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Improved traceability in seafood supply chains is achievable by minimising vulnerable nodes in processing and distribution networks

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ABSTRACT

Seafood is a globally traded commodity, often involving complex supply chains which have varying degrees of traceability. A robust traceability system for seafood supply chains enables the collection and communication of key information about catch and fisheries origins vital for assurance of the legality and sustainability of seafood products. End-to-end traceability is increasingly demanded by retailers, consumers, NGOs and regulatory bodies to ensure food safety, deter IUU fishing and verify sustainable and ethical credentials. Here, we map three UK seafood supply chains and evaluate traceability performance in: Dover sole landed in the south west of England, North-East Atlantic (NEA) mackerel landed at Peterhead, Scotland, and brown crab and European lobster, landed at Bridlington, England. Through a comparative analysis of traceability performance, this study suggests improvements to the technologies, processes, and systems for traceability in the seafood sector. The application of monitoring technologies and regulatory changes across the sector have increased traceability and potentially reduced instances of IUU fishing. While shorter supply chains are more likely to achieve end-to-end traceability, vulnerable nodes in processing and distribution networks may result in a loss of seafood traceability. While traceability systems may provide sustainability information on seafood, a high level of traceability performance does not necessarily equate to a sustainable source fishery. Encouragingly, while UK seafood supply chains are meeting minimum regulatory requirements for traceability, in the present study, many stakeholders have indicated ambitions towards traceability best practice in order to provide confidence and trust in the UK fishing industry.

1. Introduction

Seafood is a globally traded commodity and one of the most highly internationally traded food items [5,19,53]. Globalisation has resulted in large transnational companies increasing consolidation and vertical integration across supply chains from production through to retail [19, 46]. Yet for seafood products, supply chains generally consist of multiple nodes (i.e. a distinct organisation that is involved in producing and/or distribution [16]), with varying degrees of product processing and amalgamation prior to final sale [16,63]. As complexity in the supply chain and the number of nodes increases, end-to-end traceability, tracking seafood product from origin to consumer, is increasingly difficult [33]. Traceability in seafood supply chains is essential for ensuring food safety, proving legality of products, tackling Illegal, Unregulated and Unreported (IUU) fishing, and verifying sustainability [7]. A lack of traceability creates conditions in which fraud, mislabelling, IUU fishing and human rights violations can occur regularly [3,33,65].

Governments have a mandate under the Sustainable Development Goals (SDGs), in indicator 14.4 to effectively regulate harvesting, end overfishing, IUU and destructive fishing [48]. To prevent imports of IUU-sourced fish and prevent IUU-sourced fish from entering international markets, governments are increasingly using trade measures to improve traceability [48]. The EU traceability model has been reported as instrumental on the global stage in terms of influencing measures for tackling IUU [25], while contributing to a low rate of seafood mislabelling in the European seafood market [40]. In addition to top down measures to improve labelling and traceability of seafood, consumer pressure for traceability is increasing as a result of shifting attitudes towards sustainability, acceptable extraction methods and acceptable targeted species [26]. The legal framework for seafood traceability is

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largely developed, but its implementation is challenging [36]. Competent authorities still lack cost-effective methods to track and validate seafood products through the entire supply chain, and there is a lack of information on routine audits of traceability practices [36].

Although there is increasing interest from regulators, consumers and industry in the concept of end-to-end or full chain traceability, current seafood traceability systems vary in scale and scope. Management interventions such as Fisheries Improvement Projects (FIPs) aim to address environmental challenges in a fishery, and can aid progress towards meeting criteria for certification schemes by improving co-ordination and transparency between stakeholders along the supply chain [4]. Business to Business (BTB) systems, provide more simple one step forward and one step back tracing of the seafood product [3]. Whereas full chain Consumer Facing Traceability (CFT) systems aim to transparently communicate source, production methods and other "credence" qualities such as sustainability to consumers [3,39]. The Global Dialogue of Seafood Traceability (GDST) and the Seafood Business for Ocean Stewardship (SeaBOS) provide open-ended structural cooperation between fishers, processors, distributors, and retailers [48], and in 2020 the GDST issued the first industry-led Standard for Interoperable Seafood Traceability Systems determining the Key Data Elements (KDEs) that need to be documented within seafood supply chains [48]. Standardisation of KDEs across different seafood supply chains would significantly aid traceability and verification of seafood products [48]. Similarly, application of technological advances could further improve seafood traceability and verification. Biotechnological methods could have direct application to geographic traceability of seafood products (e.g. [61] and [9]) or species identification to prevent seafood fraud and mislabelling (e.g. [49]), and advances in data collection and data transmission (e.g. blockchain technology, RFID tags) could aid the flow of information and improve reliability and verification along the supply chain [20,48].

Legislative and market requirements for traceability have been applied across UK seafood supply chains for several years (Table 1). Regulations require that basic information including fishing areas and methods, sale, distribution and storage is available through the supply chain. Documentation is therefore a critical component in meeting legislative requirements for traceability, and certification bodies (e.g. Marine Council Stewardship certification) also require evidence of chain of custody to maintain credibility of certification [3,32,50]. Despite increasing pressure for traceability, there are still some instances of fraudulent and illegal activity across the seafood supply chain [16,26,31]. As seafood supply chains become more complex, and raw seafood materials are increasingly processed, pinpointing instances of fraudulent activity like mislabelling, is more challenging [16,36,52]. Several studies have also highlighted the worrying scale of fisheries crime and human exploitation across seafood supply chains that support UK consumption [64,65].

Here, we analyse three examples of UK seafood supply chains in the context of traceability performance: i) Dover sole (*Solea solea*) landed in the south west of England, ii) North-east Atlantic (NEA) mackerel (*Scomber scombrus*) landed into Peterhead, Scotland, and iii) Brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*), landed into Bridlington, England. These case studies represent a range of: targeted species (demersal, small pelagic and shellfish); fishing method (trawl, purse seine and creel); geographic location (south west England; north-east Scotland; north-east England), and varying levels of supply chain complexity. The specific objectives of this study were to: i) examine how these three supply chains operate in the context of traceability; ii) evaluate traceability performance across the three supply chains in line with best practice criteria; iii) identify challenges to improving levels of traceability in seafood supply chains.

Table 1
Legislative and regulatory requirements for traceability for UK Seafood Supply Chains.

Regulation	Region	Traceability Requirements
General Food Law Regulation (EC) 178/2002	EU*	Defines traceability as the ability to trace and follow food, feed, and ingredients through all stages of production, processing and distribution. Requires businesses to be able to identify at least the immediate supplier of the product and the immediate subsequent recipient, with the exemption of retailers to final consumers – "one step back—one step forward" approach (unless specific provisions for further traceability exist).
IUU Regulation (EC) 1005/2008	EU*	Applies to all landings and transhipments of EU and non-EU fishing vessels in EU ports, and to all trade of marine fishery products to and from the EU. This regulation establishes a control system to prevent, deter and eliminate illegal, unreported and unregulated (IUU) fishing, on fishery products entering the EU market. A catch certificate is required for fishery products imported into the EU and then re-exported from the EU to ensure traceability of the re-exported products that are processed in a third country and then sent back to the EU.
Fisheries Control Regulation (EC) 1224/2009	EU*	Provides a system of monitoring, inspection and enforcement for fishing operations in EU waters and activities of the EU fleet globally, to ensure compliance with the rules of the Common Fisheries Policy (CFP). Requires that seafood products along the supply chain, must be traceable throughout the supply chain, specifically referring to the constitution of grouped quantities of seafood products for transport and sale, known as 'lots'.
Food Information to Consumers (FIC) Regulation (EC) 1169/2011	EU*	Establishes the requirements on the provision of food information to consumers which includes the labelling of prepacked food and drink in the UK. With respect to seafood traceability, labelling must include the name of the food; the list of ingredients; the name or business name and address of the food business operator; and the country of origin or place of provenance.
Markets in fishery and aquaculture products (EU) 1379/2013	EU*	Requires fishery producer organisations to contribute to "*the traceability of fishery products and access to clear and comprehensive information for consumers*" and to the "*elimination of illegal, unreported and unregulated fishing*". In order to achieve the objective of improving the co-ordination of and conditions for making seafood products available on the EU market, inter-branch organisations (consisting of different operators in the fishery and aquaculture sector) can be established. Inter-branch organisations may then improve the quality, knowledge and transparency of products, and also conduct training activities on quality and traceability.
The Fish Labelling (Amendment) Regulations 2014	UK	Requires consumers of fishery products to be provided with information at the point of retail including: approved fish name and scientific name, the production method, the area where the

