From ocean to plate:
How DNA testing helps to ensure traceable, sustainable seafood
March 2016
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Seafood fraud – the selling of seafood products with a misleading label, description or promise – has become a widespread form of food fraud. Not only does it threaten the bottom line of reputable fishers and seafood traders, it undermines the progress being made by sustainable fisheries and can allow illegal and unregulated fishing practices to go undetected.

A recent global analysis suggested that on average 30% of seafood products are misdescribed or mislabelled. A traceable supply chain is vital to delivering the MSC’s vision of healthy oceans and its promise to consumers that MSC labelled seafood comes from a sustainable source. In 1999, the MSC developed its Chain of Custody Standard to ensure that every distributor, processor, and retailer trading in MSC certified sustainable seafood has effective traceability systems in place. To verify that these traceability requirements are effective, the MSC conducts bi-annual DNA tests on a random sample of MSC labelled products. The latest tests have revealed that 99.6% of MSC labelled seafood is correctly labelled. The study successfully sampled 256 unique products and 13 species of fish, sourced from retailers across 16 countries. These results are consistent with previous years’ and show that on average, the MSC’s DNA testing has found a mislabelling rate of less than 1% for MSC labelled seafood since 2009.

The results of the MSC’s DNA testing program are very positive. Nevertheless, the MSC takes traceability very seriously and continues to monitor the certified seafood supply chain very closely. Looking to the future, the scope of the MSC’s testing program will be broadened to other seafood products and explore the use of new technologies to verify the authenticity of sustainable seafood.
In 2013, the ‘horsemeat scandal’ sent tremors through the European food industry. The fraudulent replacement of beef with cheaper equine alternatives in burgers and convenience food left consumers and retailers reeling, alarmed that they had fallen victim to the largest food fraud in decades. The scandal not only highlighted the shortcuts being made by food manufacturers in their attempts to compete for the lowest price, it emphasized the complexity of global food supply chains and the challenges in monitoring every step. Almost overnight, the importance of traceability — the ability to track any food through all stages of production, processing and distribution — became high on public and political agendas.

Seafood fraud, the selling of seafood products with a misleading label, description or promise has become a widespread form of food fraud. As the most highly traded food commodity in the world, increased market demand for fish coupled with weak legislation has incentivised the re-naming, substitution and mislabelling of seafood to reap higher profits. Not only does this illegal activity threaten the bottom line of honest fishers and seafood traders, it undermines the progress being made by sustainable fisheries. It can also leave consumers feeling duped, misled and distrustful of retailers and brands. The need for traceability in the seafood sector is now widely recognised. Major seafood import markets such as the USA, Japan and the EU introduced traceability components to their import regulations in recent years. But despite increasing legislation, a recent global analysis revealed that on average 30% of seafood across the world is misdescribed or mislabelled, with figures as high as 43% reported in some species-specific investigations.

A transparent seafood supply chain ensures consumers know what fish they are buying and where it was sourced from.

A recent global analysis revealed that approximately 30% of seafood across the world is mislabelled.

Traceability: From ocean to plate

Part 1
What is traceability?

A number of voluntary supply chain traceability schemes have been developed to ensure the integrity of seafood supply chains. The Marine Stewardship Council’s (MSC) Chain of Custody Standard is one such scheme, covering over 3,000 seafood suppliers, distributors and processors across the world. It assures consumers that the MSC labelled seafood they buy has been sourced legally from a sustainably managed source, has not been mixed with uncertified seafood, and can be traced along the supply chain from ocean to plate.
Although it is possible for seafood to become unintentionally mixed with different species at various points along the supply chain, intentional seafood fraud is motivated by profit\textsuperscript{5,6}. Scientific investigations have repeatedly revealed higher rates of mislabelling among premium, sought after fish like Atlantic bluefin tuna (\textit{Thunnus thynnus})\textsuperscript{10} and wild-caught chinook salmon (\textit{Oncorhynchus tshawytscha})\textsuperscript{8,11} and lower rates in convenience seafood like fish fingers and processed seafood sticks\textsuperscript{12}. Higher rates of mislabelling have commonly been reported in restaurants and take-away outlets than in food retailers\textsuperscript{8,9,13}. In restaurants, unlabelled products can quickly be substituted to boost profits, or meet gaps in supply. One of the more profitable seafood substitutions revealed in a Belgian restaurant was the replacement of Atlantic cod (typically costing €20-25/kg) with the farmed Vietnamese river catfish 'pangasius' (\textit{Pangasianodon hypothalamus}; typically €4/kg). Both species share similar flaky white flesh which is likely to go unnoticed by consumers, while dishonest traders reap the benefits\textsuperscript{10}.

