Food Control 168 (2025) 110913

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Outreach & DNA-based monitoring facilitate 3-fold reduction in seafood mislabeling in Los Angeles over 10 years

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A B S T R A C T

Awareness and intervention can reduce fraudulent labeling in seafood. Using a 10-year longitudinal study approach, DNA-based monitoring data reveals a lower sushi mislabeling in Los Angeles restaurants over time. This is in part attributed to implemented recommendations by restaurants of a local academia-industry-government outreach initiative launched in 2018, The Los Angeles Seafood Monitoring Project. We found mislabeling was 3-fold lower among project-partnering restaurants than other restaurants. This difference was statistically significant, illustrating the combination of project partnering and implementation of recommendations was most impactful on reducing mislabeling rates. Lastly, the study period includes the COVID19 global pandemic, which additional monitoring effort between 2019 and 2021 did not reveal any significant change in mislabeling rates.

1. Introduction

DNA-based detection of seafood fraud in the United States marketplace began more than 20 years ago when 77% of store-bought red snapper (*Lutjanus campechanus*) were found substituted with other fish (Marko et al., 2004). Seafood fraud has persisted. Seafood is deemed fraudulent if sold under the name of another fish, an action prohibited in the U.S. (21 U.S.C. Ch. 9 § 403). Seafood mislabeling imposes health and economic costs on consumers, destabilizes the seafood supply chain, and can indirectly enable human rights violations (Pauly et al., 2005; Mendoza et al., 2016, p. 152; Brito and Willette, 2023).

Only two percent of all seafood imported into the U.S. is physically inspected, primarily for food safety reason (Love et al., 2011). Seafood fraud is difficult to detect once fish are in the supply chain because diagnostic physical features are often removed during processing and species authentication is dependent on identification documents transmitted with the product. Data reporting requirements from first harvest to end consumer have expanded in recent years with the implementation of the Seafood Import Monitoring Program (NOAA 15 CFR part 902, Vol 81) and Country of Origin Labeling regulation (USDA 7 CFR Part 60). No current U.S. regulation, however, requires DNA-based authentication of species identify, leaving opportunity and ambiguity for species substitution and fraud.

DNA barcoding is a molecular genetics method that targets a highly conservative region of the genome (e.g., Cytochrome *c* oxidase subunit I, COI), then matches the obtained sequence data of the sample to a DNA barcode library of known species (Hebert et al., 2003). The higher percentage match, the more accurate the identification, with 98% or higher generally accepted as a species level match (Dawnay et al., 2007; Hubert & Hanner, 2015). DNA barcoding is a common, well-vetted method used for seafood species identification in over 35 countries (see Table S1). Detected mislabeling rates vary by species, country, and vendor-type, among other factors. Literature reviews of seafood mislabeling studies report mislabeling rates with a broad range from of 1–98% (Barendse et al., 2019; Lea-Charris et al., 2021) yet discerning informative patterns from across the reviewed studies is limited by experimental design differences in targeted fish types, vendor, and geographic scope (Giusti et al., 2023; Singh et al., 2024). Furthermore, most studies provide only a snapshot of seafood mislabeling rates over a single period of weeks to months, inhibiting our ability to detect the most persistent mislabeling patterns, or shifts in mislabeling due to fraud-reduction campaigns and global disruptions like the COVID19 pandemic.

Here we show one-third of sampled seafood from 2012 to 2023 was mislabeled in the major U.S. city of Los Angeles, California. We also report the impact of an outreach project to eliminate seafood mislabeling in the city, resulting in a 12-percentage point decline city-wide. The impact was even greater at restaurants which implemented project recommendations, roughly a 3-fold reduction in mislabeling incidences. Mislabeling rates during the global COVID19 pandemic are also

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https://doi.org/10.1016/j.foodcont.2024.110913
Received 3 June 2024; Received in revised form 20 September 2024; Accepted 23 September 2024
Available online 28 September 2024
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reported.

2. Materials and methods

We investigated seafood mislabeling of 17 commonly sold sushi fish purchased from 32 restaurants in Los Angeles, California between 2012 and 2023. Sampling did not occur in 2016 or 2017 due to a lack of financial research support. Not all fish were available during every sampling nor from every restaurant. Sampling occurred once or twice in most years. From December 2019 through January 2021, sampling occurred every three months to assess the impact of the global COVID19 pandemic. Samples were purchased from the restaurant's available menu in-person, over the phone, or using a food take-out ordering app. Menu name of each sample, date and other metadata were recorded (see Source Data file) Photographs were taken of the available menu and of the sales receipt, when possible.

