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**Low mislabeling rates indicate marked improvements in European seafood market operations**

# Low mislabeling rates indicate marked improvements in European seafood market operations

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**Over the span of a decade, genetic identification methods have progressively exposed the inadequacies of the seafood supply chain, revealing previously unrecognized levels of seafood fraud, raising awareness among the public, and serving as a warning to industry that malpractice will be detected. Here we present the outcome of the latest and largest multi-species, transnational survey of fish labeling accuracy to date, which demonstrates an apparent sudden reduction of seafood mislabeling in Europe. We argue that recent efforts in legislation, governance, and outreach have had a positive impact on industry regulation. Coordinated, technology-based, policy-oriented actions can play a pivotal role in shaping a transparent, sustainable global seafood market and in bolstering healthier oceans.**

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In little more than a decade, the rapid and widespread use of genetic identification protocols has transformed food authenticity testing from a niche area into a highly influential biotechnological application worldwide (Ogden 2008; Yancy *et al.* 2008; Lou 2015). Although livestock and agricultural products remain the main focus of certification schemes and trading standards controls (European Commission's Database of Origin & Registration; http://ec.europa.eu/agriculture/quality/door/list.html), the most notable changes in perception and attitude have been observed with seafood. Over half the seafood intended for direct human consumption is still "hunted and gathered" from wild communities and populations (FAO 2014), over which humans cannot exert the control afforded in the case of farmed organisms. Seafood identification investigations across the world unveiled a presumably long-standing lack of transparency in trade operations (Stanziani 2007), prompting extensive media coverage (Mariani *et al.* 2014), swaying public opinion, alerting conservation groups (Warner *et al.* 2013), and urging policy makers and governments to find rapid and effective solutions (FSAI 2012; FDA 2014).

Despite these developments, most seafood identification studies conducted so far tended to have a relatively narrow focus, either adopting a regional slant (eg Miller and Mariani 2010) or targeting specific products and/or conservation concerns (eg Logan *et al.* 2008). Sampling effort and design of these studies also lacked the scope and rigor required to realistically represent the status of seafood authenticity in an entire sector of a major economy. Here, we present results of the largest seafood authenticity investigation conducted to date, spanning six European countries and nine different seafood products/species (Table 1). The analysis was designed to determine the current level of labeling accuracy in wild fisheries products in the European Union (EU) mainstream seafood retail sector, and to examine labeling accuracy in the context of EU regulations, the public perception of seafood authenticity, and similar recent multi-state, multi-species surveys conducted in North America (Warner *et al.* 2013; FDA 2014; Khaksar *et al.* 2015).

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## Methods

We obtained fresh, frozen, and tinned products labeled as "cod" (*Gadus* spp), "tuna" (*Thunnus* spp), "haddock" (*Melanogrammus aeglefinus*), "anchovy" (*Engraulis* spp), "hake" (*Merluccius* spp), "monkfish" (*Lophius* spp), "plaice" (*Pleuronectes platessa*), "swordfish" (*Xiphias gladius*), and "sole" (*Solea solea* in Germany; *S solea* for "Dover sole", *Microstomus kitt* for "lemon sole", and *Limanda aspera* for "yellowfin sole" in the UK) – and/or using the corresponding, accepted market names in each respective country – from retailers in 19 cities in France, Germany, Ireland, Portugal, Spain, and the UK (Table 1) between 2013 and 2014 (WebTable 1). Samples of cod and tuna, the most popular finfish products consumed in Europe, were collected in all countries, while other species were also selected to cover a broad spectrum of popular finfish on offer in Western Europe. To ensure proper replication and extensive spatial coverage, we surveyed between two and four cities within each country (Table 1). In each of the cities, sampling was conducted over a wide metropolitan area and included collection of products from supermarkets, traditional markets, and specialized fishmongers. Collected tissue samples were stored in molecular-grade ethanol, and were subsequently transferred to the laboratory and genetically identified using a suite of established molecular and bioinformatics procedures (details in WebPanel 1).