Mislabelling motivations

<table>
<thead>
<tr>
<th>Wild chinook salmon</th>
<th>$4.37/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmed Atlantic salmon</td>
<td>$0.50/lb</td>
</tr>
</tbody>
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Seafood fraud has knock-on consequences for fishers as well as consumers. Given the US consumption of salmon is 20,000 metric tonnes/year, the substitution of wild-caught chinook salmon (typical wholesale price $4.37/lb) for farmed Atlantic salmon ($0.50/lb) is thought to cost the industry over $7 million each year\textsuperscript{13}. 

Traceability: From ocean to plate

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Part 2

What’s in a name?
The consequences of mislabelled seafood

Whatever the incentive, the implications of seafood mislabelling can be alarming and wide ranging.

Illegal, unreported and unregulated (IUU) fishing

IUU fishing refers to fishing activities that do not comply with national, regional, or international fisheries conservation or management legislation or measures. A global analysis of IUU fishing from 54 countries, comprising 75% of global catch, revealed that an estimated 11 - 26 million tonnes of IUU fish are landed each year, representing a loss of between $10 bn and $23.5 bn to the fishing industry. Such massive levels of illegal harvesting affect the reliability of fisheries management models and can lead to inaccurate targets being set for legally caught fish. This can potentially contribute to the collapse of some stocks or hinder the recovery of others. IUU fishing also poses a significant risk to marine ecosystems. It has been associated with destructive fishing practices, high levels of bycatch and the abandonment of nets that go on to cause ghost-fishing. It can also squander the protection offered by marine reserves and have serious impacts on coastal communities in developing countries who rely on local fish stocks both for their livelihoods, and as primary source of protein.

An estimated 11-26 million tonnes of IUU fish are landed each year, representing a loss of between USD $10 bn and $23.5 bn to the fishing industry.
Spot the difference:

It can be near impossible to accurately identify the species of fish present in a product from sight alone, as shown by these two battered fillets of Atlantic cod (*Gadus morhua*) (left) and Pangasius (*Pangasianodon hypophthalmus*) (right).

**Consumer health implications**

Not only can mislabelled seafood affect ocean health, it can have health implications for consumers. Although not all traceability systems specifically include food safety requirements, the simple substitution of one fish for another can lead to consumers unwittingly purchasing fish that should be presented with health warnings.

For instance, escolar (*Lepidocybium flavobrunneum*) and rough-scale oilfish (*Ruvettus pretiosus*), both members of the snake mackerel family that may cause unpleasant digestive issues when eaten in large quantities, have been recorded as being sold as ‘white tuna’ in 84% of 114 samples collected from sushi restaurants in the USA. The sale of these fish is prohibited in some counties or requires a specific warning label in others.

**Consumer deception**

Consumers are increasingly demanding fish from sustainable sources often using ‘fish to eat/avoid’ guides to aide their purchasing choices. Others make an ethical decision to choose wild-capture fish over farmed products. Where fish are incorrectly labelled, these consumers could unwittingly be eating options that are less sustainable, or that do not meet their ethical criteria.

For example, a UK seafood labelling study showed that in one major retailer, Atlantic cod (*Gadus morhua*) was being sold as sustainably sourced Pacific cod (*Gadus macrocephalus*). Similarly, a study of salmon mislabelling in North America revealed that at certain times of the year wild-caught salmon were frequently replaced with farmed salmon in restaurants without making consumers aware.

