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Seafood mislabeling in Honolulu, Hawaiî

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ABSTRACT

Seafood mislabeling misleads consumers about the abundance of commercially harvested and cultured species, hinders consumer choice, and allows overfished and threatened species to reach the marketplace. Despite the importance of seafood in local culture and in the tourist-driven economy of Hawaiî, no studies of seafood label accuracy have been conducted in the state. Here, we use mitochondrial DNA barcoding to investigate patterns of seafood mislabeling in restaurants, groceries, and sushi bars in the greater Honolulu area. Our results revealed an overall mislabeling rate of 21 % (+9.3%). Sushi bars had the highest rate (27 %), followed by restaurants (23 %) and groceries (17 %). The most common mislabeled fish was Swai (*Pangasianodon hypophthalmus*), sold as more expensive fish under a variety of names. The overall mislabeling rate in Honolulu was lower than the national rate (33 %) found in the largest study from the U.S. mainland by Oceana, but similar to a more recent, but smaller national Oceana survey (21 %). However, comparisons of overall rates across studies can be misleading because much of the geographic variation in mislabeling is confounded by varying proportions of samples obtained from different kinds of retailers. Finally, the widespread use of acceptable – but generic – market names in Hawaiî concealed the true diversity of species for sale, including endangered species. Two species in our study (*Anguilla anguilla* and *Thunnus maccoyii*) labeled with generic but acceptable market names are considered "Critically Endangered" by the International Union for Conservation of Nature.

1. Introduction

Seafood provides a source of income and nutrition for hundreds of millions of people worldwide [1]. To satisfy the global demand for fish and shellfish, the seafood supply chain has grown into a multi-billion-dollar global industry, with more than 50 % of seafood originating from international trade. In the U.S.A., where total annual sales generated by commercial and recreational fishing exceeds $200 billion [2], more than 90 % of seafood is imported from other countries [3].

Internationally-traded seafood is often processed for more efficient preservation and cost-effective shipping, a practice that often removes distinguishing morphological features that can otherwise identify species. Combined with the depletion of many desirable fish and invertebrate stocks, globalization of the seafood supply chain promotes the economic incentive for seafood fraud in which less desirable and less expensive species are mislabeled as species that are more expensive to obtain [4–,5,6,7,8]. Mislabeling can be intentional or unintentional and can happen at any step in the increasingly complex global seafood supply chain [7,9]. Numerous studies have shown that seafood mislabeling is prevalent worldwide (e.g. [10–13],) and may be the norm rather than the exception for some seafood products, such as "Red snapper," whose names are rendered meaningless in some markets by 100 % mislabeling [10,12,14,15].

Seafood fraud is illegal [16–18] but mislabeling also deceives consumers about the availability and quality of seafood, exposes consumers to potential health risks, and thwarts consumers' efforts to support sustainable and locally-produced products [4,11,19–22]. Accurate seafood identification and traceability is necessary to stop illegal, unreported, and unregulated fishing, enforce sustainable management, and limit overfishing [23,24]. In the U.S.A., *The Seafood List*[1] provides guidance about what the Food and Drug Administration (FDA) considers acceptable market names for seafood sold in the United States. Although the "FDA's guidance documents . . . do not establish legally enforceable responsibilities", seafood is "deemed to be misbranded . . . if its labeling is false or misleading."1 Nevertheless, seafood mislabeling rates typically exceed 20 % in most major metropolitan areas of the U.S.A. [10,25].

Hawaiî is the only state in the U.S.A. consisting entirely of islands and has among the largest coast-to-land ratios in the country [26]. Not surprisingly, both wild-caught seafood and aquaculture has been an important source of food for human populations in Hawaiî since the

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[1] https://www.accessdata.fda.gov/scripts/fdcc/?set=seafoodlist.

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islands were colonized [27,28]. Today, per capita seafood consumption in Hawaiʻi by edible weight is nearly twice that on the mainland [29–31], and Hawaiʻi residents spend more than twice as much money on seafood per person than mainland residents [30,31]. Although proximity to marine resources has been a primary factor driving historical seafood consumption in Hawaiʻi, residents of and visitors to the archipelago now depend on the global seafood supply chain to satisfy consumer demand: 57 % of the supply by edible weight consists of foreign imports [30] and 75 % of all seafood comes from outside the state [32]. Among the modern drivers for high seafood demand in Hawaiʻi are the large number of immigrants from countries with high seafood consumption and approximately 6 million visitors per year to the state that expect to eat locally-caught fish [30,32,33].

