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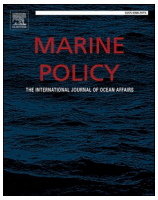

The last mile challenge: Certified seafood and federal labeling laws out of sync at the end of the supply chain in Los Angeles, California

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ABSTRACT

Seafood certification programs aim to aid consumers in identifying products with reduced environmental impacts and assure accuracy in labeling and traceability, complementary to or in the absence of governmental regulatory action. The most widely recognized seafood certification program is led by the Marine Stewardship Council (MSC), whose Chain of Custody Standard emphasizes accuracy in fish sourcing from harvest to retail using tracebacks and audits. Here explicit testing was conducted on the labeling accuracy of MSC-certified seafood sold in the world's second largest seafood importing market, the United States, per stringent application of federal labeling laws. Samples of commonly sold MSC-certified fresh fish were collected from processors (123) and grocers (149) in Los Angeles, California from 2017 to 2019 and identified to species using DNA barcoding. Grocers' mislabeling rates were statistically higher than those of processors. Most mislabeling was attributed to substitution among congeners or labeling with invalid FDA names. Data-driven recommendations include regular DNA-based testing and greater harmonization between certification programs and federal guidelines, particularly in coordination with supply chain end vendors.

1. Introduction

Seafood sustainability requires accuracy in labeling. The scale and complexity of the global supply chain conceals the actual value and costs of harvested seafood [1] while also creating space for seafood mislabeling and illegal fishing [2,3]. In response, recent multi-lateral agreements by policy agencies including the United Nation's Food and Agricultural Organization, the Asian-Pacific Fisheries Commission, the Southeast Asian Fisheries Development Center, and the European Union have set the framework for corrective action. In the United States (US), long-standing policies including the US FWS Lacey Act of 1900 (US 16 U. S.C. §§ 3371 – 3378) and the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (FWS 16 USC 1801 MSA § 2) prohibit the selling of fish in violation of state, federal, or foreign laws. More recently, provisions have been implemented to increase traceability. The Seafood Import Monitoring Program (SIMP) requires data reporting from initial harvest to arrival at the US port of entry (NOAA 15 CFR part 902, Vol 81) and the Country of Origin Labeling (COOL) regulation mandates importers and retailers maintain data on seafood origin and production method from US port of entry to end consumers (USDA 7 CFR Part 60). Policies requiring tracking of seafood throughout the supply chain have the capacity to reduce seafood mislabeling, particularly when utilizing chain-of-custody traceability instruments [4,5].

Environmental performance certification or ecolabeling is a market-based incentive to help consumers make informed choices of product attributes, for example 'organic', 'wild-caught' or 'dolphin-safe'. Although ecolabels can indicate the product's reduced environmental impact, a fish labeled 'organic' or 'dolphin-safe' does not imply the fish was harvested sustainably [6]. Environmental certification of seafood is a promising tool that provides consumers with verified information on the species identity, source fishery, and/or use of sustainable fishing practices [7]. Sourcing sustainable seafood can be a proactive strategy to enhance transparency and resilience of seafood supply chain [8].

The Marine Stewardship Council (MSC) ecolabel certification

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program is the largest and most globally recognized in certifying sustainable fisheries. MSC-certified fisheries cover 14% of total marine catches, are valued at USD $8.4 billion and sold in more than 100 countries [9]. Central to the certification program are the 1998 MSC Fisheries Standard – stating seafood can be harvested indefinitely without overexploitation, adverse impacts on marine ecosystems are avoided, and fishing is in compliance with all local, national and international laws; and the 2001 MSC Chain of Custody Standard – stating all actors in the supply chain, from the point of harvest to retail, abide by the MSC criteria ([10], [11], [12]). The MSC Chain of Custody Standard also requires that certified and non-certified are not mixed together [12]. Only when these standards are met is a fish product deemed MSC-certified, an assurance of complete traceability back to the harvest event from a sustainable fishery [13]. Yet studies have been critical of the MSC program for failing to meet its own standards. Criticism has included overly lenient discretion to third-party certifiers, incentives which encourage certification of fisheries that may be ill-managed or overfished, misleading over-representation of the proportion of small-scale fisheries in promotional materials, shortcomings in species and fishery stock substitutions that obscure potential mercury toxin exposure to consumers, and a costly and burdensome mechanism for voicing formal objections to MSC fishery certification [10,14–18].