(*continued on next page*)

Table 1 (*continued*)

Regulation	Region	Traceability Requirements
		product has been caught, and a previously frozen declaration.
Fisheries Act (2020)	UK	Provides the framework for UK fishing policy. Traceability of seafood is defined "*ability of any person to discover information about how, where or when the fishery products were (a) caught, harvested or made, or (b) transported, stored or sold*".
Joint Fisheries Statement (2022)	UK	Outlines the policies of the UK fisheries policy authorities for achieving, or contributing to the achievement of the Fisheries Act (2020) objectives. For control of fishing activity in UK waters and to tackle IUU fishing, ensuring traceability of fish products will be central. To build the resilience of the seafood supply chain sector transparency and traceability will be encouraged through the use of Sustainability and Quality Indicators. Further, the statement states that "*national fisheries authorities will seek to facilitate the development of robust labelling and traceability systems which can support accreditation and are understandable to the consumer*".

* Retained into UK law

2. Methods

2.1. Case study selection

Seafood supply chains for Dover sole (*Solea solea*), North-East Atlantic (NEA) mackerel (*Scomber scombrus*), and Brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*) were chosen for this study based on their importance to UK seafood production and as examples of demersal, pelagic and shellfish landings. Dover sole is a species with a high commercial value; landings into the UK by UK vessels in 2021 were valued at £ 21.3 million with the largest UK ports for Dover sole landings located in south-west England [45]. Scottish landings predominantly comprise of pelagic species; NEA mackerel is a high volume product which makes up a large proportion of Scottish landings with a high export value (2021: 54,100 tonnes, 15% by weight; £96 million, 6% by value) [45]. In 2019, the UK accounted for approximately 60% of the total global catch of brown crab, at 50.5 tonnes [12]; 17.4% (310 tonnes) of the national landings for European lobster were landed into Bridlington representing the largest lobster fishery by volume landed in Europe [44,51].

2.2. Semi- structured interviews

To identify challenges and opportunities for improving traceability in UK seafood supply chains, semi-structured interviews with seafood supply chain stakeholders were undertaken. Participants were first asked to review the operation of the supply chain they represented (e.g. structure, stakeholders involved) and requirements for traceability across the supply chain. The participants were then asked to expand on the systems and technologies for traceability, and the opportunities, barriers and drivers for traceability from their perspective. Participants were purposively selected from across the supply chain (i.e. representatives from fishing, processing and distribution) and based on their contact information being available on official websites, from relevant industry meetings attended by the project team and existing links of the research team to industry stakeholders. From this initial engagement, several organisations declined to participate owing to stakeholder fatigue, particularly in the context of traceability within the supply chain, and limited capacity within the organisation to contribute to the study. A total of 36 stakeholders across the three case study supply chains were interviewed (Dover Sole (11); North-East Atlantic (NEA) mackerel (9) brown crab and European lobster (5), in addition to nine government representatives and two retailers). Interviews were held via video call between December 2022 and March 2023, and each interview lasted between 30 and 60 min. Two researchers conducted each interview, recording detailed notes which were consolidated and shared with the participants after the interview to allow for clarification and verification. All participation was voluntary and responses anonymised, participants could withdraw from the study at any time and all participants provided informed consent. Ethical approval for this study was granted by the University of Hull, Faculty of Science and Engineering Ethics Committee (Ref: FEC_2023_14)..

2.3. Data analysis

Following initial desk based research conducted by the authors, an initial supply chain diagram for each of the three supply chain case studies was produced. Each supply chain diagram was then verified by the relevant stakeholders interviewed. The stakeholders provided feedback on the structure of the supply chain, including the types of organisations involved and detail on the operational links between stages. Following this verification of structure, traceability information collated from the stakeholder interviews was mapped onto each supply chain to indicate the level of traceability for the different stages of the supply chain. From a literature search of academic and grey literature on food supply chain traceability a list of Traceability Performance Criteria was refined by the authors. Criteria were drawn from best practice guidelines including: Zhang and Bhatt [70]; Hosch and Blaha [27]; Borit and Olsen [8]; The Global Dialogue on Seafood Traceability [18] and Blaha et al. [6]. Information from the stakeholder interviews was collated and qualitatively assessed against each of the Traceability Performance Criteria. The interview data was also thematically coded to enable the identification of challenges and barriers to achieving full supply chain traceability.

3. Results: mapping UK seafood supply chains

3.1. Dover sole

Dover sole (*Solea solea*), also known as common sole, is a demersal flat fish species distributed across the north-east Atlantic, North, Baltic, Mediterranean, and Black seas [29]. Prior to the introduction of beam trawls in the 1960 s, catchability of Dover sole remained low [29]. Following the expansion of the beam trawl fishery, greater power, larger beams and more chains, increased landings for Dover sole [29]. Dover sole is now landed primarily by twin beam trawlers as part of a mixed fishery which includes plaice and other flatfish; gill nets are also used in local inshore waters, particularly during the spawning season [29]. In

Table 2
Category and number of interview participants for each case study: Dover sole, NEA mackerel, brown crab and European lobster.

Participant Role	Dover sole	NEA mackerel	Brown crab and European lobster
Fisher/Fisheries Stakeholder Group	4	3	2
Port	3		
Merchant/Auction	1		1
Primary Processor	2	3	1
Secondary Processor		3	
Wholesaler/Trader	1		1
Total*	**11**	**9**	**5**

* 9 Government representatives (including local authorities) and 2 retailers relevant to multiple case studies were also interviewed

2021, landings of Dover sole into the UK by UK vessels were valued at £ 21.3 million, the fourth highest demersal species behind monkfish and anglers (reported as a species group), cod, and haddock [45]. Of the total Dover sole landings into the UK in 2021 by UK vessels, 65% were landed at the ports of Brixham, Newlyn and Plymouth collectively [45].

The initial stages of the supply chain for Dover sole are complex owing to various different routes to the point of first sale, and no vertical integration between fishers and processors (Fig. 1). The first point of sale for a large proportion of Dover sole in the south west of England is facilitated by auction houses at Brixham, Newlyn and Plymouth. There are multiple routes from landing to auction for the mixed demersal catch. Catches are landed at a port and sold at that port's auction house, or are landed at one port and transported to be sold at a different port's auction house, the choice of auction house being driven largely by vessel skipper preference. Alternatively, catches are landed at smaller ports and harbours and then transported to one of the larger ports with an auction house. Some direct selling from vessels to individual consumers, restaurants and fishmongers occurs. At auction, Dover sole may be sold to processors, export companies, further wholesale markets such as Billingsgate or fishmongers. A large proportion of UK Dover sole landings by value are exported (79% in 2021) [45], but there is also a domestic market for whole or gutted Dover sole for retail and restaurants.