Although seafood is an important component of the local culture and tourist-driven economy of Hawaiʻi [27,33–36], no study of seafood mislabeling has been conducted in this unusual U.S. market. On the one hand, the demand for high quality, fresh seafood combined with the highest food prices in the country may promote seafood mislabeling. On the other hand, a resident population that frequently consumes a wide variety of seafood may be more discriminating, potentially driving down fraud. We have therefore investigated seafood mislabeling through the use of DNA barcoding of mitochondrial DNA (mtDNA) of fish and invertebrates sold in in the greater Honolulu area. We describe rates and patterns of seafood mislabeling separately for three different retail groups (groceries, restaurants, and sushi bars) because of the high variance in mislabeling rates among different types of retail outlets [25]. Our data are novel for Hawaiʻi, but our analysis also emphasizes the limitations of direct comparisons of overall mislabeling rates across studies, the importance of separating comparative data by retail source, and the role that acceptable, but generic market names play in misleading seafood consumers.

2. Materials and methods

Seventy-five seafood samples were purchased from a convenience sample of 28 retail outlets in the greater Honolulu area between September and April 2016. Retailers were one of three types: restaurant, grocery store, or sushi bar. Seafood samples were stored in 75 % ethanol and DNA was extracted using a Qiagen DNeasy blood and tissue kit following the manufacturer's protocol with minor modifications (10 μL of proteinase K were used instead of the recommended 20 μL and DNA was eluted with 100 μL of buffer AE rather than the suggested 200 μL).

Depending on the taxa, segments of mitochondrial cytochrome c oxidase subunit-I (*co1*) and the mitochondrial control region (or "D-loop") were amplified using one of three primer pairs. First, *co1* was amplified from invertebrates using jgLCO1490 and jgHCO2198 [37] with the following thermal cycler profile: 94 °C for 1 min, 30 cycles of 94 °C for 1 min, 48 °C for 1 min, and 72 °C for 1 min followed by a final extension step at 72 °C for 7 min. Second, *co1* was amplified from fish extractions with FishF1 and FishR1 [38] using the following thermal cycler profile: 95 °C for 2 min, 35 cycles of 95 °C for 30 s, 44 °C for 30 s, and 72 °C for 1 min followed by a final extension step at 72 °C for 10 min. Third, to provide greater species-discrimination of samples of tuna (*Thunnus*), the variable 5′ end of the mitochondrial control region was amplified from tuna extractions using CB3R420 and 12Sar430 primers [39] with the following thermal cycler profile: 94 °C for 2 min, 35 cycles of 94 °C for 1 min, 50 °C for 1 min, and 72 °C for 1 min followed by a final extension step at 72 °C for 5 min. This portion of the control region provides sufficient phylogenetic resolution to distinguish species of ʻAhi on the market in Hawaiʻi, such as yellowfin (*T. albacares*) and bigeye (*T. obesus*) tuna, the two most abundant species of tuna for sale in Hawaiʻi [40].

All PCR reactions included 12.5 μL of 2x MyTaq Ready Mix (Bioline, Inc.), 11 μL H_2O, 1 μL of each primer (from 10 μM stock solutions), and 1 μL DNA (approximately 50 ng/μL). Amplification products were purified using a combination of digestion with Exonuclease I (New England BioLabs) and Shrimp Alkaline Phosphate (Affymetrix, Santa Clara, CA). Purified products were sequenced in both directions (using both PCR primers) on an Applied Biosystems 3730XL sequencer at the Advanced Studies in Genomics, Proteomics and Bioinformatics facility at the University of Hawaiʻi at Mānoa. New sequences were submitted to GenBank under the Accession numbers MW027139-MW027213.