**The trade of vulnerable and endangered species can go unnoticed**

A major obstacle to the traceability of seafood in some parts of the world is the inadequate naming and labelling of seafood as it travels along the supply chain. In the USA, ambiguous names such as ‘groupers’ can legally be used to describe any one of 65 species of grouper, including the critically endangered Warsaw grouper (*Hyporthodus nigritus*) and Atlantic goliath grouper (*Epinephelus itajara*) with no requirement to provide more species-specific information.
The MSC traceability standard

Despite the clear threats posed by seafood fraud, there is hope. In 1999, the MSC developed its Chain of Custody Standard to ensure that every distributor, processor, and retailer trading in MSC certified sustainable seafood has effective traceability systems in place. Today, over 3,000 companies worldwide are MSC certified.

In order to sell MSC labelled seafood, each company along the supply chain must have a valid MSC Chain of Custody certificate and pass regular independent audits to retain it. During each audit, the company must demonstrate that the certified seafood it sells:

- Originated from a certified supplier
- Has systems in place to segregate and prevent mixing between certified and non-certified seafood
- Is identifiable at all times
- Has a traceability system in place so that any product sold can be traced back to a certified supplier, and all products can be traced forwards from point of purchase to point of sale.

These steps ensure that MSC certified seafood can be traced along its journey from ocean to plate giving buyers confidence in its provenance.

To ensure that these traceability measures are effective, the MSC regularly conducts a series of monitoring activities, summarised below.

1. **Tracebacks** on MSC labelled products check that the correct paperwork is in place along each step of the supply chain from the point at which a product is sold back to a sustainable source. Trace-backs are conducted regularly, with a focus on markets that could be at higher risk of mislabelling.

2. **Volumes** of MSC certified seafood are recorded along the supply chain and are monitored to detect product substitutions or mislabelling.

3. **Unannounced audits** ensure that MSC certificate holders are complying with traceability requirements.

4. **DNA testing** is carried out on hundreds of MSC certified products around the world to ensure that they are correctly labelled.

Leading global seafood retailers including WholeFoods in the USA, Sainsbury’s in the UK and Coles in Australia include MSC certified seafood in their sourcing policy to ensure the sustainability and traceability of their products. The Aquaculture Stewardship Council has also adopted the MSC’s traceability standard to ensure the integrity of responsibly farmed seafood.
The colour, shape and texture of fish and other marine species can often be altered beyond recognition during the manufacture of seafood products². This makes it near impossible to accurately identify the species of fish present in a product from sight alone. But regardless of how a seafood product is stored (fresh, canned, frozen), and what form it is in (fillet, eggs, fin, processed product), even the smallest fragment will contain a unique genetic code.

By comparing a particular segment of DNA with a reference library holding the genetic codes of most fish species, scientists can identify exactly which species is present in a sample and, for some species with very distinct populations, where in the world that species was caught.

The use of DNA testing has revolutionised seafood traceability over the past decade²² and there is ongoing research and development to improve efficiency and accuracy for an ever-growing number of species²³. It provides a vital tool to verify the authenticity of seafood products, deterring the commercialisation of endangered and vulnerable fish species² and to preventing seafood fraud.
The MSC’s DNA testing program

Since 2009, the MSC has commissioned DNA tests on hundreds of MSC certified products, from all over the world.

In combination with product tracebacks and supply chain volume reconciliations, the MSC’s DNA testing program is used to monitor the effectiveness of the MSC Chain of Custody certification program, and to verify the authenticity of products carrying the blue MSC label.

Using a list of all MSC licenced seafood products across all global markets (total of 8218 unique products at the time of testing), and with an aim of collecting a statistically significant sample size from this list, 257 MSC labelled product samples were randomly selected, collected and processed by an independent laboratory (the Wildlife DNA Forensics unit at Science and Advice for Scottish Agriculture, SASA). The products came from 16 countries, included 13 species of fish and covered a wide range of different product forms (fresh, frozen, chilled, preserved and surimi). The tests used by the laboratory identified a specific section of DNA, or ‘genetic barcode’ within each sample.

For each test SASA ensured that the genetic barcode identified could be clearly distinguished from those of closely related species, or those likely to be used as substitutes, to prevent false positives. Established genetic reference libraries were used to validate the barcodes (BOLD database, Fish Trace database, augmented with voucher specimen sequences from Genbank). The tests were repeated up to four times on samples that failed to produce a result. In order to ensure the independence and consistency of testing, all samples, with the unavoidable exception of canned products, were provided to the laboratories without the product details.