In support of its Chain of Custody Standard, MSC implements multiple monitoring activities including paperwork tracebacks to confirm fish are from a sustainable source and unannounced audits of distributors, processors and retailers [12]. As validation of certified labeling, MSC has recently reported DNA barcoding results of over 1400 MSC-certified products, finding a mislabeling rate of less than 1% [19]. This rate is well below the average mislabeling rates (8–30%) in reviews of non-certified seafood substitution studies [20,21]. DNA barcoding studies of MSC-certified products are uncommon, however, Marko et al. [22] found 8% of MSC-certified Chilean sea bass *Dissostichus eleginoides* were mislabeled whereas Shehata et al. [23] found a much higher rate of mislabeling (33%) of MSC-certified Chilean sea bass, all identified as *D. mawsonii* or *D. eleginoides* but sold under invalid names. Barendse et al. [19] obtained MSC-certified samples from 18 countries between 2009 and 2015, including 105 sequenced samples from the US with a single sample mislabeled. For these samples, US Food and Drug Administration (FDA) labeling regulations provide explicit guidance that seafood must be sold using either the Acceptable Market Name or Common Name, of which an unambiguous scientific species name is provided via the Seafood List (US FDA CFR 101.18c). FDA regulations do not, however, permit the use of scientific names by themselves but may be used to supplement labeling with the Acceptable Market Name or Common Name. Barendse et al. [19] did not test labeling accuracy using US-specific names, likely because the international scope of the study. Additionally, ~39% of all MSC-certified fish products tested were resolved only to the genus or multi-species level and most judged correctly labeled. Given MSC-certification requires each certified product to be traced back through the supply chain, more unequivocal identification should be within reach.

The present study expressly tests MSC-certified seafood for labeling accuracy using current US FDA seafood regulations. Specifically, the study (a) collected only seafood exhibiting the MSC-certified ecolabel, (b) targeted fish most consumed in the US per the National Health Nutrition Survey [24], and (c) focused on the Los Angeles (California) region to identify potential trends over time from reoccurring sampling; strategies consistent with best practices for characterizing seafood mislabeling [20]. Additionally, same-month sampling of retailers and processing plants was included to investigate mislabeling at multiple levels of the supply chain, a finding of past seafood studies [23,25].

2. Methods

2.1. Grocer sampling design

MSC-certified seafood were purchased from 13 Los Angeles area grocers where consistently sold. To avoid duplicate sampling, only one sample per fish type was purchased per visit and each grocer sampled a maximum twice per month. Approximately one-tenth pound cuts of fish were purchased with certification confirmed by the display sign and sales receipt. Per the MSC Chain of Custody Standard, fish labeled MSC-certified are fully traceable to a certified fishery (Anton et al., 2020). Authors made the reasonable assumption that fish labeled MSC-certified were accurate and the Standard enforced. Purchased fish were kept on ice, taken to lab, and subsamples of ~0.5 g were preserved in 95% ethanol in individually labeled tubes until molecular analysis as described in Willette et al. [26].

A total of 149 samples were purchased from 2017 to 2019. A minimum of 10 samples were obtained for the following marketed fish Atlantic cod (*Gadus morhua*), halibut (*Hippoglossus stenolepis, H. hippoglossus*), coho salmon (*Oncorhynchus kisutch*), king salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*), and Chilean seabass (*D. eleginoides, D. mawsoni*) (Table 1). Marketed fish sold as black cod, Icelandic cod, true cod, and California halibut were included despite low sample size because these names do not appear as FDA Acceptable Market or Common names and warranted further investigation.

