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Seafood is one of the most traded food commodities in the world with demand steadily increasing [1]. There is, however, a rising concern over the vulnerability of seafood supply chains to species mislabelling and fraud [1,2]. DNA methods have been widely used to detect species mislabelling and a recent meta-analysis of 4500 seafood product tests from 51 publications found an average of 30 percent were not the species stated on the label or menu [3]. This high rate poses a serious threat to consumer trust, reputations of seafood businesses and the sustainability of fishery resources. Seafood certification schemes may help reduce this problem. Here, we use DNA barcoding [4] to validate the species identity of 1402 certified seafood products derived from 27 species across 18 countries and find that in over 99% of cases species labelling was correct.

Species mislabelling, unintentional or deliberate, may be caused by many factors. Unintentional mislabelling may result from misidentification or ambiguities in product naming, for example, closely related species misidentified at capture, confusion over common names of species used along the supply chain, and the use of catch-all trade names such as 'snapper' or 'skate' [5]. Deliberate fraud occurs when there is intentional substitution for financial gain. Usually a higher value species is substituted with one of lower value, for example, a restaurant meal advertised as wild caught Atlantic cod (*Gadus morhua*) was recently diagnosed as farmed catfish (*Pangasius sp.*) [6]. Fraud may also arise when species from unsustainable or illegal fisheries gain access to the market through substitution for species from reputable or certified fisheries.

While mislabelling and seafood fraud can be directly combated through regulation and enforcement, there are also initiatives that aim to reduce the risk via market-based incentives. These include eco-labelling standards for sustainable fisheries and supply chain certification programmes, such as the Marine Stewardship Council (MSC). MSC certification requires every distributor, processor, and retailer trading certified seafood to have a documented trace-back system. How effective this system has been in reducing the incidence of species mislabelling, however, has yet to be thoroughly investigated at a global scale. Genetic identification approaches are key to resolving this issue [7,8].

MSC labelled seafood products are diverse, available in over 100 countries and may comprise single species (e.g. fillets) or multiple species (e.g. processed forms such as surimi 'fish sticks'). To validate the species identity of MSC certified seafood products, we sampled a total of 1463 MSC certified products between 2009 and 2016. DNA barcoding unambiguously identified the species in 1402 of these samples (Data S1). For thirteen of these samples (0.92 %), the product label was inconsistent with the species identified by DNA barcoding (Table 1). Mislabelled products were found in both retail products (fresh and frozen pre-packed products) and restaurants, mainly in western Europe, with one case in the USA. All cases of mislabelling were identified in white-fish (cods, hakes, hoki, flatfish). No cases of mislabelling were identified in small pelagic species (e.g. herring), salmon, tuna, or toothfish (Supplemental information). Obtaining good quality DNA from canned tuna products was problematic; thus tuna was under-represented in our results.

While DNA testing may unambiguously demonstrate species mislabelling, it is insufficient on its own to confirm if deliberate substitution (fraud) has taken place. DNA testing needs to be partnered with product purchase and sale documentary trace-back evidence from supply chains to determine how and when the mislabelling occurred, and whether it was deliberate or unintentional. For the thirteen mislabelled products, records for the MSC chain of custody Standard were obtained from each company at each stage in the supply chain. Trace-backs revealed that only two mislabelled samples (0.1 %) could be confirmed as intentional substitutions with species of uncertified origin and thus were likely to be fraudulent (Table 1). In both instances, the MSC chain of custody certificates were suspended. There were two instances where species substitution at point of capture or during onboard processing (prior to entering the chain of custody) appears to have occurred due to misidentification between closely related, morphologically similar species that co-occur in the catch. Rare instances of misidentification are inevitable and while steps must be taken to avoid this they are unlikely to be deliberate or systematic. In the other cases, as substitution occurred between additional or alternative, but certified, species, thus lacking financial incentive, it was likely to be unintentional. In these cases, non-conformities were raised by auditors and a corrective plan of action prescribed.

This is the largest and most comprehensive global assessment of species validation of MSC product labels, demonstrating over 99 percent species accuracy across a wide range of certified products. Compared with an average mislabelling rate of 30 percent found across other studies [3], our results suggest that combining regular DNA testing with documentary trace-backs across the full supply chain, as part of MSC's chain of custody certification program, is an effective deterrent for systematic and deliberate species substitution and fraud. The MSC certifies stocks and fisheries rather than species, and as such there remains the risk for substitution between certified and uncertified stocks of the same species [9]. For tests with this level of resolution, we are trialling next generation sequencing and isotopic and trace element profiling [10].

SUPPLEMENTAL INFORMATION

Supplemental Information including experimental procedures, one table and a dataset can be found with this article online at https://doi.org/10.1016/j.cub.2019.02.014.

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Table 1. DNA testing results presented by single species or species group on the product label, detailing DNA result, species, country, product type and trace-back results in cases of mislabelled products. *Indicates the 2 cases where deliberate substitution (fraud) was evident. Sample ID code refers to Data S1.

Species label on product	Number sampled products	Number mislabelled	DNA test result — species identified	Trace-back results	Country	Sample ID code	Product type
All other species where label matched DNA (see Supplemental Information)	809	0	NA	NA	Multiple	Multiple	Multiple
Gadus macrocephalus/ ogac (Pacific cod)	74	2	*Gadus morhua* (Atlantic cod)	MSC certified substitution	UK	LF201223	Retail pre-pack
		1	*Gadus morhua*	Inconclusive	Belgium	A0603	Retail pre-pack
		1	*G. chalcogrammus* (Alaska pollock)	Source misidentification	UK	TM11	Retail pre-pack
Gadus macrocephalus/ G. morhua	43	1	*Melanogrammus aeglefinnus* (haddock)	MSC certified substitution	UK	MSC16-M0601	Restaurant
Gadus chalcogrammus (Alaska pollock)	294	2	*Merluccius productus* (North Pacific hake)	MSC certified addition to mixed product	Netherlands	NS10, NS07	Retail pre-pack
Lepidopsetta bilineata (rock sole)	3	1	*Lepidopsetta polyxystra* (northern rock sole)	MSC certified substitution	Germany	MSC15-MO173	Retail — frozen
Merluccius capensis/ M. paradoxus (Cape hakes)	35	1	*M. productus*	MSC certified substitution	France	ELB11	Retail pre-pack
M. capensis/ M. paradoxus/ M. australis/ M. merluccius (hake species)	72	1	*Pollachius virens* (saithe)	Inconclusive substitution	UK	BS20122, BS20123	Restaurant
P. virens (saithe)	12	1	*Gadus morhua*	MSC certified substitution	Netherlands	A0642	Restaurant
Macruronus novaezelandiae (New Zealand hoki)	1	1	*M. productus*	Non-MSC substitution*	USA	NV04 - US	Retail pre-pack
M. aeglefinus (haddock)	59	1	*G. morhua*	Non-MSC substitution*	UK	A0839	Restaurant
Total	1402	13 (0.97%)					

DECLARATION OF INTERESTS

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