99.6% of 256 MSC labelled products we tested were correctly labelled

i. The laboratory used Single Nucleotide Polymorphisms (SNPs) which identify single nucleotide differences within sequences otherwise common between species and DNA sequencing which identifies a sequence unique to a particular species. Full details available upon request: standards@msc.org
2015 results by geography and species

100% correctly labelled

99.6% correctly labelled

16 different countries had MSC labelled products tested

256 different MSC labelled seafood products successfully tested

Correctly labelled

Incorrectly labelled

112 Herring

55 Pollock

29 Pacific Salmon

3 Pacific Cod

28 Atlantic Cod

8 Haddock

3 Saithe

2 Plaice

5 Hake

5 Hoki

4 Sardine

1 Rock Sole

1 Rock Sole
From ocean to plate

Traceability: From ocean to plate

“Oceana’s own DNA testing has revealed the scale of mislabelling within the global seafood market. Robust and credible traceability systems are essential to keeping illegally caught fish out of the international market while providing more information to consumers about their seafood purchases.”

Lasse Gustavsson, Senior Vice President and Executive Director, Europe with Oceana.

Supply chain traceability

Overall, 256 of the 257 products sent to the lab could be successfully identified from the DNA test results.

One sample that failed to yield a result after four attempts was a halibut product from the USA. The product was a pouch of seafood chilli so the processing and preserving processes may have denatured the sample’s DNA, an occasional limitation of the DNA testing process.

Only one product among the 256 successfully tested was found to be mislabelled. The mislabelled product was identified as a frozen fish fillet from a European retailer and was labelled as MSC certified Southern rock sole (Lepidopsetta bilineata). The DNA test results instead identified the product as the Northern rock sole species (Lepidopsetta polyxystra). This single incident was immediately investigated by tracing back the documentation through the supply chain, notifying the related certification bodies, and informing the brand owners of the result. The results of the investigation did not show any evidence of the deliberate substitution of an MSC certified species with a non-certified species, but rather the accidental mix-up of two closely related species, both of which had been caught in MSC certified fisheries. The mislabelling issue related to the two species not being correctly identified on documentation within the supply chain. The issue has been raised to the independent certification body who will ensure the issue is addressed at the next audit.

<table>
<thead>
<tr>
<th>Year</th>
<th>Correctly labelled (%)</th>
<th>No. MSC products successfully tested</th>
<th>No. species tested</th>
<th>No. mislabelled products</th>
<th>No. countries products sourced from</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>99.6</td>
<td>256</td>
<td>13</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>2013</td>
<td>99</td>
<td>320</td>
<td>13</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>2012</td>
<td>99.2</td>
<td>381</td>
<td>9</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>2011</td>
<td>97.4</td>
<td>195</td>
<td>6</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>2009</td>
<td>100</td>
<td>240</td>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>
The Data:
How MSC’s results compare with other studies

This table summarises the results of the most recent DNA testing studies that have been carried out on seafood products in different parts of the world.

Given the high levels of mislabelling found in the open market, the results of the MSC’s DNA testing program are very positive. For example, a recent scientific meta-analysis compared 51 similar DNA surveys including a total of 4,500 samples of seafood (primarily sampled from the retail sector) and revealed an average global mislabelling rate of 30%.

Nevertheless, any anomalies are thoroughly investigated and corrections made to ensure that the MSC Chain of Custody Standard continues to be applied correctly.