2.2. Processor sampling design

A total of 123 samples were obtained from two seafood processing plants in April and May 2019. Sampling exclusively targeted MSC-certified fish that had been also been sampled from grocery retailers. Six fish types were available from the processing plants – Pacific halibut (*H. stenolepis*), king salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*), Chilean seabass, albacore tuna, and Icelandic cod. A minimum of 10 samples were obtained per fish type, except for king salmon (Table 1). Whole fish were directly sampled with fish identity confirmed by container label, attached fish label tag, and/or accompanying fish invoice. Tools were cleaned between samples to avoid cross-contamination. Samples were immediately placed in 95% ethanol in individually labeled tubes and stored at room temperature until molecular analysis.

2.3. DNA barcoding

Genomic DNA was extracted from roughly 25 mg of preserved fish tissue in 300 μL of 10% Chelex solution in 1.7 mL tubes (BioRad, California, US) as described by Walsh et al. [27] or using column-based Quick-DNA miniprep extraction kit (Zymo Research, California, US) following the manufacturer's instructions. A 650-bp fragment of mitochondrial COI gene was amplified using the primers C_FishF1t1 and C_FishR1t1 [44] and the Illustra puReTaq Ready-To-Go polymerase chain reaction bead 0.2 mL tubes (GE Lifesciences, Pennsylvania, US). Each reaction mixture included 19 μL of molecular grade water, 1.25 μL of each 10 MM primer, and 1 μL of gDNA for a total volume of 25 μL. The thermocycle progression consisted of an initial denaturing at 94 °C for 5 min, then 35 cycles of denaturing at 94 °C for 30 s, annealing at 50 °C for 45 s, extension at 72 °C for 60 s, and a final extension at 72 °C for 10 min. PCR product was verified via gel electrophoresis and successful amplicons were purified and sequenced using the M13 sequencing primers [28] at a commercial sequencing facility (PsomaGen, Maryland, US).

Sequenced reads were assembled, trimmed, and proofread in Geneious software Prime 2019 (BioMatters, New Zealand). Resulting FASTA files were identified to species-level using the National Center for Biotechnology Information's (NCBI) Basic Local Alignment Search Tool (BLAST) (http://blast.ncbi.nlm.nih.gov/Blast.cgi) using the MegaBLAST option. This identification step introduces a level of uncertainty in the

Table 1
Mislabeling rate of MSC-certified fish by marketed name and source. United States Food and Drug Administration (FDA) species name associated with acceptable/common name provided. Fish labeled with a non-FDA acceptable or common are included separately.

Marketed Name	FDA Species Name	Processor			Grocer			Combined		
		Mislabeled	Total	%	Mislabeled	Total	%	Mislabeled	Total	%
Cod-Atlantic	*Gadus morhua*	–	–	–	2	15	13.3	2	15	13.3
Halibut	*Hippoglossus stenolepis,H.hippoglossus*	–	–	–	0	23	0.0	0	23	0.0
Halibut-Pacific	*Hippoglossus stenolephis*	5	38	13.2	3	17	17.6	8	55	14.5
Salmon-Coho	*Oncorhynchus kisutch*	–	–	–	0	30	0.0	0	30	0.0
Salmon-King	*Oncorhynchus tshawytscha*	0	4	0.0	0	11	0.0	0	15	0.0
Salmon-Sockeye	*Oncorhynchus nerka*	0	17	0.0	1	12	8.3	1	29	3.4
Seabass-Chilean	*Dissostichus mawsoni, D, eleginoides*	0	27	0.0	3	27	11.1	3	54	5.6
Tuna-Albacore	*Thunnus alalunga*	0	24	0.0	–	–	–	0	24	0.0
Total		**5**	**110**	**4.5**	**9**	**135**	**6.7**	**14**	**245**	**5.7**
Marketed names not FDA Acceptable/Common Name										
Cod-Black	–	–	–	–	1	1	100.0	1	1	100.0
Cod-Icelandic	–	0	13	0.0	0	6	0.0	0	19	0.0
Cod-True	–	–	–	–	4	4	100.0	4	4	100.0
Halibut-California	–	–	–	–	3	3	100.0	3	3	100.0
Grand Total		**5**	**123**	**4.1**	**17**	**149**	**11.4**	**22**	**272**	**8.1**

