medium-long term issues to allow effective preventative action (FAO 2016b; Kleboth et al. 2016). In response, research publications (Lalonde and Boiral 2012; Aven 2016; Kleboth et al. 2016; Marvin et al. 2016; Spink et al. 2016b), government and regulatory guidance (FAO 2016b; PAS 96 2014; SSAFE 2015; FSA 2016; NSF International 2014; TiFSiP 2016; USP 2014) and international standards (e.g. BRC and COSO) provide guidance on the steps to eliminate these opportunities. A synthesis of these methodologies reveal themes which coincide with the stages in the vulnerability analysis critical control point (VACCP) tool i.e. intelligence gathering, preliminary steps, vulnerability assessment, mitigation strategies, monitoring, verification and responsibility. This VACCP approach, is advocated in numerous scientific publications, government and industry reports (Curll 2015), Foodfraud.msu.org (2016), The food fraud think tank and the Global Food Safety Initiative (GFSI) Position paper on food fraud (GFSI 2014) and the British Retail Consortium (BRC) Global Standard for Food Safety version 7 (BRC 2015). This tactic is advantageous as it is based on fundamental criminology and crime scene theories, whereby the focus is on reducing the opportunity rather than the numerous types of fraud, and offending personnel and organizations (Spink et al. 2016a). Moreover, it is based on the already internationally accepted hazard analysis and critical control point (HACCP) concept, but introduces the term vulnerability to food control. It allows the industry to understand the fraudulent opportunity and how it manifests itself and reduces loss and enhances business image to customers. VACCP also supports the work of the National Food Crime Unit in England, Wales and Northern Ireland, and allows businesses to alert the unit to identified issues, which require an enforcement response. Moreover, it creates a culture where staff are aware of the increased vigilance to fraudulent activity and gives them the confidence to report suspicions of wrongdoing (Powell et al. 2013; TiFSiP 2016). Threat analysis critical control point (TACCP) is another risk-based tool advocated in the literature for food fraud. However, this is a tool for addressing intentional food offence issues carried out for malicious purposes, not food fraud carried out for economic gain. It is therefore evident that academia and the industry need clarity on the categorisation of the factors influencing food integrity and the proposed risk assessment tools. The proposed food integrity matrix (Fig. 5) addresses this confusion and illustrates that food fraud, offence, quality and safety are the four factors which affect food integrity. Food quality and safety factors are the unintentional biological, chemical and physical hazards to food quality and safety addressed by HACCP. Food offence is an intentional threat to food safety and quality for malicious purposes addressed by TACCP. Food Fraud is an intentional act for economic gain, which could lead to a food quality or safety incident, addressed by VACCP. Whilst each of these factors are stand-alone entities by definition and motivation, they are integrated as they each compromise food integrity and create uncertainties to the other three factors. Moreover, their consequences and methods for detection and mitigation include similar aspects. This is illustrated in the numerous examples of food fraud incidents, which create food quality and food safety repercussions.

Ultimately, a food integrity management system comprising of HACCP, VACCP and TACCP is crucial to help the industry assign countermeasures which protect food safety, quality, authenticity and security issues and achieve consumer trust in the food industry (Kleboth et al. 2016; Jenson and Sumner 2012; Jevsnik et al. 2008; Papademas and Bintsis 2010; Powell et al. 2013;Ramsingh 2014). Recently, Kleboth et al. (2016) carried out a similar review of the food fraud literature. This literature proposed complex system risk-based auditing, which is a function of triggers, goal, context, food chain participant, time, methodology and content. These stages are all involved in the VACCP procedure, and thus would involve unnecessary duplication or change to current industry certification schemes. Moreover, it does not recognise the need for evidence gathering and targeted education and awareness. However, the proposed framework (Fig. 5) is a promising initiative for regulatory and third party certification schemes to address current audit limitations.

6.2 Evidence

Food Fraud VACCP, although a similar concept to HACCP, is fundamentally different. For HACCP very capable practices and governance already exist, but the ever evolving and emerging nature of opportunistic fraud introduces new VACCP gaps (TiFSiP 2016; Manning et al. 2016). There has been a range of different detection methods applied to food authenticity, including spectroscopy (ultraviolet-visible (UV), near infrared (NIR) and mid infrared (MIR), Raman), isotopic analysis, chromatography, electric nose, polymerase chain reaction, enzyme-linked immunosorbent assay and thermal analysis, and their combination with multivariate data analysis software (Reid et al. 2006; Ellis et al. 2012; Black et al. 2016). These methods must be evaluated in full for ease of use, rapidity and cost whilst surviving the rigours of a legal process to provide a sufficient deterrent (Black et al. 2016). Similarly, the literature and the persistence of food-borne illnesses and scandals has raised significant concern on the functioning of the supply chain and the monitoring methods employed for their supervision, particularly exposing weaknesses in current traceability and audit systems (Folinas et al. 2006; Aven 2012; Powell et al. 2013; FAO 2016b; Ringsberg 2014; Lidskog et al. 2015; NFCU 2016; Stamatis et al. 2015; Kleboth et al. 2016; Manning et al. 2016). A preliminary review of the data suggests that the underlying cause of such events is shortcomings in audits, enforcement and current countermeasures within the industry, as opposed to the HACCP, VACCP and TACCP tools. It is also important to recognise that the advancement of detection and research efforts in the supply chain have contributed to the increased uncovering of 'scandals', which have potentially existed for decades. Nevertheless, this exposes a significant flaw in current research efforts. The literature continues to identify weaknesses and develop and propose enhanced methods of detection. However academia, industry experts and policy makers have failed to collaborate and take the responsibility to evaluate this research, allocate acceptable and economically viable analytical methods and mitigation strategies and standardise definitions and methodologies for the supply chain. Thus, the research has limited benefit to the industry and has failed to achieve a sufficient deterrent to diminish fraudulent opportunity. The nature of food fraud and current information gaps makes evaluating and assigning effective and efficient countermeasures one of the most challenging aspects of assuring food integrity. Thus, a task force or working group, such as funding academic institutions to support a public-private partnership which addresses food fraud, is imperative. The working group should conduct research and gather evidence on the factors affecting food fraud, including the macro-economic trends (such as global commodity price fluctuations), the micro-economic factors (such as vulnerability of a product transported through an unregulated free trade zone), suitable countermeasures, the resources and ongoing activities in the country and the category of offenders and their modus operandi (such as identifying sequences, settings, and how the activity fits into supply chain networks) (Canter 2000; Williams 2001; Felson 2006; Spink et al. 2013; PAS 96 2014; Spink et al. 2014; Manning et al. 2016; Spink et al. 2016a). Ultimately, this research is fundamental to contributing to a governance plan which considers a balance between resources, constraints, including inspection and oversight, as well as optimizing the public and private activities (Spink et al. 2016b).