The level of traceability achieved beyond the first point of sale in the UK Dover sole supply chain varies substantially and can depend on end market requirements. Catch and landings of Dover sole are reported via a combination of e-logbooks, paper-based logbooks and the mobile phone application "CatchApp" in line with UK regulation. Within auction houses, provenance back to vessel is facilitated through the use of electronic tallies and branded crates containing information such as vessel name, external identification number (PLN), species, weight and grade, ensuring that skippers can be paid accordingly post-sale at auction. Further information provided to buyers at auction includes area of capture, landing date (date before sale), gear type and additional information required to populate export documents. Some smaller processors are able to provide full chain traceability data to their customers in response to commitments for "catch-to-plate" or end-to-end traceability, although this is labour intensive. Larger processors dealing with higher volumes of Dover sole are unlikely to segregate catch from different vessels during transport and processing, restricting traceability back to a group of vessels.

3.2. North- East Atlantic Mackerel landed at Peterhead, Scotland

North-East Atlantic (NEA) mackerel (*Scomber scombrus*) is a migratory, pelagic shoaling fish with a wide ranging distribution across the North Atlantic, North, Baltic, Mediterranean, and Black seas [30]. NEA mackerel is comprised of three main stock units (southern, western and North Sea), but assessments are undertaken as a combined stock [30]. Historically, the North Sea mackerel stock was mainly targeted by Norwegian purse seiners, and catches rose steeply in the 1960 s, (up to 900 000 tonnes in 1967) but dropped to an extremely low level in the 1980 s [28]. The North Sea mackerel stock has remained at low levels since historic overfishing and as a result of continued poor recruitment [30]. NEA Mackerel is now predominantly targeted by an extensive

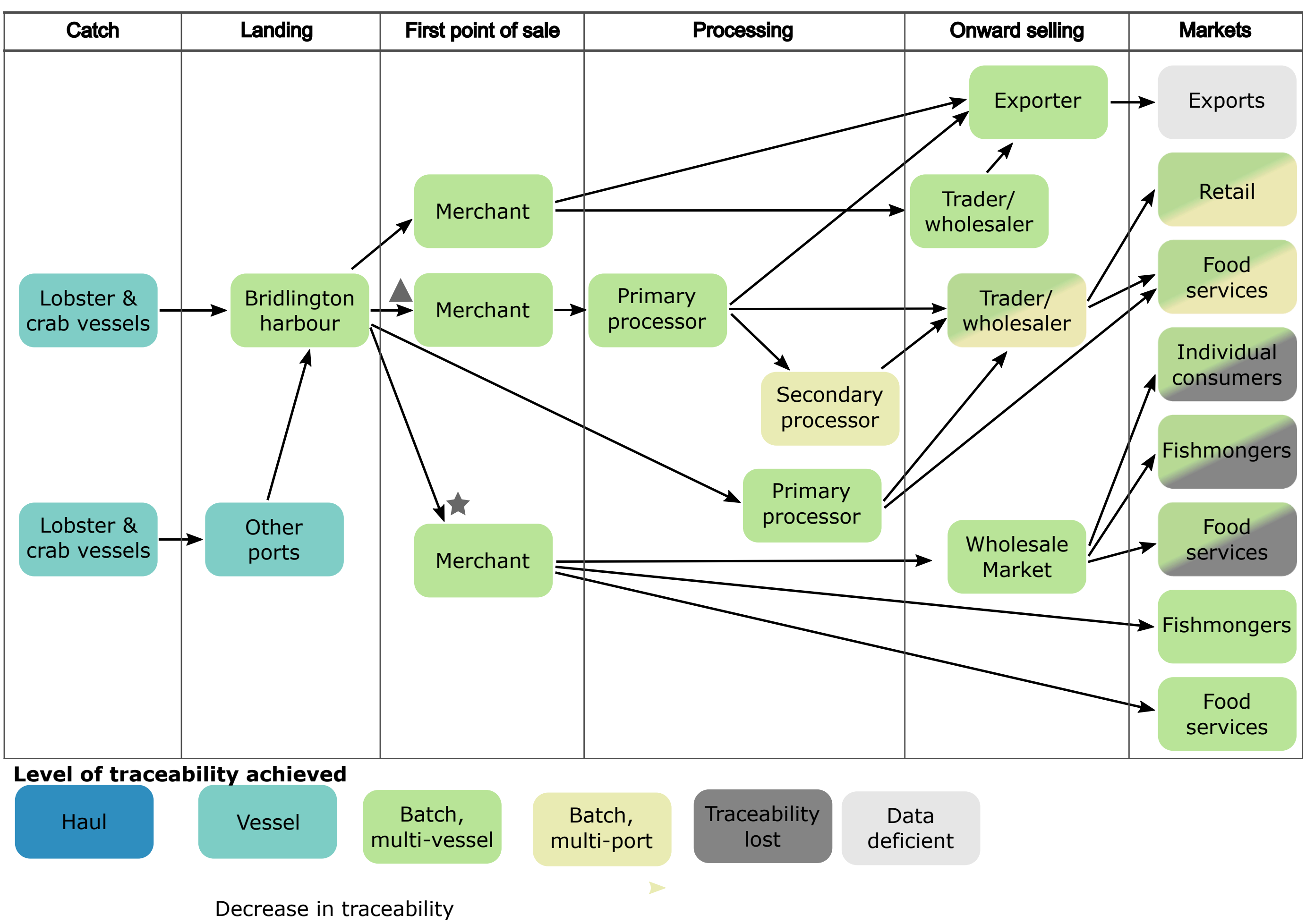

Fig. 1. Dover sole supply chain showing the first point of traceability loss during processing and then the further loss in traceability after substantial mixing from onward selling to final markets.

freezer-trawler pelagic fleet, with most of the UK vessels based in ports in the north-east of Scotland (Fraserburgh, Peterhead and Lerwick) [21,30,45]. In 2021, the UK fleet caught more mackerel than any other single species at 220 000 tonnes accounting for 32% of the total UK catch [45]. Of the landings into the UK, 97% (by volume) was landed into Scottish ports, but a high proportion of NEA mackerel caught by UK vessels (60%) is landed into foreign ports, [45], due in part to higher prices available at European market auctions.

The supply chain of NEA mackerel landed into the UK is relatively linear, with high levels of vertical integration, particularly in the initial stages of the supply chain (Fig. 2.). There is full or partial ownership of vessels in the Scottish pelagic fleet by three primary processor organisations located at Peterhead. UK vessels landing into Shetland are not directly owned by a primary processor, but there are long-standing relationships between the vessel owners and primary processers. Landed NEA mackerel is transported directly to primary processors with the exception of a very low volume of inshore hook and line caught mackerel, sold at Peterhead market. One secondary processor located in the north-east of Scotland, purchases whole fresh mackerel from the four primary processors to produce canned mackerel. Additionally secondary processors, buy mackerel from the Peterhead primary processors to produce smoked mackerel for the UK chilled retail and frozen foodservice sectors. Domestic consumption of NEA mackerel in the UK internal market is limited and thus the UK relies mainly on export markets [21]. The UK has traditionally been a net exporter of mackerel with 54 100 tonnes exported in 2021 accounting for 15% of all UK fish exports [45]. Over time, export destinations have varied [21], and in 2021, the largest share of mackerel exports was to Lithuania (15 000 tonnes), with other key export markets in Europe and China [45].

All vessels in the Scottish pelagic fleet comply with UK regulations regarding the use of e-logbook catch recording, Vessel Monitoring Systems (VMS) and the submission of landing declarations. In 2021 a number of vessels in the Scottish pelagic fleet were accredited by the Responsible Fishing Vessel Standard (RFVS), achieving higher standards of catch traceability than required by UK regulation, becoming some of the first fishing vessels in the world to meet this standard [55]. Primary and secondary processors have internal production and quality control teams that manage traceability processes. Batch codes are assigned to each landing and capture information including vessel details and landing date. Batch codes are added to labels on physical crates, and to internal and externally shared documentation. The digitalisation of this information also facilitates end-to-end traceability of NEA mackerel through the supply chain. Risk of traceability loss is relatively low due to the small number of organisations between which data is transferred, and the high degree of co-operation between organisations such as the Scottish Pelagic Fishermen's Association (SPFA) and Scottish Pelagic Processors Association (SPPA).