## Results and discussion

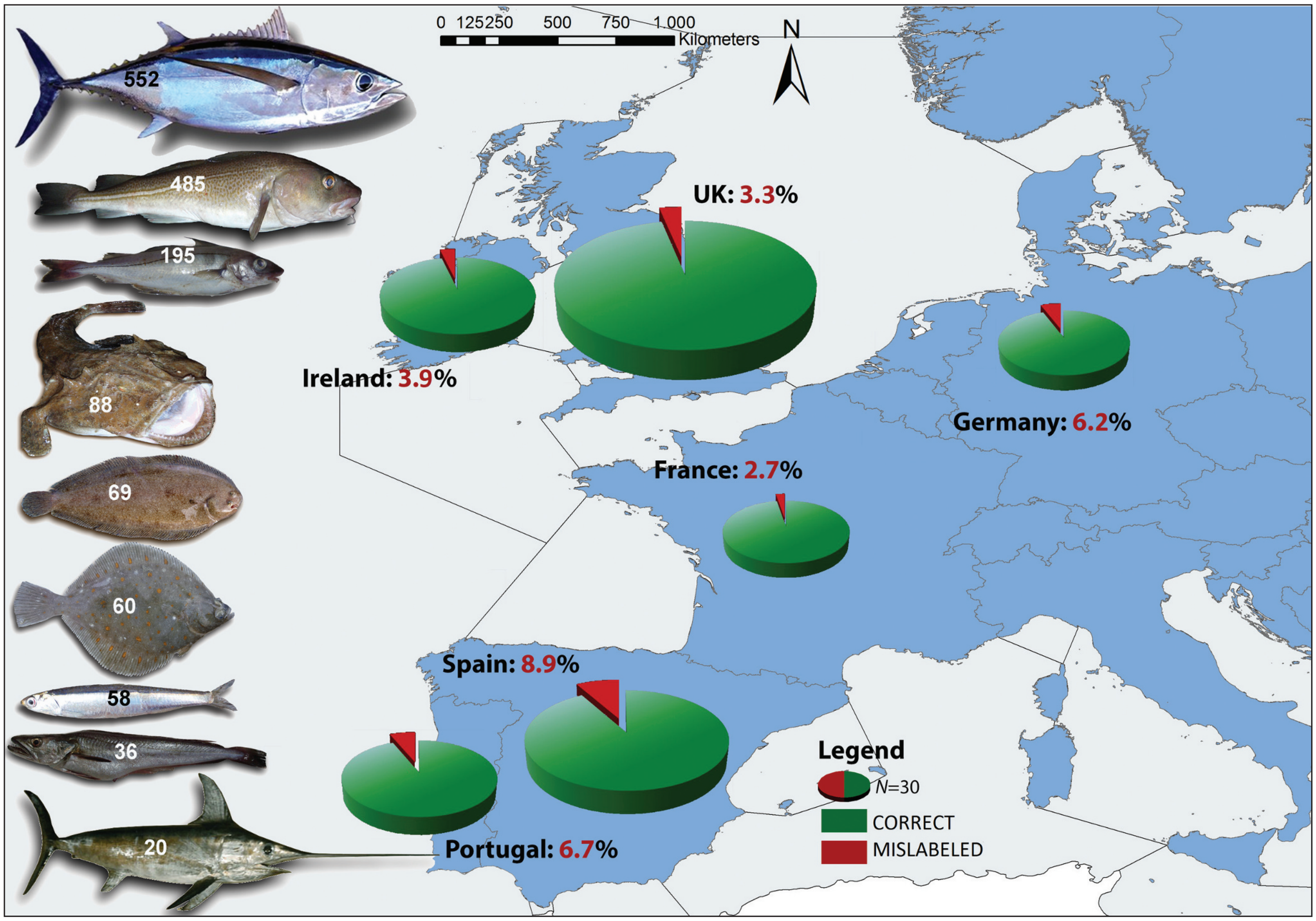
High-quality DNA sequence data were obtained for 1563 samples, of which only 77 (4.93%) proved to be mislabeled under European law (see WebTable 1). For each country, overall mislabeling rates were 2.7% (France), 3.25% (UK), 3.9% (Ireland), 6.21% (Germany), 6.7% (Portugal), and 8.9% (Spain) (Figure 1). Out of 15 possible inter-country pairwise comparisons, percentages were significantly different only between Spain and France ($\chi^2 = 10.9$; degrees of freedom [df] = 1; $P = 0.02$) and Spain versus the UK ($\chi^2 = 5.18$; df = 1; $P = 0.001$). However, this difference was caused by the high mislabeling incidence in Spanish tinned anchovy products, six of which had to be deemed mislabeled purely because the word "anchoa", rather than "anchoas", was used on labels containing non-European *Engraulis* species. If these six samples are not taken into account, the Spanish mislabeling rate drops to 6.74% and becomes statistically indistinguishable from all others. Sampling effort did not explain variance in mislabeling rates among either countries (Spearman's $r = 0.08$, $P = 0.84$) or seafood products ($r = 0.10$, $P = 0.77$), and no effect of retail product type was detected, including in the largest and most diverse category of mislabeled samples: tinned versus fresh/frozen tuna products ($\chi^2 = 0.36$, $P = 0.54$). The city of Vigo was the only place where yellowfin tuna (*Thunnus albacares*) was on occasion found to be replaced by albacore (*Thunnus alalunga*) and where other *Thunnus* species