A 650-bp fragment of mitochondrial COI gene was sequenced as described in Willette et al. (2017) and resulting sequences were identified to species-level using the National Center for Biotechnology Information's (NCBI) Basic Local Alignment Search Tool (BLASTn) (http://blast.ncbi.nlm.nih.gov/Blast.cgi). A total of 960 samples yielded sequences with a 98% or greater identity match and are presented here. 2012 to 2015 data was first analyzed in Willette et al. (2017). DNA-based identity was compared to the listed menu or sales receipt name. Per FDA labeling rules (US FDA CFR 101.18c), seafood was mislabeled if the listed menu or sales receipt name and DNA-based identity did not match. Average mislabeling rates by year and fish type were calculated with Agresti-Coull confidence intervals (Agresti & Coull, 1998) to assess uncertainty. Average annual mislabeling rates were contrasted between 2012 and 2015 versus 2018–2023 to test the impact of the Los Angeles Seafood Monitoring Project (Willette et al., 2018), a voluntary outreach initiative among seafood restaurants, local universities, and government agencies to reduce mislabeling rates using best practices and evidence-driven recommendations. A two-way logistic regression was used to test jointly for annual mislabeling rate and restaurant type (project-partnering or other). A logistic regression was used to test for significant differences in mislabeling rate between samplings during the COVID19 pandemic.

3. Results and discussion

Our results show a 10-year average mislabeling rate of 38% (367/960, 95% CI of 35.2–41.3%) (Fig. 1). Mislabeling was 46.8% (148/316, 95% CI of 41.4–52.3%) from 2012 to 2015, then 34.0% (219/644, 95% CI of 30.5–37.8%) between 2018 and 2023, after the launch of the outreach project. The difference of 0.125 in these rates was significant (Agresti-Caffo test, p = 0.00005). Seafood mislabeling dropped substantially at partnering restaurants that implemented labeling recommendations of the Los Angeles Seafood Monitoring Project. Three of the 32 restaurants partnered with the project (~10%), with 192 of 960 (~20%) of samples obtained from these three restaurants. Mislabeling declined from 44.4% to 15.7% at partnering restaurants, whereas mislabeling declined from 47.1% to 40.3% at non-partnering restaurants over the same period. Neither year before or after the implementation of the Los Angeles Seafood Monitoring Project, nor role as project partnering restaurant or non-partnering restaurant were as impactful as the joint effect of partnering and implementation (Table 1). Average mislabeling rates did not differ statistically through the COVID19 pandemic between December 2019 and January 2021 ($p = 0.90$).

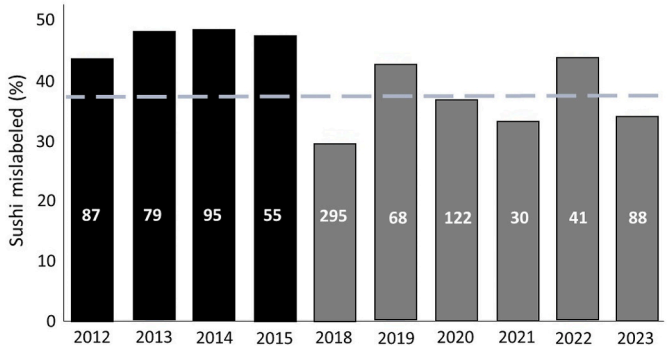

Fig. 1. Frequency of mislabeling of sushi fish by year; grey dashed line represents 10 year average. Numbers in bars indicate total number of samples per year. Bar color indicates before Los Angeles Seafood Monitoring Project (black) and after (grey).

Mislabeling varied greatly by fish types. Halibut, black snapper, Japanese snapper, and red snapper were mislabeled 100% (Fig. 2). Amberjack, bluefin tuna and fluke were never found mislabeled, whereas albacore, salmon, and tuna were rarely mislabeled (<5%).

Why does sushi mislabeling occur? This 10-year longitudinal study suggests reasons for the most egregious cases. The 100% mislabeling of halibut observed here is higher than reported in other studies (Warner et al., 2013, pp. 1–69; Wong & Hanner, 2008). The FDA instructs sushi sold as halibut should be *Hippoglossus hippoglossus* and *H. stenolepis*. Nearly all halibut sampled in this study was a species of *Paralichthys*, including which 60% were *P. olivaceus*, olive flounder. Consuming olive flounder raw is a health concern due to the uncommon occurrence of a myxospore parasite which can cause gastroenteritis (Iwashita et al., 2013). California Fish and Game Code (Section 8391, 2015) does permit *P. californicus* to be labeled as California halibut, however, no sampled halibut was ever identified as *P. californicus* in the 10 years of this study. Beginning in 2018, partnering restaurants replaced the menu name 'halibut' with 'fluke'. Fluke is an FDA accepted name for *Paralichthys* spp. and was never found mislabeled in this study.