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Food outlets tested</th>
<th>% correctly labelled</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>2013</td>
<td>Restaurants, grocery stores, sushi venues</td>
<td>67.0 (1215)</td>
<td>9</td>
</tr>
<tr>
<td>Europe</td>
<td>2015</td>
<td>Retailers, caterers, cold stores, processors, points of import</td>
<td>94.0 (3906)</td>
<td>24</td>
</tr>
<tr>
<td>Europe</td>
<td>2015</td>
<td>Retailers</td>
<td>95.1 (1563)</td>
<td>22</td>
</tr>
<tr>
<td>UK</td>
<td>2015</td>
<td>Retailers</td>
<td>96.7 (647)</td>
<td>22</td>
</tr>
<tr>
<td>Spain</td>
<td>2015</td>
<td>Retailers</td>
<td>91.1 (267)</td>
<td>22</td>
</tr>
<tr>
<td>Ireland</td>
<td>2015</td>
<td>Retailers</td>
<td>96.1 (180)</td>
<td>22</td>
</tr>
<tr>
<td>Portugal</td>
<td>2015</td>
<td>Retailers</td>
<td>93.3 (178)</td>
<td>22</td>
</tr>
<tr>
<td>France</td>
<td>2015</td>
<td>Retailers</td>
<td>97.3 (146)</td>
<td>22</td>
</tr>
<tr>
<td>Germany</td>
<td>2015</td>
<td>Retailers</td>
<td>93.8 (145)</td>
<td>22</td>
</tr>
<tr>
<td>Belgium</td>
<td>2015</td>
<td>Restaurants and canteens</td>
<td>68.2 (280)</td>
<td>10</td>
</tr>
<tr>
<td>South Africa</td>
<td>2012</td>
<td>Wholesalers and retail outlets</td>
<td>69.3 (140)</td>
<td>25</td>
</tr>
<tr>
<td>Canada</td>
<td>2011</td>
<td>Retailers, takeaways, sushi venues</td>
<td>58.9 (236)</td>
<td>26</td>
</tr>
</tbody>
</table>
Conclusions and future plans

Although these results are promising, there remain a number of limitations with DNA testing. The MSC is seeking to address these as well as continuing to use targeted trace-backs, unannounced audits and volume reconciliations to ensure the integrity of of the certified seafood supply chain.

Broadening the scope of the DNA testing program to include food service

The latest DNA testing program verified the authenticity of a fully randomised, independent and representative sample of MSC labelled products in the retail sector. Although there are limitations to this approach, product availability and access restrictions (e.g. to schools) currently prevent an equally representative sample of products being collected from the foodservice sector. To address this, and as higher rates of mislabelling have frequently been reported in restaurants, canteens and takeaways than in retailers\textsuperscript{8-10,18,13} the MSC plans to introduce a requirement for randomised testing in certified food service outlets and introduced a DNA-testing requirement into the certification audits of consumer facing companies (including fish counters) in 2015.

Improving tuna testing

The MSC’s latest round of DNA testing did not include tuna products. Canned tuna products (the majority of MSC labelled tuna products) are notoriously difficult to extract good quality DNA from, because the heating process used to cook and sterilize the fish during canning, and the liquid the tuna is stored in (oil, brine, vinegar), can denature the DNA, preventing the genetic barcodes of different species from being identified\textsuperscript{27}. Although the MSC’s 2013 DNA testing program included 40 tuna products, with no evidence of mislabelling, the test failed for 12 tuna products (30%), so tuna testing was discontinued in 2015. The MSC are currently working closely with Australia’s Commonwealth Scientific and Industrial Research Organisation (CSIRO) to develop a test which will be able to distinguish between all commercially important tuna species, and their likely...
substitutes, and is more effective for canned products. This test will be trialled in 2016 and, if successful, included in ongoing testing from 2017 onwards. While these tests are in development the MSC is conducting a series of tracebacks specifically targeting tuna supply chains to ensure they are compliant with the MSC’s traceability standard.

**Research and improvements**

The MSC is also fostering other research partnerships in the field of seafood traceability. In addition to CSIRO, the MSC collaborates with geneticists at the University of Bangor and with the LABELFISH initiative which encourages greater synergies in protocols, research or testing.

DNA testing is currently less developed for shellfish. Looking to the future, the MSC’s testing program will be expanded in scope to include other seafood products like prawns and mussels. The MSC is currently collaborating with researchers in Australia to explore the use of Trace Element Fingerprinting (TEF) as a traceability tool. The technique is currently being trialled by Austral Fisheries as a technique to determine the probable origin of shrimp on the Australian prawn industry, with potential for international expansion in future. Considered one of the most robust methods for determining the likely origin of seafood, the method compares the trace element profile (i.e. concentration of minerals) identified in the shells and tissue of seafood products with the trace element profile found in fisheries and shrimp farms to look for matches. The inclusion of new population-level genetic tests that determine the geographic origin (catch area) of some species will also be explored where potential supply chain risks are identified.
References


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