**Table 1. Summary of seafood product genetic identification across retailers from 19 European cities between 2013 and 2014**

| | *Cod* | *"Tuna"* | *Haddock* | *Anchovy* | *Hake* | *Monkfish* | *"Sole"* | *Plaice* | *Swordfish* | *TOTAL* | *(mislab)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UK (647/21) | | | | | | | | | | | |
| *Cardiff* | 35 | 42 | 33 | | | 12 | | | 5 | 127 | *(6)* |
| *Glasgow* | 30 | 38 | 33 | | | 12 | | | 7 | 120 | *(2)* |
| *Manchester* | 40 | 40 | 41 | | | 20 | 53 | 60 | 8 | 262 | *(10)* |
| *Plymouth* | 41 | 36 | 40 | | | 21 | | | | 138 | *(3)* |
| Spain (267/24) | | | | | | | | | | | |
| *Bilbao* | 11 | 10 | | 12 | | | | | | 33 | *(5)* |
| *Madrid* | 13 | 20 | | 11 | | | | | | 44 | *(2)* |
| *Santiago de Compostela* | 50 | 27 | | 15 | | | | | | 92 | *(3)* |
| *Vigo* | 48 | 30 | | 20 | | | | | | 98 | *(14)* |
| Ireland (180/7) | | | | | | | | | | | |
| *Cork* | 21 | 27 | 20 | | | 16 | | | | 84 | *(6)* |
| *Dublin* | 35 | 26 | 28 | | | 7 | | | | 96 | *(1)* |
| Portugal (178/12) | | | | | | | | | | | |
| *Faro* | 14 | 11 | | | 5 | | | | | 30 | *(3)* |
| *Lisbon* | 33 | 46 | | | 18 | | | | | 97 | *(6)* |
| *Porto* | 24 | 14 | | | 13 | | | | | 51 | *(3)* |
| France (146/4) | | | | | | | | | | | |
| *Boulogne sur Mer* | 22 | | | | | | | | | 22 | *(0)* |
| *Marseille* | 4 | 59 | | | | | | | | 63 | *(4)* |
| *Nantes* | 22 | 39 | | | | | | | | 61 | *(0)* |
| Germany (145/9) | | | | | | | | | | | |
| *Berlin* | 8 | 20 | | | | | 3 | | | 31 | *(1)* |
| *Frankfurt* | 6 | 12 | | | | | 5 | | | 23 | *(2)* |
| *Hamburg* | 28 | 55 | | | | | 8 | | | 91 | *(6)* |
| Total | 485 | 552 | 195 | 58 | 36 | 88 | 69 | 60 | 20 | **1563** | **(77)** |
| *Mislabeling rate* | *3.50%* | *6.88%* | *3.07%* | *15.5%* | *11.1%* | *0%* | *2.89%* | *0%* | *0%* | | |

**Notes:** Partial country-specific sampled/mislabeled ratios are reported in parentheses adjacent to country names. Numbers in parentheses appearing in the "*(mislab)*" column refer to city-specific mislabeling levels. Product-specific mislabeling levels are summarized along the table's bottom row.




Fish images: © A Clay, © H Hillewaert, © K Vanhalst, and © WWF

***Figure 1.*** *Map summarizing the levels of fish product mislabeling recorded in six European countries. The nine species tested are stacked to the left, with overall sample numbers imprinted on the images. Pie chart size is proportional to the number of samples screened (see chart size corresponding to a sample size of* N = 30 *in the legend). Red segments and percentages indicate mislabeled products.*

were used as substitutes for Atlantic bluefin tuna (*Thunnus thynnus*); Manchester and Hamburg had a higher incidence of yellowfin–bigeye tuna (*T albacares–Thunnus obesus*) substitution (WebPanel 1). However, despite our use of a stringent 100% sequence match criterion to define species identity, currently available diagnostic methods – when applied to distinguishing between these closely related species – yield ambiguous results (Viñas and Tudela 2009); thus, caution is warranted in such instances. Overall, no country-associated trends were identified.