DNA sequences were manually checked for ambiguous base pairs and miscalled nucleotides using Geneious Prime version 2020.1.2 [41] by trimming the ends of individual reads, aligning complimentary sequences, and visually inspecting individual base calls. For *co1* sequences, consensus sequences for each sample were identified using the Basic Local Alignment Search Tool (BLAST) provided by the National Center for Biotechnologies Information (NCBI) website.[2] Control region sequences from the genus *Thunnus* were identified by building a phylogeny that included reference sequences electronically-retrieved from GenBank (Table S1). The phylogeny was constructed with a 100 million step Markov-Chain Monte Carlo search using the Bayesian inference criterion implemented in the software package MrBayes [42,43] using the General Time Reversible nucleotide substitution model and gamma-distributed rate variation. The first 25 % of the run was discarded as burn-in and the tree was rooted with sequences from the outgroups *Sarda australis* and *Auxis rochei*.

After the samples were identified, *The Seafood List* was used to determine whether seafood products were accurately labeled. We classified samples as mislabeled if they were sold with a name that was not listed as an "acceptable market name" on the FDA list. However, following the guidance of the FDA, we did not consider seafood as mislabeled if it was sold under a name that provided the same or greater specificity as the acceptable market name or was "an appropriate, non-misleading statement of identity."[3] (e.g., "ʻAhi" for Bigeye or Yellowfin Tuna rather than the FDA market name "Tuna").

For comparison, we downloaded mislabeling data for major U.S. metropolitan areas from the largest study of seafood mislabeling in the U. S.A. [10], which had sample sizes for regions or cities that were similar to those in the present study and included a breakdown of results among groceries, restaurants, and sushi bars.

3. Results

We obtained sequence data from 75 samples (Table 1) purchased at restaurants (30 %), groceries (40 %), and sushi bars (30 %) in the greater Honolulu area. The 75 samples of fish (80 %) and invertebrates (20 %) were labeled with 42 different names. Several species of tuna were the most common type of seafood sampled (20 %). Only one sample was labeled as an aquaculture product ("farmed") and only one was labeled as wild-caught ("wild"); both were purchased from a grocery retail outlet.

The sequence data revealed that across all three retail types, 16 of 75 or 21 % ($\underline{+}$ 9.3%) of the samples were mislabeled, meaning that we can be 95 % confident that between 12 % and 30 % of seafood in Honolulu is mislabeled with unacceptable FDA market names or names that do not provide the same level of specificity. Sushi bars had the highest mislabeling rate (27 %), followed by restaurants (23 %) and groceries (17 %). For all three retail types, mislabeling in Honolulu was relatively low compared to mainland metropolitan areas with similar sample sizes (Fig. 1).

All of the mislabeled samples were fish. The most common mislabeled fish (4 of 16 mislabeled fish) was Swai (*Pangasianodon hypophthalmus*) sold in our study as "Red snapper," "Sea bass," "Mahi-mahi," and "Basa." All samples labeled as "Red snapper," "Snapper," and "Sea bass," were mislabeled. Although 16 different species may be acceptably labeled as "Sea bass", none of the samples sold under that name were correctly labeled.

[2] http://blast.ncbi.nlm.nih.gov/Blast.cgi.

[3] https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-seafood-list.

Table 1
Barcoded seafood samples from the greater Honolulu area.