3.3. Brown crab and European lobster landed at Bridlington, England

Shellfish (Mollusca and Crustacea) from both aquaculture and wild capture, accounted for 25% of global aquatic food consumption in 2019 [15]. In the UK, a recent focus on high value shellfish products has been driven by a combination of loss of fin fish stocks, lack of fin fish quota and the availability of shellfish export markets [62]. In 2021, UK shellfish landings were valued at £ 331 million, ahead of both pelagic and demersal landings [62]. Brown crab (*Cancer pagurus*), also known as edible crab, is widely distributed across the eastern Atlantic, ranging from northern Morocco to northern Norway [14], and is a key commercial shellfish species for the UK. In 2019, 60% of the total global catch (50.5 tonnes) for brown crab was caught by the UK [12]. European lobster (*Homarus gammarus*), widely distributed across the eastern

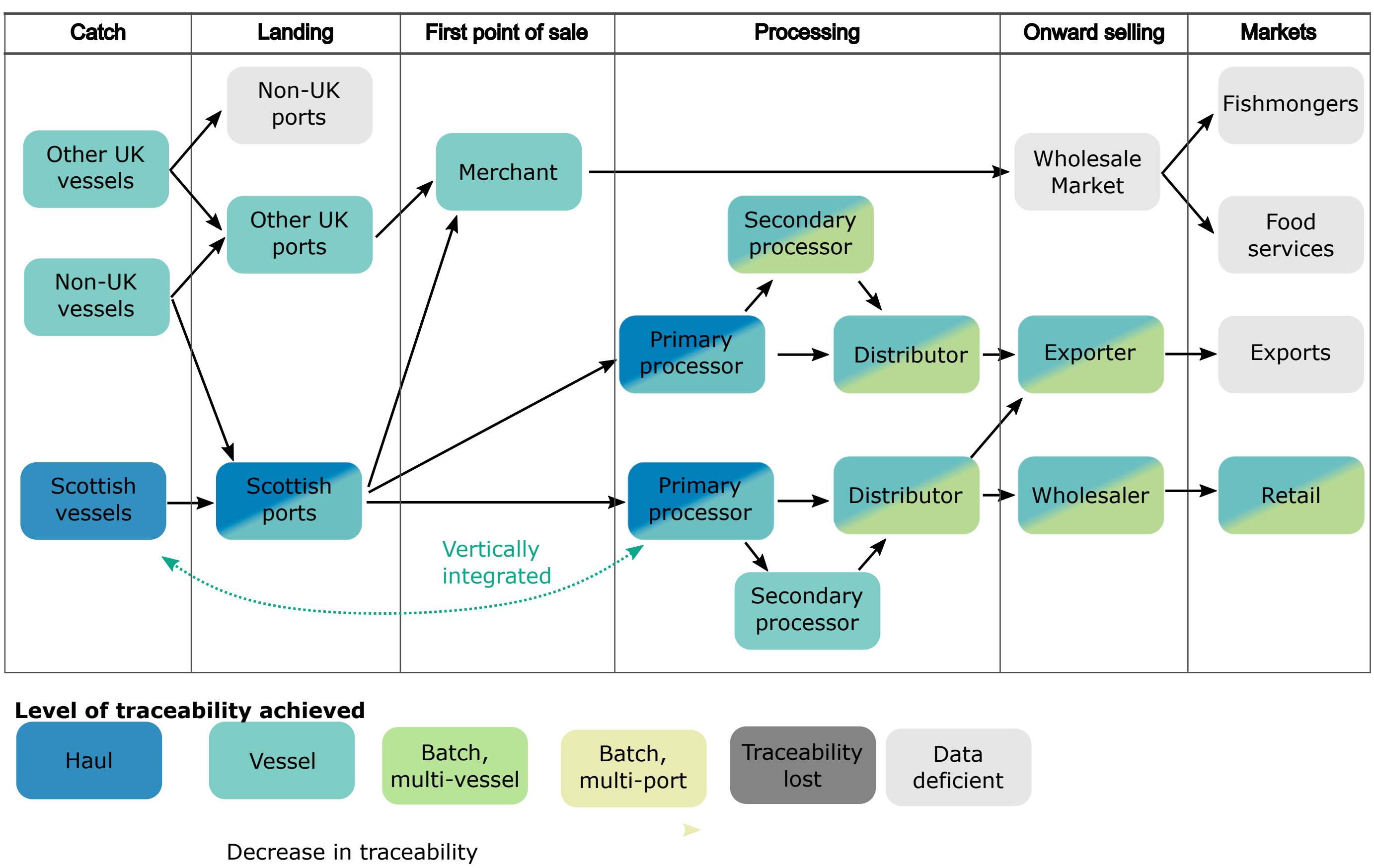

Fig. 2. North-East Atlantic (NEA) mackerel supply chain showing high level (haul and vessel) traceability through much of the chain because of vertical integration early in the chain and little mixing between network nodes.

Atlantic Ocean from the Norwegian Arctic to Morocco and across the Mediterranean and Black Sea [60], is another high value shellfish species to the UK. Bridlington in the north-east of England, in particular, is an important port for shellfish, with landings representing the largest European lobster fishery by volume in Europe [51]. Both species are targeted by commercial vessels using baited pots and traps immersed for varying periods, operating from close to shore to outside of 70 nautical miles [51].

A key distinction for shellfish supply chains in comparison with other seafood products is live storage and transport; efficiency is needed to preserve value and ensure food safety as shellfish are perishable due to their susceptibility to bacterial contamination [72]. Typically within UK supply chains, brown crab are initially sold live, and once dead either sold whole (chilled or frozen) or as processed value-added products (e.g. dressed crab, crab cakes or crab paste) [12]. European lobster is usually delivered and stored live until sold, but can also be sold frozen (raw or cooked) and to a lesser extent as processed product (e.g. bisque) [11]. The first point of sale is between fishers and three merchant organisations that handle brown crab and European lobster landed into Bridlington or transported to Bridlington from nearby ports. There is also some direct selling from fishers to processors. Though there is no reported vertical integration of fishers, merchants or processors, well-established relationships between supply chain nodes are reported. Logistical constraints on the successful transport of live lobster result in a "streamlined" supply chain (Fig. 3.), with lobster passing through relatively few supply chain nodes (fishmongers, food services i.e. restaurants and caterers, and wholesale markets) before being sold to final consumers. A significant portion of lobster is exported to the continent either directly by the Bridlington merchants or indirectly via traders. Brown crab is predominantly sold by merchants to processors and to traders who sell at wholesale markets such as Billingsgate, with smaller volumes also being sold to local fishmongers and food services. There are various configurations of the supply chain for brown crab beyond the first point of sale (Fig. 3.), with numerous primary processors, secondary processors, traders and wholesalers, resulting in a fairly complex and diverse structure.

As with the Dover sole supply chain, catches of brown crab and European lobster are reported via a combination of e-logbooks, paper-based logbooks and the mobile phone application "CatchApp" in line with UK regulation. Traceability of brown crab and European lobster back to a group of vessels is facilitated through merchant records, but traceability back to individual vessels and a specific landing date is complicated by the use of amalgamated batches and vivier tanks respectively. Beyond the first point of sale, some live European lobster wholesalers actively maintain traceability through tagging individual holding units with dates of purchase and port of origin. Whereas, brown crab meat from multiple ports and regions may be further amalgamated by processors, resulting in a limited ability to determine the exact provenance of final products. Batch codes are added during production as part of internal traceability, and then added to packaging, though the degree of traceability facilitated by packaging labels varies across the industry.