6.3 Awareness and targeted education

The UK has been proactive in recognising and funding research into food fraud. To date this work has been typically carried out by a working group of academia and industry experts. However, it is crucial that the supply chain players are informed of known intelligence and verified methodologies. The provision of targeted education should be used as a means of raising awareness and informing the industry of the issues in the seafood supply chain and ensuring they are competent in assigning and implementing effective and economically viable countermeasures. This is vital as it has been suggested that many actors are unable to fully understand the complexity of the supply chain, in all its facets, disciplines and developments. Consequently straightforward and insufficient mechanisms of control are introduced (Kleboth et al. 2016). In addition, Williams (2001) argues that bureaucratic rivalry and competition; inter-agency antipathies and; a hesitance to share information, align databases and coordinate operations constrains current practices. Information sharing would allow the government to understand and construct enhanced legislation, inspection and enforcement and allocate sufficient resources and support to the industry to equip them with the skills to implement VACCP optimally. Eventually, the increased awareness and uptake of prevention, surveillance and detection measures would encourage a food safety culture, increase the apprehension of 'getting caught' and act as a deterrence.

6.4 Governance

It can be challenging to govern food fraud as it can be implemented internally and externally in a specific company and/or its subsidiaries at any node of the supply chain. Moreover, in many cases small-medium enterprises cannot perform or afford the reliable and high specification technology to detect and gather evidence of conventional adulterants, as described previously (Reid et al. 2006; Ellis et al. 2012; Black et al. 2016). It is therefore of utmost importance that deterrence of food fraud is implemented by each player in the supply chain and verified and governed by suitable guardians such as regulatory bodies and recognised third party certification schemes. In order to facilitate this, a government wide food prevention plan needs to be constructed. This plan needs to ensure a food fraud responsibility and food integrity management system, comprising HACCP, TACCP and VACCP, that is defined and required in legislation, specifically under existing food regulations (Spink et al. 2016a). It should include mapping of the whole supply chain, provide identification of the vulnerabilities and allocate monitoring and mitigation strategies, resources and responsibility (TiFSiP 2016). This clarity is fundamental in order to assign responsibility and accountability to each enterprise in the supply chain, stipulate the required standards and identify the critical points which inspection and enforcement officers should evaluate and verify against a standard and prosecute as necessary. Ultimately, the goal of this mitigation plan is to proactively reduce the opportunity for fraud. However, this is still a relatively new concept for the industry and those carrying out fraud may continue to find new opportunities and methods to intervene. In this case, detection, enforcement, prosecution and punishment become important elements to further reduce the opportunity (Spink and Moyer 2014).

7 Conclusion

Combatting food fraud is an integral component of ensuring food integrity. It is important to ensure the sustainability of the food industry and responsible enterprises in the supply chain, to allow consumers' rights and confidence in food production and to eliminate any uncertainties regarding consumer health. This review has mapped the seafood supply chains, identified the opportunities for the nine sins of seafood at each node and revealed examples of fraud, which have occurred in the seafood supply chains. The examples used are only a sample of the issues, which have occurred within the seafood supply chains but they highlight the extensive difficulties encountered by fraud specialists (analysts). The next stage is for stakeholders, including academia, analytical laboratories, regulatory bodies and industry to investigate these seafood supply chains and work together to evaluate and allocate effective, economically viable and standardised mitigation strategies. This review has led to some key future recommendations whereby it will be important to carry out sound risk ranking on the vulnerability of the seafood supply chains to fraud; to assign effective economically viable mitigation strategies at critical control points; to evaluate current and innovative detection methods for the authenticity of food; to work towards robust, easy to use, rapid and inexpensive analytical techniques which would be upheld in legal proceedings; to construct a governing plan which considers a balance between resources and constraints and assigns responsibility and accountability to each supply chain player and guardian; to implement targeted education to the supply chain players and equip them with the knowledge to implement HACCP, VACCP and TACCP optimally; to work together to address the challenges of current traceability practices in the increasingly complex and global supply chains. This review illustrates the fundamental first steps to be undertaken for all food commodities in understanding the nodes of vulnerability to food fraud for the introduction of effective risk ranking and mitigation strategies.

Compliance with ethical standards

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