Sample	Date	Retail type	Neighborhood	Sold as	Barcoded as	Acceptable market name(s)	Mislabeled
1	2/10/2016	Restaurant	Kaimuk	ʻAhi	*Thunnus albacares*	Tuna	No
2	2/11/2016	Grocery	Hawaiʻi Kai	Salmon	*Salmo salar*	Salmon	No
5	2/14/2016	Restaurant	Kaimuk	Maine Lobster	*Homarus americanus*	Lobster	No
6	2/14/2016	Restaurant	Kaimuk	Salmon	*Salmo salar*	Salmon	No
7	2/14/2016	Restaurant	Kaimuk	Shrimp	*Litopenaeus vannamei*	Shrimp	No
10	2/15/2016	Sushi bar	Kaimuk	ʻAhi	*Thunnus obesus*	Tuna	No
11	2/15/2016	Sushi bar	Kaimuk	ʻAhi	*Thunnus obesus*	Tuna	No
12	2/15/2016	Grocery	Kaimuk	ʻAhi	*Thunnus albacares*	Tuna	No
13	2/15/2016	Sushi bar	Kaimuk	ʻAhi	*Thunnus obesus*	Tuna	No
14	2/15/2016	Sushi bar	Kaimuk	Ika	*Sepia aculeata*	Cuttlefish	No
15	2/15/2016	Sushi bar	Kaimuk	Eel	*Anguilla rostrata*	Eel	No
16	2/15/2016	Sushi bar	Kaimuk	Salmon	*Salmo salar*	Salmon	No
17	2/15/2016	Sushi bar	Kaimuk	Octopus	*Octopus vulgaris*	Octopus	No
18	2/15/2016	Restaurant	Mānoa	ʻAhi	*Thunnus maccoyii*	Tuna	No
20	2/15/2016	Grocery	Waiʻalae-Kāhala	Swordfish	*Xiphias gladius*	Swordfish	No
21	2/15/2016	Grocery	Waiʻalae-Kāhala	Mahi-mahi	*Coryphaena hippurus*	Mahi-mahi	No
22	2/15/2016	Restaurant	Kaimuk	Octopus	*Octopus cyanea*	Octopus	No
23	2/15/2016	Restaurant	Kaimuk	Crab	*Portunus pelagicus*	Crab	No
24	2/15/2016	Restaurant	Kaimuk	ʻAhi	*Thunnus obesus*	Tuna	No
25	2/15/2016	Restaurant	Kaimuk	Cod	*Gadus macrocephalus*	Cod, Alaska cod	No
26	2/15/2016	Restaurant	McCully- Mōʻiliʻili	Red snapper	*Pangasianodon hypophthalmus*	Swai, Sutchi, Striped Pangasius, Tra	Yes
27	2/15/2016	Restaurant	McCully-Mōʻiliʻili	Red snapper	*Pangasianodon hypophthalmus*	Swai, Sutchi, Striped Pangasius, Tra	Yes
28	3/1/2016	Restaurant	Kaimuk	Mahi-mahi	*Coryphaena hippurus*	Mahi-mahi	No
29	3/2/2016	Restaurant	McCully-Mōʻiliʻili	Sea bass	*Pangasianodon hypophthalmus*	Swai, Sutchi, Striped Pangasius, Tra	Yes
30	3/13/2016	Restaurant	Kaimuk	ʻAhi	*Thunnus obesus*	Tuna	No
31	3/13/2016	Restaurant	Waikk	Lobster	*Homarus americanus*	Lobster	No
32	3/13/2016	Restaurant	Waikk	Crab	*Chionoecetes opilio*	Snow crab	No
33	3/13/2016	Restaurant	Waikk	Shrimp	*Litopenaeus vannamei*	Shrimp	No
34	3/17/2016	Restaurant	Kaimuk	Mahi-mahi	*Coryphaena hippurus*	Mahi-mahi	No
39	2/26/2016	Grocery	Downtown-Chinatown	Tilapia	*Oreochromis niloticus*	Tilapia	No
40	3/22/2016	Grocery	McCully-Mōʻiliʻili	Amber jack	*Seriola rivoliana*	Amberjack	No
42	3/22/2016	Grocery	McCully-Mōʻiliʻili	Sockeye salmon	*Oncorhynchus nerka*	Salmon, Sockeye or Red or Blueback	No
43	3/22/2016	Grocery	McCully-Mōʻiliʻili	Tako	*Octopus cyanea*	Octopus	No
44	3/22/2016	Grocery	McCully-Mōʻiliʻili	ʻAhi	*Thunnus obesus*	Tuna	No
45	7/5/2016	Restaurant	Ala Moana-Kakaʻako	Monchong	*Taractichthys steindachneri*	NA[a]	No
46	7/5/2016	Restaurant	Ala Moana-Kakaʻako	Mahi-mahi	*Coryphaena hippurus*	Mahi-mahi	No
47	7/14/2016	Grocery	Downtown-Chinatown	Blue cod	*Parapercis colias*	Sandperch	No
48	7/14/2016	Grocery	Downtown-Chinatown	Bangamary	*Cirrhinus molitorella*	Carp	Yes
49	7/14/2016	Grocery	Downtown-Chinatown	Basa	*Pangasianodon hypophthalmus*	Swai, Sutchi, Striped Pangasius, Tra	Yes
51	7/14/2016	Grocery	Downtown-Chinatown	Octopus	*Octopus cyanea*	Octopus	No
52	7/14/2016	Grocery	Downtown-Chinatown	Sunfish	*Oreochromis niloticus*	Tilapia	Yes
53	7/14/2016	Grocery	Downtown-Chinatown	Catfish	*Ictalurus punctatus*	Catfish	No
54	7/14/2016	Grocery	Downtown-Chinatown	Fish	*Lepidocybium flavobrunneum*	Escolar or Oilfish	Yes
55	7/14/2016	Grocery	Downtown-Chinatown	Baby octopus	*Amphioctopus aegina*	Octopus	No
56	7/14/2016	Grocery	Downtown-Chinatown	Manila clams	*Venerupis* (*Ruditapes*) *philippinarum*	Littleneck clam	No
57	7/14/2016	Grocery	Downtown-Chinatown	Squid	*Todarodes pacificus*	Squid, calamari	No
58	7/17/2016	Restaurant	Waikk	Mahi-mahi	*Pangasianodon hypophthalmus*	Swai, Sutchi, Striped Pangasius, Tra	Yes
59	7/17/2016	Restaurant	Waikk	Sea bass	*Dissostichus eleginoides*	Toothfish or Chilean sea bass	Yes
62	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Salmon roe	*Oncorhynchus keta*	Salmon, Chum or Keta	No
63	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Tobiko	*Mallotus villosus*	Capelin	Yes
64	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Salmon	*Salmo salar*	Salmon	No
65	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	ʻAhi	*Thunnus albacares*	Tuna	No
66	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Unagi	*Anguilla anguilla*	Eel	No
67	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Hamachi	*Seriola quinqueradiata*	Amberjack	No
68	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	ʻAhi	*Thunnus albacares*	Tuna	No
69	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Tobiko	*Mallotus villosus*	Capelin	Yes
71	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Flathead	*Platycephalus indicus*	NA[a]	No
73	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Scottish salmon	*Oncorhynchus mykiss*	Trout, Rainbow or Steelhead	Yes
74	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Stripped jack	*Pseudocaranx dentex*	Jack or Trevally	Yes
75	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Bigeye	*Thunnus obesus*	Tuna	No
76	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Snapper	*Beryx splendens*	Alfonsino	Yes
77	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Halibut	*Paralichthys olivaceus*	Flounder	Yes
78	9/7/2016	Sushi bar	Ala Moana-Kakaʻako	Clam	*Fulvia mutica*	Not in FDA list	No
80	9/7/2016	Grocery	Mānoa	Imitation crab meat	*Gadus chalcogrammus*	Pollock	No
81	9/7/2016	Grocery	Mānoa	Dover sole	*Microstomus pacificus*	Sole	No
82	9/7/2016	Grocery	Makiki-Tantalus	Miso butterfish	*Anoplopoma fimbria*	Sablefish	No