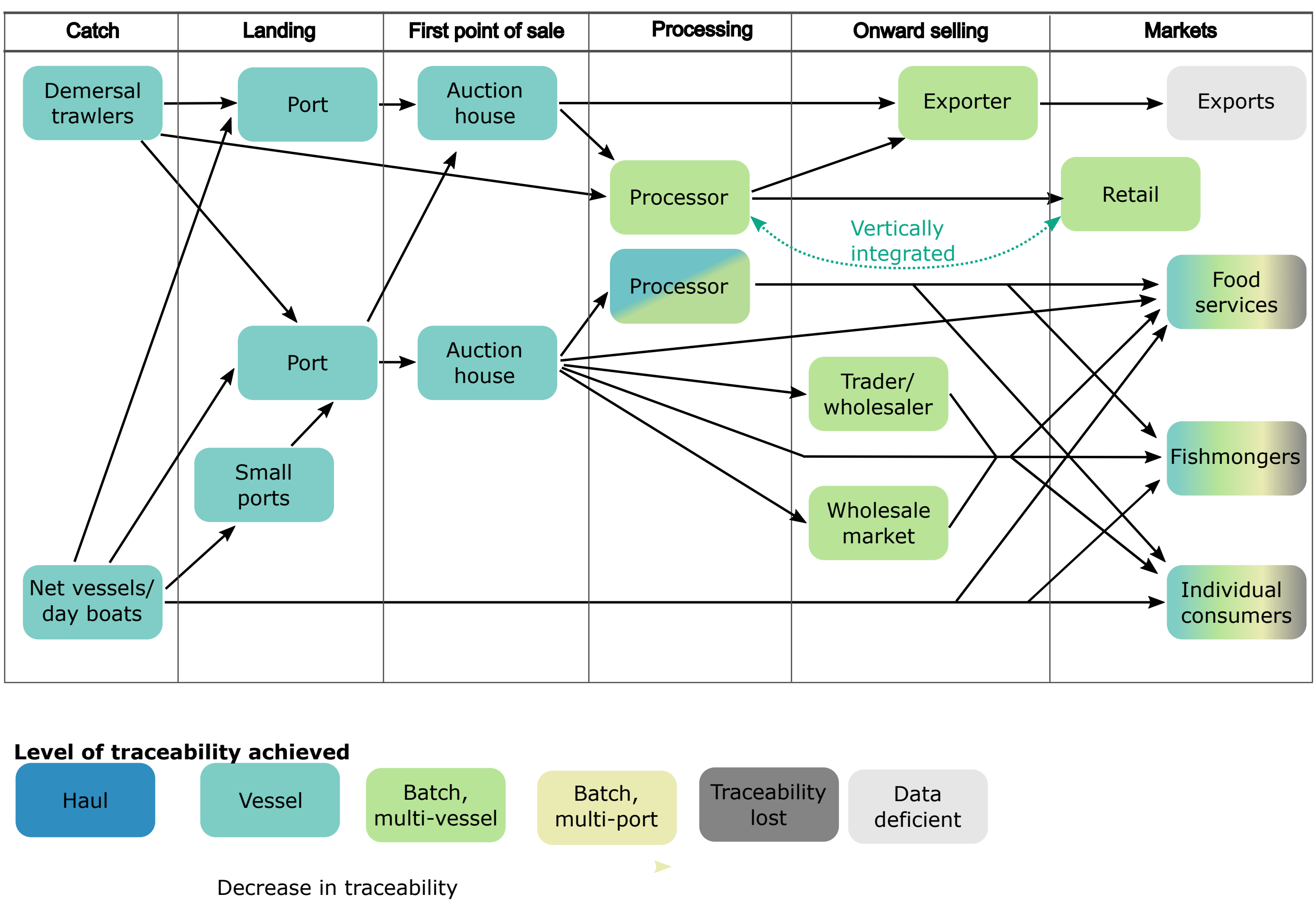

Fig. 3. Brown crab and European lobster supply chain showing the initial breakdown in traceability during post-mortem batch mixing of crab and live batch mixing of lobster at landing and first point of sale stages. Further loss of traceability can be seen to occur during processing. The grey triangle shows a link dominated by brown crab and the grey star shows a link dominated by European lobster.

4. Traceability performance

Traceability performance across the three UK seafood supply chains analysed in this study is variable (Table 3). There are minimum legal requirements that must be met, but performance against traceability "best practice" is largely voluntary or driven by market and consumer demand rather than top down regulation. Voluntary certification via the Responsible Fishing Vessel Standard (RFVS) for the Scottish pelagic fleet provides an additional level of assurance of traceability early in the NEA mackerel supply chain beyond government regulation. Guidelines produced by the Global Dialogue on Seafood Traceability (GDST) define the Key Data Elements (KDEs) (e.g. species, vessel name, landings date, catch area, and capture method) that should be captured and linked with a product as it moves through the supply chain [18]. Only 11 out of 35 KDEs identified by the GDST as best practice are mandated by UK law. Timely and accurate capture, storing and sharing of information across the supply chain is a critical component for supply chain traceability, and the availability of this information electronically is considered best practice [70].

Traceability to vessels in the NEA mackerel supply chain is enabled by a simplified structure early in the supply chain, where one landing moves directly to processor and forms one production batch. While mackerel processors have invested in digital platforms to simplify information management across their operations, the low structural complexity of the supply chain is key in aiding traceability. The Dover sole, and brown crab and European lobster supply chains are similar whereby landings can be comprised of catch from several smaller day-vessels in addition to larger multi-day vessels. Landings post-first sale are often aggregated from multiple vessels into production batches resulting in traceability only to the group of vessels.

5. Challenges to traceability in UK seafood supply chains

Globally, there is a push towards digitalisation of seafood supply chain information [58]. Some vessels within UK supply chains are still using a paper-based reporting system (e.g. 10 – 12 m vessels), and smaller businesses often use a combination of paper-based records and digital systems to manage their internal traceability. While paper-based systems can meet current UK regulatory requirements for traceability, paper-based systems can delay or hinder information transfer across a supply chain, and can be more susceptible to fraud [3,23]. In high economic value supply chains such as NEA mackerel, companies have been able to invest in technologies and resources to effectively manage internal traceability. However, even in digitalised supply chains there is little interoperability between the software systems of different supply chain nodes. This lack of interoperability is often cited as the main barrier to achieving full end-to-end traceability across a supply chain [23] and can also increase administrative burdens due to time consuming manual cross checks of data submitted between multiple systems. The requirement for any additional traceability information could also add to the administrative burden of businesses, a burden which many in the seafood industry feel has increased since Brexit [47]. Therefore, a drive to meet global best practice guidelines for traceability, in terms of technology and the amount of information collected, may need to address bureaucratic and financial costs.

A recent industry horizon scan of UK seafood consumption suggests seafood prices are expected to increase further over the next five years and contribute to a suppressed seafood market [17]. Nodes in the seafood supply chain, may therefore be unwilling to invest in traceability systems beyond those required to meet minimum regulatory requirements. There was reluctance in the NEA mackerel supply chain to adopt blockchain technology due to the perceived negative environmental impacts of intensive energy usage and little additional advantage beyond systems already in place. This hesitancy to adopt digital technologies is reflective of other studies (e.g. [58]), and highlights a key challenge in practical implementation of technological initiatives to

Table 3
Comparison of traceability performance for the UK Dover sole, NEA mackerel, brown crab and European lobster supply chains against best practice criteria.