Likewise, the 100% mislabeling of red snapper may be attributed to differences in state and federal labeling guidelines. The California Code of Regulations (14 CCR §103) permits local *Sebastes* rockfish species to be labeled "Pacific red snapper"; whereas the FDA only allows *L. campechanus* to be labeled "red snapper". No *Sebastes*, however, were identified in this study. Rather, 73% of sold "red snapper" sushi was identified as *Pagrus major*, which the FDA accepted name is sea bream. Like with halibut labeling, in 2018, partnering restaurants replaced the menu name "red snapper" with "sea bream". Sea bream was rarely mislabeled. Related, nearly all "black snapper" and "Japanese snapper" were mislabeled, and 60% of these samples were identified as *P. major*, suggesting broad confusion on labeling fish snapper instead of sea bream.

4. Conclusions

Seafood mislabeling has declined in Los Angeles. Yet, further reductions in the most egregious cases are achievable. For instance, in recent years the FDA has added the Japanese name as an accepted market name for madai (sea bream/*P. major*) and kanpachi (amberjack/*S. rivoliana*). Current FDA guidelines only permit the use of English names for most of this study's targeted fish types. We encourage regulators to consider the addition of additional Japanese names as accepted names, which may help reduce mislabeling attributed to being lost in

Table 1
Two-way logistic regression test of mislabeling by annual rate (year before or after implementation), restaurant type (project partnering or other) and the interaction of these two factors.

	Estimate	*p*-value
intercept	−0.1178	0.3176
partner	−0.1054	0.7947
after	−0.2755	0.0666
interaction	−1.1777	0.0117

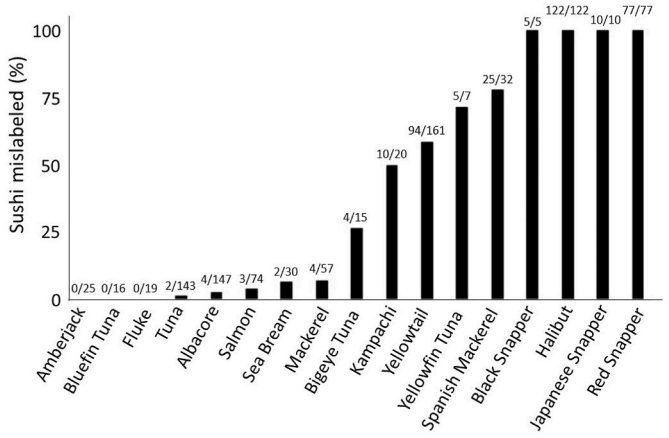

Fig. 2. Mislabeling frequency by fish type over 10 years of study. Values above bars represent number of mislabeled samples/total number of samples.

translation. Furthermore, we continue the advocacy (Willette et al., 2017; Willette et al., 2019) to build capacity, accessibility, and policy of DNA-based testing for seafood identification, including the use of emerging environmental DNA (eDNA) methods that may accelerate monitoring (Brito & Willette, 2023; National Aquatic eDNA National Aquatic Environmental DNA Strategy, 2024). To our knowledge, this is the longest continuous study (10 years of data) to use DNA-based testing to monitor seafood labeling, with well-vetted and accessible methods that can enable regular and impactful testing in the seafood supply chain. Lastly, this study illustrates the impact of communication and partnership among seafood stakeholders, including restaurants, researchers, and government agencies to reduce seafood mislabeling in Los Angeles. Further city-wide implementation of the project's recommendations would likely drive down mislabeling, enabling resources to be focused on a narrower field of instances that pose the greatest health, economic, and conservation risks.

CRediT authorship contribution statement

Demian A. Willette: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Kelli Andrade:** Writing – review & editing, Investigation. **Ben Fitzpatrick:** Writing – review & editing, Formal analysis. **Kesterlyn Wilson:** Writing – review & editing, Investigation.

Declaration of competing interest

The authors have no competing interests with this study.

Data availability

Data will be made available on request.

Acknowledgements

We acknowledge funding from LMU Seaver College of Science and Engineering and FishWise. We thank T. Deboer, E. Caldera, L. Kock, J. Greenberg, P. Cummins, all participants of the LA Seafood Monitoring Project workshops, and dozens of LMU and UCLA students who assisted in sampling sushi over the years. D. Willette thanks M. Joaquin for logistical support. We also thank the three anonymous reviewers for their generous help and ideas to strengthen this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2024.110913.

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