analysis between this study's DNA sequence and the corresponding match from the NCBI BLAST tool. Consequently, only sequences with a 98% or greater match were deemed verified to species identity; matches 97% or less were re-analyzed from the extraction step onward and only included if a high percent match could be obtained. A second source of uncertainty could come from PCR error. Commercial polymerases are highly accurate [29]. The error rate for the proprietary Illustra puReTaq Ready-To-Go PCR beads was unavailable, but a rate of 4.3×10^{-5} mutations/bp for Taq polymerase and even greater accuracy for other types of high fidelity enzymes generally minimizes PCR error [29]. The fragment size used in this study was ~700 bp fragment thus an estimated error rate <1% would be reasonable.

2.4. Data analysis

DNA-based identity obtained using the NCBI BLAST tool was then compared to the product-label (per sales receipt/invoice) for each sample using the Acceptable Market Name or Common Name per the FDA Seafood List. Strictly following FDA labeling rules (US FDA CFR 101.18c), seafood was deemed mislabeled if the scientific names of the DNA-based identity and product-label did not match. Mislabeling rates by species, year, and source (processor or grocer) were calculated. Agresti-Coull confidence intervals [30] were used to assess uncertainty in mislabeling rates, and the related Agresti-Caffo test [31] was used to compare mislabeling rates from grocers and processors. The Agresti-Caffo test was used over the Fisher's exact test, the latter which is recommended against for its conservatism and lower power than better alternatives [32,33].