Traceability Performance Criteria*	Dover sole	NEA Mackerel	Brown crab & European lobster
Regulatory performance – Does the supply chain meet minimum legal requirements for traceability?	The current minimum legal data requirements are met for the Dover sole supply chain with the "one step back, one step forward" approach achieved for lot traceability. In the context of IUU fishing, the introduction of the CatchApp (applies to England) is thought to have increased visibility of operations in vessels < 10 m due to the requirement for daily catch reporting, lowering levels of suspected unreported fishing.	The current minimum legal data requirements are met for the NEA mackerel supply chain with the "one step back, one step forward" approach achieved for lot traceability. The Scottish pelagic fleet is certified by the Responsible Fishing Vessel Standard (RFVS), a voluntary programme that aids catch traceability management. The requirements under RFVS exceed those required by UK regulation. Catches are segregated by area, fish stock and gear type.	The current minimum legal data requirements met for brown crab and European lobster supply chains with the "one step back, one step forward" approach achieved for lot traceability. In the context of IUU fishing, there are some reports of suspected scrubbing of egg-bearing lobsters ("berried lobsters"), which is prohibited under UK law. There are challenges in enforcing prohibition of scrubbing due to difficulties in collecting evidence of the practice. As with Dover sole, the introduction of the CatchApp is thought to have lowered levels of unreported fishing.
Breadth - What Key Data Elements (KDEs) are captured for the supply chain?	The Dover sole supply chain meets the minimum UK legal requirements for capture of KDEs. However, only 11 out of 35 KDEs identified by the GDST are required by current UK regulations. Data captured in the e-logbooks includes: species (GDST KDE W15), weight (W03), vessel name (W04), vessel PLN (W06), area of capture (W14.1), gear type (W10), vessel trip dates (W08), dates of capture (W09). For landing, vessels additionally submit: landing date (W22) and	The NEA mackerel supply chain meets the minimum legal requirements for capture of KDEs. However, only 11 out of 35 KDEs identified by the GDST are required by current UK regulations. Data captured in the e-logbooks includes: species (W15), weight (W03), vessel name (W04), vessel PLN (W06), area of capture (W14.1), gear type (W10), vessel trip dates (W08), dates of capture (W09). No transhipment (W29, W30 and W33) is reported as occurring for the Scottish fleet. For landing,	The brown crab and European lobster supply chains meet the minimum legal requirements for capture of KDEs. However, only 11 out of 35 KDEs identified by the GDST are required by current UK regulations. Data captured in the e-logbooks includes: species (W15), weight (W03), vessel name (W04), vessel PLN (W06), area of capture (W14.1), gear type (W10), vessel trip dates (W08), dates of capture (W09). For landing, vessels additionally submit: landing date (W22) and landing location

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Table 3 (*continued*)

Traceability Performance Criteria*	Dover sole	NEA Mackerel	Brown crab & European lobster
	landing location (W21). Although not a GDST KDE, data on discards is also required under UK regulations. Auction houses provide buyers with sales information including: species (W15), weight (W03), grade, vessel name (W04), vessel PLN (W06), area of capture (W14.1), product form (W16), and landing date (W22). Vessel trip dates (W08) are also available to prospective buyers, but dates of capture (W09) are not provided. Gear type (W10) can be provided from the auction house to processors to aid with sustainability credentials. Larger retailers may request additional data on human labour practices such as vessel safety standards and crew composition including the number of migrant workers and recruitment methods (see W34). However, this is not considered common practice.	vessels additionally submit: landing date (W22) and landing location (W21). RFVS certification requires high standards of vessel management and safety (W34). Further processing information is added to production labels including: product form (W16), expiry/production date (W23) and product country of origin (W24).	(W21). Although not a GDST KDE, data on discards is also required under UK regulations. Crew lists are compiled for health and safety reasons, and could be used to guard against illegal labour, but there are no specific checks on social metrics (i.e. labour practices) (W34). This is because the fishery at Bridlington is characterised by family owned boats with small numbers of local crew members.
Data performance (depth) – How far back or forward is information tracked in the supply chain?	“One step back, one step forward” traceability is achieved for the Dover sole supply chain. Beyond their immediate supplier it may be very challenging for a business to obtain additional information on businesses elsewhere in the supply chain. The level of information available will depend on what is agreed contractually in the product specifications, therefore how far information can be tracked back in the supply chain may vary.	Due to the high level of vertical integration between vessels and primary processors for NEA mackerel, seafood information can be traced along the supply chain. One landing typically forms one production batch with a batch code that enables tracing back to vessel and landing date.	“One step back, one step forward” Traceability is achieved for the brown crab and European lobster supply chains. Beyond their immediate supplier it may be very challenging for a business to obtain additional information on businesses elsewhere in the supply chain. The level of information available will depend on what is agreed contractually in the product specifications, therefore how far information can be tracked back in the supply chain may vary.
Critical Tracking Events (CTEs) – Are instances where product is moved or processed, recorded?	Catch from multiple vessels may be transported in one vehicle to auction houses for first sale. Branded crates and tallies, and no amalgamation of catch at this stage ensures seafood delivered to auctions can be traced back to vessels and therefore skippers paid accordingly. There is some differentiation between seafood products with MSC certification (e.g. hake (*Merluccius merluccinus*), for chain of custody, at auction houses, but this is limited to the addition of the MCS label on the tally. At this point in the supply chain, MSC hake has an equal level of traceability to other seafood (i.e. Dover sole) sold at auction. Post the point of first sale at the auction house, there may be amalgamation of seafood purchased from different vessels and therefore traceability to vessel can be lost at this point.	There is a high degree of vertical integration between vessels and primary processors for NEA mackerel, but sales notes are still generated as product moves from vessel to processor, capturing product movement. Within the supply chain there is a relatively simple production flow, enabling CTEs to be captured more easily, one landing typically equals one processing batch.	For brown crab, there are similar issues to the Dover sole supply chain when catches are amalgamated. Brown crab catch can be amalgamated to create a production batch, or for onward transportation for export, and traceability to vessel may be lost at these points. Brown crab supply chains can be particularly complex with multiple stages where processed product is traded between suppliers before being sold on the market. For European lobster, loss of traceability can occur when lobsters are stored in vivier tanks, and during transportation for export.
Accuracy – How accurately can a seafood product’s movement or characteristics be pinpointed?	VMS is perceived to act as a deterrent to catch area misreporting; historic catch area misreporting is thought to have occurred due to difference in catch limitations for Dover sole across ICES fishing areas.	Though NEA mackerel of a particular batch may be sorted according to size, quality or production type, mackerel from different batches are not mixed and therefore a single processing run can be traced back to a single	Due to poor survivability in vivier tanks, the majority of brown crabs are sold daily, therefore accuracy of landing date is generally maintained. But, due to amalgamation of catch from multiple small

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Table 3 (*continued*)