A few notable outcomes arise from this study. First, the rate of mislabeling across a considerable portion of the European seafood market is rather low, and decisively lower than that originally documented by the initial wave of seafood identification studies conducted only a few years ago (Logan *et al.* 2008; Wong and Hanner 2008; Miller and Mariani 2010). Interestingly, these current mislabeling rates are consistent with those found in two independent analyses of fish market samples from France (371 samples; Bérnard-Capelle *et al.* 2014) and the UK (386 samples; Helyar *et al.* 2014). Together, these results appear to lend support to the suggestion that rapid changes in seafood trade operations may be influenced in part by mass media coverage (Mariani *et al.* 2014). Although Di Pinto *et al.* (2015) reported high rates of mislabeling in a southeastern portion of Italy, the narrow regional context, the niche market investigated ("perch", "grouper", and "swordfish"), and the lack of information on sampling dates make those findings difficult to compare with our broad, standardized, Western European analysis.

A second line of evidence emerging from our Europe-wide dataset contrasts sharply with even the most recent investigations in the US retail sector (Warner *et al.* 2013; Khaksar *et al.* 2015), which document mislabeling rates between 12% and 41%. Even when the US Food and Drug Administration recently applied genetic testing to wholesale seafood products prior to the point of retail (FDA 2014), mislabeling was still around 15%, a rate that is likely to be higher in the retail sector, as the products move farther along the supply chain (Miller *et al.* 2012).

The fact that such low levels of mislabeling, and the underlying mechanisms, appear essentially consistent across several European countries with profound historical and cultural differences in seafood provision and consumption indicates that a common, transnational set of factors is currently at play in regulating the European market. Media coverage may have had a measurable short-term impact (Mariani *et al.* 2014) in raising consumer awareness and holding industry operators accountable for unacceptable trading standards, but less encouraging results from North America show that mass media and civil society action alone cannot serve as industry regulators (Warner *et al.* 2013). On the other hand, the factor that appears to be driving the difference between Europe and the US is the EU policy-making process, which continues to introduce updated food-labeling regulations to be implemented by member states, with emphasis on standardization and traceability (EC 2013). US federal regulations on food labeling, by contrast, are less detailed, often non-binding (FDA 2014), and inconsistent, with notable differences in accepted market names of fish observed among US states (Logan *et al.* 2008). Considering that North America mostly lacks the historical, political, and language barriers present in Europe, it is reasonable to expect relatively greater efficiency in the processes of standardization, legislation, implementation, and enforcement in North America than in the EU. Recent efforts advocating for an alignment of US labeling standards with European regulations (Lowell *et al.* 2015) may help promote the necessary steps for a more transparent and accountable retail sector.


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***Figure 2.*** *A typical European fishmonger's display (Barcelona, Spain). Popular aquaculture finfish products (salmon, gilthead sea bream, sea bass) are on sale alongside produce from wild catches, such as tuna loins (in the background), hake, Atlantic bonito, and monkfish (in the foreground).*

Europe and North America play similarly influential roles in the world's seafood trade (FAO 2014), with substantial impacts on natural resources and the global economy. Both regions also act as pivotal research hubs for scientific advancement in this field; thus, positive breakthroughs achieved in Europe and the US are likely to result in positive change at the global level. Undoubtedly, even a small percentage of mislabeled seafood products available in the market have undesirable consequences for human health, the economy, and the environment. Furthermore, greater challenges lie outside the bounds of the mainstream retail sector (Figure 2); restaurants (including "carry-out" or "take-away" options) and other food services are subject to relatively fewer labeling regulations and to reduced enforcement (Mariani *et al.* 2014), and arguably represent the next target for a standardized assessment of seafood substitution (Kappel and Schröder 2015). Yet the scenario emerging from this Europe-wide assessment shows that rapid, positive changes in the seafood supply chain are possible. Perhaps for the first time since the repercussions of seafood mislabeling studies started to influence the fields of fisheries, environmental conservation, and food science, we document a clear and substantial improvement in EU seafood retail sector operations, an improvement that stands as an exceptional opportunity to realize a sustainable global seafood market. Improved legislation, continued surveillance entrenched within governance, and the adoption of forensic genetics tools represent the foundation upon which a safe and transparent food supply chain can be built.

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