3. Results

Successful PCR and sequence data were obtained from 272 samples

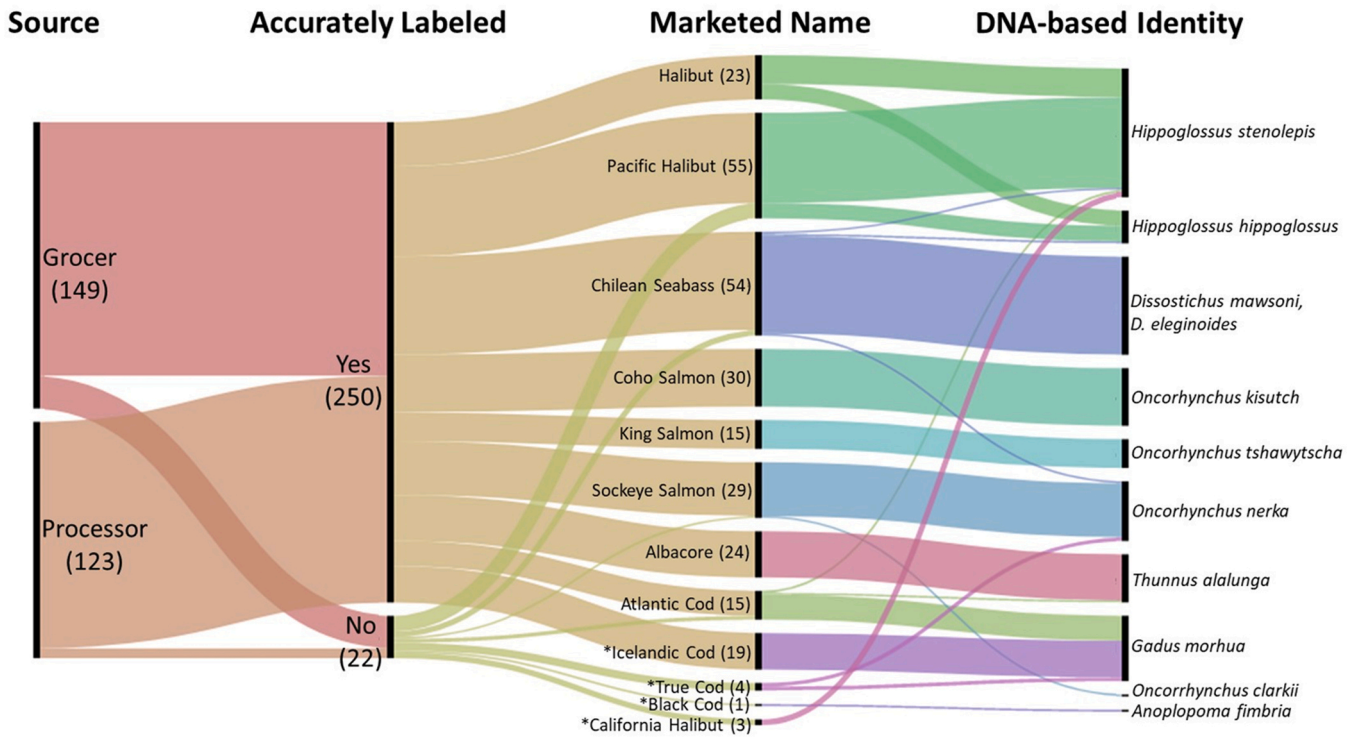

Fig. 1. Species level identification of MSC-certified fish by marketed name obtained from grocers and processors. * indicates FDA Seafood List does not include an Acceptable or Common name for marketed fish. Number in parenthesis indicates number of fish sampled by source, if accurately labeled and marketed name.

and all fish were identified to species level using BLAST (See SM Table S1). Overall mislabeling rate was 8.1% (95% CI of 5.4–12%), with processor mislabeling rate lower at 4.1% (95% CI of 1.5–9.5%) and grocer mislabeling rate higher at 11.4% (7.2–17.6%) (Table 1, Table S1, S2). With a *p*-value of 0.0144, the one-sided Agresti-Caffo proportion difference test indicates grocer mislabeling is significantly higher than processor mislabeling. Though mislabeling rate increased for processors (4.5%) yet decreased for grocers (6.7%) when excluding fish sold with invalid FDA names (n = 27). Mislabeling was not homogenous as eight of the 12 types of fish had mislabeling rates of either 0% or 100% (Fig. 1, Fig. S1), a result consistent with Luque and Donlan [20].

Five fish types (Chilean seabass, Sockeye salmon, King salmon, Pacific halibut, Icelandic cod) were available and sampled from both grocers and processors during the study period. A specific comparison among these fish types and months illustrated a higher average mislabeling rate at the grocer level 9.6% (95% CI of 4.5–18.9%) than processor level 5.1% (95% CI of 1.9–11.7%); however, the reduction in sample size leads to an increased *p*-value of 0.1342 in the Agresti-Caffo one-sided test of proportion difference.

4. Discussion

This study's overall seafood mislabeling rate of 8.1% was higher than the 0–2.6% rate in MSC annual reports from 2009 to 2015 [12], and higher than the <1% rate reported by Barendse et al. [19]. The discrepancy between this study and the ~1% rate reported elsewhere may be partially attributed to three factors – (1) failure to adhere to specific national labeling regulations, (2) substitution among congeners within the supply chain, and (3) accidental mix-up among fish by retail staff. For example, both Anderson [12] and Barendse et al. [19] obtained MSC-certified products from countries including Canada, the United Kingdom, and the US and validated seafood labeling accuracy based on MSC package label, but not per each source country's labeling regulations – respectively, the Canadian Food Inspection Agency's (CFIA) Fish List, the United Kingdom Commercial Designations of Fish guidance, and the US Seafood List. To be deemed accurately labeled, seafood sold in each of these countries must match the designated scientific and common name when marketed and sold. Such discrepancy between MSC product labeling in Canada and the CFIA Fish List was also recently reported by Shehata et al. [23] Notwithstanding, the 1998 MSC Fisheries Standard requires compliance with all local, national, and international laws and the 2001 MSC Chain of Custody Standard specifically emphasizes accuracy in fish sourcing from harvest to retail using tracebacks and unannounced audits. The current study's 8.1% mislabeling rate across multiple MSC-certified fish types all sampled from a single country is thus unexpected, yet in line with single species surveys of MSC-certified seafood sampled from a single country [22,23]. The 8.1% is lower than average seafood mislabeling rates reported in recent reviews of DNA barcoding surveys (30%: [21]; 23%: [25], 24% at study-level but 8% at product-level: [20]). Luque and Donlan [20] emphasize the high degree of uncertainty in mislabeling (largely due to the small sample size of individual studies). It is also lower than several geographically focused studies on non-MSC-certified seafood mislabeling in Los Angeles, California (52%: [34]; 47%: [26]). Seafood ecolabeling programs have great promise and are convenient for consumers to understand, yet greater harmonization with national labeling requirements is needed, particularly for some problematic fish types.