Traceability Performance Criteria*	Dover sole	NEA Mackerel	Brown crab & European lobster
	Within the Dover sole supply chain, the allocation of landing date is largely accurate, but there are some instances (e.g. landings and deliveries over weekends/ holidays and from small (< 10 m) vessels) where the landing date may be inaccurately reported. There are logistical, operational and financial barriers to identifying and separating seafood according to the landing date. The use of branded crates and tallies and no amalgamation of seafood ensures traceability back to vessel at the point of first sale.	landing and vessel.	vessels, traceability back to a specific vessel may be lost. European lobster are stored live within vivier tanks upon landing. Lobsters landed over a small time period (typically 2–4 days) are grouped into a single vivier tank and as lobsters are not individually tagged, a range of landing dates is therefore possible. When lobsters are sold, merchants may aim to select the oldest stock first, but this process is not documented and no labels are added to the tanks. As there is no individual tracking of lobsters, all vessels that contributed to a particular day's landing are listed on documentation to buyers.
Technological performance – Are the different information technology systems used in the supply chain interoperable?	A combination of e-logbooks, paper-based logbooks and the CatchApp are used to record catch and landings. Catch data can be extracted from e-logbooks and sent to auction houses in advance of vessel landings. Auctions are electronic and there is possible scope to improve interoperability with regulatory data systems. Beyond the first point of sale, interoperability may be compromised by the use of paper-based systems.	Although there is a high uptake of technology for tracking NEA mackerel products through the supply chain, including: catch recording via e-logbooks, the use of VMS and CCTV monitoring at sea activity, and the use of digital systems for data and stock management by processors, there are still instances of paper- based data collection for traceability purposes. Additionally there is a lack of interoperability between nodes in the supply chain. Negative views of further technologies (i.e. blockchain) were expressed, particularly concerning intensive energy usage required and little additional benefit above the existing processes and systems for mackerel supply chain.	Interoperability of information is varied and often low across the brown crab and European lobster supply chains, due to a mixture of paper-based and digital reporting. Though there is a joint data sharing agreement between the MMO and the North-eastern Inshore Fisheries and Conservation Authority (NEIFCA) which has jurisdiction to 6 nm, there are duplicate and inconsistent data submission requirements for fishers from the two organisations.
Internal traceability – Are seafood products traceable within a company's own production and processes?	Branded crates and tallies are used to ensure that seafood delivered to auctions can be identified back to the vessel. Auction houses sort vessel catch into auction-owned boxes of a single species and grade, resulting in multiple boxes per vessel. This process places logistical and resource constraints on auction houses, limiting further division of seafood product by other criteria such as landing date. Seafood from multiple vessels is never amalgamated into a single box, however boxes may be grouped for collective sale to a buyer. Processors manually ensure that the label provided by the auction house is retained with the seafood during processing at their facility. At some processing facilities, vessel and catch details are transferred onto paper labels for packaging, while labour intensive, this "ensures vessel to plate" or end-to-end traceability is captured.	For NEA mackerel, companies have been able to invest in technologies and resources to effectively manage internal traceability. Batch codes are assigned by processors and appear on all internal documentation throughout the production process. The batch codes facilitate traceability between catch information and the physical product.	For Brown crab and European lobster, merchants use internal documents called "landing sheets" to record: species, weight, vessel details and a daily batch code assigned for each species. These details are manually entered into an internal sales and stock management system. Processors for brown crab and European lobster manage their internal traceability with batch codes. This code will link the finished product back to the raw material inputs.
External traceability – Is there communication of product identity and transport of information between links in	E-logbook "return to port" notifications are submitted to regulatory authorities (i.e. MMO) and landing dates are provided on	There are high levels of vertical integration in the early stages of the NEA mackerel supply chain, between vessel owners and primary	Maintaining external traceability is challenging for brown crab, particularly if multiple sources of crab meat are used in

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Table 3 (*continued*)

Traceability Performance Criteria*	Dover sole	NEA Mackerel	Brown crab & European lobster
the supply chain?	landing declarations are submitted for each vessel. Sales notes from auction houses also carry vessel details. Regulatory authorities should be able to cross-check and verify information on landing declarations and sales notes, however the uncertainty of landing date on the sales notes makes this difficult. There is some infrequent resale of seafood back into auction houses, and in these instances, only species, grade and weight is provided to buyers with no vessel information. Therefore this is a loss of traceability back to vessel beyond the first point of sale.	processors enabling a high degree of external traceability between nodes across the supply chain.	production batches, or if there are multiple processing stages. In theory, external traceability could be maintained through the reconciliation of batch codes between stages in a supply chain though this is dependent on the record keeping accuracy of individual businesses.
End to End initiatives – Can a seafood product be traced from source (i.e. fishing vessel) through to the consumer?	A paper-based end-to-end traceability system is observed for Dover sole sold to premium market consumers. For some larger processors, traceability to vessel is lost when auction lots post first sale are amalgamated for onward transportation.	The NEA mackerel supply chain is an example of an end-to-end traceability system where key data is linked to production batches as they move through the supply chain. End-to-end traceability in this case is facilitated by having a small number of fishing vessels making large volume landings, with one landing typically forming a production batch. For canned mackerel, consumers are able for one brand, to scan a label code which will provide information on the specific vessel. Smoked mackerel products can also be traced back to vessel via batch code.	For brown crab and European lobster, there are many smaller fishing vessels landing relatively small volumes. Landings for brown crab, and for European lobster will often be amalgamated by the first buyer to form a production batch. Minimum traceability requirements will be met, but ultimately the production batches will only be traced back to a group of vessels.

* Traceability performance criteria were drawn from: Zhang and Bhatt [70]; Hosch and Blaha [27]; Borit and Olsen [8]; The Global Dialogue on Seafood Traceability [18] and Blaha et al. [6].

improve traceability. Within the Dover sole supply chain, various perceived negative implications of improving traceability further were raised by study participants, including: issues of competition, lack of desire of certain markets to advertise product origin (e.g. French and Belgium markets not wishing to advertise seafood as from the UK), and cumbersome reporting processes reducing profitability. Improving traceability risks increasing equity gaps across the sector [48]. Smaller nodes within the supply chain are the most likely to have lower economic and technological capacity to absorb costs associated with increased traceability [23].

Although the UK seafood market may struggle in the shorter term, there are also indications that seafood could be a key protein source in health driven diets, supported by supply chains with ethical and sustainable credentials [17]. Overall research indicates that drivers for seafood consumer preferences are mixed [66], but that there is a UK market for eco-labelled seafood [54]. Eco-labels (e.g. MCS certification) are the primary tool used by retailers to provide consumers with assurance on the sustainability attributes of a product [67]. Participants in this study highlighted their awareness of consumer demand for sustainably caught fish, but also their frustration at the lack of enforcement of UK legal requirements to specify catch methods on seafood labels, limiting consumer ability to make ethical and sustainable purchasing decisions. Mislabelling of catch method is a component of seafood fraud [16], and specification of catch method is one of the GDST KDEs for traceability best practice [18], so there are IUU fishing prevention and traceability drivers for improving information collection and transfer on sustainability attributes across the supply chain. However, while traceability systems may provide sustainability information on seafood products, these data still need to be verified [8]. Technological advancements may aid verification of supply chain information, but do not replace labour intensive inspection and monitoring [48].

The Dover sole supply chain is potentially an example of where monitoring technologies and changes to regulations have had an impact in increasing traceability and reducing instances of IUU fishing. The introduction of VMS and single area licenses was perceived by participants to have reduced historical misreporting of capture area for Dover sole, but instances of illegal landings of Dover sole outside the regulated and monitored systems are still suspected by study participants. Enforcement of current regulations rather than additional regulations or paperwork was suggested as the way to provide an acceptable guarantee of provenance and deterrence for IUU fishing. In the European lobster supply chain, reports of suspected illegal practice of scrubbing egg-bearing lobsters were highlighted, but there are challenges in collecting evidence of the practice. Seafood supply chain traceability initiatives have been introduced with a goal of helping to reduce IUU fishing and illicit fish trade [63,68]. However, although there has been expansion of traceability efforts, there is limited understanding and their effectiveness in addressing IUU fishing [10,63].

A key governance challenge for the UK seafood supply chain in the context of traceability is that fisheries and downstream businesses often have contrasting perspectives; for example, fisheries are focused on the allocation of fishing opportunities and regulatory intervention, and the focus of downstream businesses is on meeting customer demands, assuring product quality, and securing market access [56]. This need to develop a ‘common language’ between sectors has been emphasised previously [56] and is further compounded by differences in the enforcement of regulations across the supply chain. For example, in England, the MMO has responsibility to enforce traceability up to the point of first sale and export, and has a remit to prevent IUU fish from entering the supply chain. Whereas, the Food Standards Agency (FSA), focuses on food safety, and devolves power to local authorities to undertake food safety inspections on businesses in the supply chain after the point of first sale. Outside of government-led processes, non-state market driven governance tools, such as seafood guides, seafood sourcing policies, and voluntary labelling guidelines have aided traceability initiatives [22]. However, participating in non-state market driven governance regimes does not replace regulatory requirements and therefore in practice the fishing industry could be regulated by both public and private governance processes [22] which if not mutually supportive could add greatly to the administrative and regulatory burden for traceability.