4.1. Cod

Cod is among the most popular fish in the US [24] and one of the few fish mislabeled in previous DNA testing of MSC fish [19]. Our study included four cod fish types – Atlantic cod, Icelandic cod, true cod, and black cod (Table 1). Two mislabeled Atlantic cod were identified as *H. stenolepis* and *T. alalunga*, likely accidental sales counter errors given other Atlantic cod were accurately identified from these grocers. Icelandic cod from both grocers and processors was identified as *G. morhua* or Atlantic cod per the Seafood List. Although not included in the Seafood List, Icelandic cod is permissible per US FDA CFR 101.18c as it is a truthful representation of geographic origin [35]. The single black cod sampled was genetically identified as *Anoplopoma fimbria* and should have been labeled sablefish. Notably, black cod is highlighted as a fictitious name for sablefish per FDA Import Alert 16–04 [36]. Four true cod were sampled and genetically identified as either *O. nerka* sockeye salmon, likely human error, or as *G. macrocephalus* Pacific cod. The latter may reveal a hidden challenge for seafood retailers. The legal authority and responsibility of seafood labeling in interstate commerce lays with the US FDA, yet the US National Oceanic and Atmospheric Administration (NOAA) provides information on domestically caught seafood that can differ. For example, the NOAA FishWatch program lists *A. fimbria* as sablefish and black cod, and *G. macrocephalus* as Pacific cod and true cod. Thus, labeling fish black cod or true cod may not be attempts to deceive consumers but rather a consequence of unaligned labeling conventions across agencies.

4.2. Halibut

Halibut sold in Los Angeles sushi restaurants has frequently been mislabeled, most often substituted for olive flounder *Paralichthys olivacea* or summer flounder *P. lethostigma* (23%: [34]; 100%: [26]). In contrast here, all fish sold under the generic moniker 'halibut' were accurately labeled and identified as either Atlantic halibut *H. hippoglossus* or Pacific halibut *H. stenolepis*. Fish explicitly labeled as Pacific halibut, however, were substituted with Atlantic halibut. The swapping among geographical congeners may have been accidental or require increased attention as sampled grocers and processors sell both MSC-certified Atlantic and Pacific halibut. All fish sold as California halibut were genetically identified as Pacific halibut *H. stenolepis*. The market name California halibut is problematic as it is not an FDA Seafood List acceptable market name for any fish but is listed as an unacceptable vernacular name for California flounder *Paralichthys californicus*.