6. Discussion and conclusions

In the present study, we analysed traceability performance across three seafood supply chains in the UK. There have been improvements to the technologies, processes and systems for traceability in the seafood sector, and dramatic changes to UK seafood supply chains over the last 40 years [56]. Digitalised catch reporting, a better protected "cold--chain", and improved supply chain efficiencies have resulted in increased quality and legality of products across the sector [2,43]. However, here we have demonstrated there are different levels of traceability, realised across different seafood supply chains as a result of broader fishery contexts, supply-chain complexity, and investment capacity for technology to enable traceability.

Supply chains operate with multiple nodes are more vulnerable to loss of traceability as information moves between them. Longer supply chains with more nodes have more points of vulnerability; hence shorter supply chains appear to show better traceability. Vulnerable nodes in the seafood supply chain include points of product mixing from multiple batches and catches (e.g. brown crab), amalgamation of live product in vivier tanks (e.g. European lobster) and amalgamation of product post the point of first sale (e.g. Dover sole). Globally, supply chain traceability could be improved by reducing the number of nodes in a given network and increasing vertical integration, or by adopting initiative such as end-to-end traceability, which are product focussed and value tracing product from source to consumer as seen in terrestrial farming systems (e.g. "Farm to Fork").

There is growing interest in full-chain digital traceability in seafood supply chains and the potential improvements this will make towards ensuring safe, legal, sustainable and accurately labelled seafood products [23]. Electronic end-to-end traceability is promoted by initiatives such as the GDST through their global standards [18]. Further technological advances are changing the methods of monitoring and managing traditional seafood supply chains [34]. For example, technology is being employed to more efficiently match supply and demand, using social media for direct marketing of catches [1]; Big Data approaches are increasingly used as part of "Smart Fisheries Management" which could enhance sustainability in the supply chain and detect IUU fishing [34] (e.g. Global Fishing Watch); and consumer-facing technology is increasingly adopted to guide choices for sustainable and ethically sourced seafood (e.g. Marine Conservation Society Good Fish Guide [41] (MCS 2023a)).

Traceability systems can aid in the assessments of supply chain sustainability [3,36,37]. Consumers and regulators are increasingly demanding information related to ethical and sustainable sourcing and traceability systems can help capture some of this information. Reporting on catch location and specific fishing gear can be linked to fish stock sustainability; information on manufacturing processes and transportation can be linked to carbon footprint, and stringent documentation across the supply chain can help mitigate against fraud [16,24,35,36]. However, simply linking traceability performance to sustainability measures is not adequately specific [71]. In seafood supply chains, there are key knowledge gaps surrounding the impact of traceability systems on sustainability objectives and the cost effectiveness of these efforts [63]. Here, we have documented a high level of traceability performance in the UK NEA mackerel seafood supply chain, yet in 2019, NEA mackerel had MSC certification suspended and in 2023, a lack of consensus on quotas and measures for sustainable management of stocks, led the Marine Conservation Society to describe NEA mackerel as "no longer a sustainable choice" [42]. Sustainability concerns have also been raised regarding practices of UK caught fish being shipped internationally for processing before reimport into the UK [67]. Focusing on shorter supply chains has been proposed as a way to improve overall supply chain sustainability by reducing carbon footprint, an increasingly important criteria for seafood products [38,48,69]. Shorter, less complex supply chains are also easier for achieving end-to-end traceability, and therefore less prone to seafood fraud [34].

Consumer preference and willingness to pay for eco-labelled seafood in many markets is prompting retailers to demand source fisheries meet minimum environmental and social requirements [13]. Businesses are increasingly wary of any reputational risks, such as modern day slavery, associated with the fisheries they are sourcing from [67]. Traceability systems have aided in in ensuring recruitment practices meet ethical and legal guidelines [65], but are far from revealing all risks encountered by workers in the supply chain [33]. A simultaneous demand from consumers and public authorities to increase transparency across seafood supply chains (for ethical, sustainable and food safety objectives), is a core driver of the establishment of traceability systems applicable to both consumer empowerment and improved fisheries management [48]. Fisheries in this study highlighted their ambitions towards traceable supply chains to provide confidence and trust in the UK fishing industry and to legitimise the UK as a fishing nation.

Since the 1970 s, the UK seafood supply chain has changed from largely domestic landings, to one where domestic consumption is heavily dependent on imports, and most of the domestic caught seafood is exported [56]. A combination of factors including: economic rationalisation, greater international competition, the emergence of a free market approach to fisheries management, and changes in the perception of fish from UK consumers, has resulted in fewer registered landing points, wholesale markets, processing facilities and small retail outlets handling fish [56]. UK consumers have strong preferences for large pelagic species (e.g. tuna), demersal whitefish (e.g. cod and haddock), salmon and prawns [57], and to meet these demands, the UK is almost entirely reliant on imports for some of these species [67]. Our study considered three case studies in which species are caught in UK waters and landed into UK ports by UK vessels, but a more complete picture of the UK seafood supply chain is complicated by the practice of exporting and reimporting seafood products. UK domestic consumption focuses on processed products rather than whole fish as a result of consumer preferences [67]. Some larger processing companies export unfinished product for processing (e.g. filleting) before reimporting the semi-finished product for value added processing [56]. Seafood products may be processed multiple times, substantially changing form and content, with multiple countries involved in the supply chain at different stages of processing [59,67]. Given the global and complex nature of seafood trade, there is a potential for IUU catch or illegally traded seafood to enter into UK markets via less-regulated markets with limited traceability initiatives [16,63,67].

Achieving full chain or end-to-end traceability requires a shift in focus away from "batch-based" identification towards documenting all key properties relating to the product anywhere in the supply chain [8,48]. This is a substantial change from current traceability systems and regulatory requirements which have resulted in companies focusing largely on their own internal traceability, rather than the flow of information across the whole supply chain [8]. Here, we have demonstrated that three UK seafood supply chains are achieving the minimum regulatory requirements for traceability and in some areas are moving towards best practice. However, key challenges for implementing best practice in seafood supply chain traceability remain. Achieving end-to-end traceability is likely to require investment in technology and systems to enable the better flow of information between nodes in the supply chain, resulting in a financial burden which some smaller nodes may be unable to absorb. A reluctance to adopt new technologies due to perceived limited additional benefit may hinder interoperability if only part of the supply chain implements improves traceability systems. Crucially, traceability information needs to be verified and there is a lack of evaluation of the effectiveness of traceability initiatives towards achieving sustainability, IUU and modern slavery objectives [36,63]. Improving traceability of seafood products through the supply chain is critical for ensuring better management of fish stocks, tackling IUU fishing and promoting sustainable and ethical practices in the seafood sector [7,36]. Common traceability goals across international supply chains may also increase co-operation and function as a stabilising influence in areas of disputed fishing practices [25]. The traceability requirements for entering the EU market have been influential in tackling IUU and seafood fraud across international boundaries. However, how consistently traceability systems are implemented on a regional and global scale, and to what extent traceability best practice is achieved is unclear. Implementing traceability best practice is challenging, but systems can be implemented quickly when faced with powerful drivers. For example, in response to concerns over food safety during the COVID-19 pandemic, China launched a fully digital traceability platform for imported seafood [25]. For wider traceability implementation across global seafood supply chains, sustained investment in technology, capacity and verification of information captured will be needed.

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CRediT authorship contribution statement

The authors confirm contribution to the paper as follows: study conception and design: NMB, CRH and CG; data collection SR and AC; all authors contributed to analysis and interpretation of results; draft manuscript preparation: CRH, SR and NMB. All authors reviewed the results and approved the final version of the manuscript.

Data Availability

Data will be made available on request.

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