4.3. Comparing grocers and processors

MSC-certified seafood was mislabeled more commonly at the grocer level than at the processor level overall, when comparing only among fish labeled with FDA acceptable market names, and when specifically examining the same fish types in the same sampling months. Furthermore, the five cases of mislabeling at the processor level were all Atlantic halibut swapped for Pacific halibut, a mix up of MSC-certified congeners from different geographic regions. Sources of mislabeling at the grocer level were more diverse, including geographic substitutions, use of invalid FDA acceptable market names, and several clearly erroneous labeled fish that may have been human error at the fish sales counter. One limitation here may be from the decision to obtain only one sample per fish type per visit from grocers to prevent repeat sample the same fish, a problem overcome at processing plants where whole fish were sampled. Although this sampling strategy yield more fish types from grocers than processors, overall study sample sizes were similar. While the magnitudes of mislabeling rates (and corresponding p-values) are different, non-certified DNA research showing higher, yet not statistically different rates in retailers than processors [23] suggests consistency in mislabeling. Although restaurants were not sampled in the current study, purchasing location is an influential factor in explaining mislabeling across the broader supply chain [23,25] thus future research should test if mislabeling rates of MSC-certified seafood in restaurants and sushi venues are higher than reported here for processors and grocers. Whereas the complexity and multiple transactions of the global seafood supply chain challenge accurate labeling [37], MSC-certified fish benefit from the organization's Chain of Custody Standard which guarantees traceability 'from ocean to plate' [13]. This said, there is

room for improving accuracy in MSC-certified seafood in the world's second largest fish import market [38] and a top destination for MSC-certified products [9].

4.4. Conclusions and recommendations

For nearly a decade DNA-based seafood studies around Los Angeles have triggered moments of media attention and enthusiasm for action, yet inaccurate labeling and fraud persists [4,26,34]. Innovation is needed to catalyze lasting change. One example is The Los Angeles Seafood Monitoring Project, a local collaboration among researchers, restaurateurs, non-profit organizations, and government agencies to combat seafood mislabeling [39]. In view of the complex uncertainties noted in the meta-analysis of Luque and Donlan [20], it is crucially important to increase sampling for improved monitoring accuracy. In addition to identifying ambiguities in seafood labeling regulations, the Project conducts regular city-wide DNA-based testing of seafood and supports open communication among partners to promote seafood literacy. The Project is not an environmental certification program yet its coordinated effort is an example of how DNA testing can provide complementary verification of both certified and non-certified seafood in the last mile of the supply chain.

Ecolabeling incentivizes environmentally conscious use of natural resources, complementary to or in the absence of governmental regulatory action [40]. Consumers trust ecolabels and are willing to pay a premium [41], thus environmental certification organizations must assure the authenticity of fish identity for consumers. The MSC assures consumers of labeling authenticity through its Chain of Custody Standard – attesting seafood is from sustainably managed fisheries, certified seafood is kept separate from non-certified seafood, and that fish can be traced back through the supply chain from the point of sale to the fishery (Anderson et al., 2019). DNA barcoding is a validation method towards overcoming seafood security and sustainability challenges and should be broadly incorporated into seafood supply chain surveillance and monitoring [42], particularly given the precipitous decline in DNA sequencing costs [43]. Although recent policy like the US's Safety and Fraud Enforcement for Seafood (SAFE) Act of 2013 promote coordination among seafood regulators to use best practices, the pairing of certification programs and DNA barcoding has yet to be broadly adopted.

The following policy actions are suggested to build upon the transformative work MSC and other programs have begun towards attaining seafood security and improving traceability. First, wider and regular incorporation of DNA-based species identification in environmental certification programs is needed, complementary to existing visual inspections and trace-back systems. Next, policies to encourage greater harmonization between certification programs and national-level seafood labeling regulations should be pursued, including the systematic use of scientific names and forensic testing. Given MSC-certified products are sold in 100 + countries, this coordination should first be piloted in several large markets on fraud-prone species. Lastly, as fisheries regulations evolve, genetic-based testing should underpin updates to fisheries policies, help coordinate fish labeling nomenclature, and be leveraged to champion seafood literacy.

CRediT authorship contribution statement

Demian Willette: Conceptualization, Methodology, Formal analysis, Original draft preparation, Supervision. **Sofia Esteves**: Conceptualization, Investigation. Writing. **Ben Fitzpatrick**: Formal analysis, Writing. **Marie Smith**: Investigation, Writing. **Kesterlyn Wilson**: Investigation, Writing. **Xiaoya Yuan**: Investigation, Writing.

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Competing interest statement

The authors have no competing interests to declare.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2020.104380.

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