(continued on next page)

Table 1 ***(continued)***

Sample	Date	Retail type	Neighborhood	Sold as	Barcoded as	Acceptable market name(s)	Mislabeled
83	9/7/2016	Grocery	Makiki-Tantalus	Mahi-mahi	*Coryphaena hippurus*	Mahi-mahi	No
84	9/7/2016	Grocery	Makiki-Tantalus	Au/Marlin	*Oreochromis niloticus*	Tilapia	Yes
85	9/7/2016	Grocery	Makiki-Tantalus	Shutome	*Xiphias gladius*	Swordfish	No
86	9/7/2016	Grocery	Makiki-Tantalus	Salmon	*Oncorhynchus tshawytscha*	Chinook or King salmon	No
89	9/26/2016	Grocery	Makiki-Tantalus	ʻAhi	*Thunnus albacares*	Tuna	No
92	9/26/2016	Grocery	Makiki-Tantalus	ʻAhi	*Thunnus albacares*	Tuna	No
93	9/26/2016	Grocery	Makiki-Tantalus	Opah	*Lampris guttatus*	Opah	No
95	12/18/2016	Grocery	Diamond Head-Kapahulu	ʻAhi	*Thunnus albacares*	Tuna	No
96	12/21/2016	Sushi bar	Ala Moana-Kakaʻako	Unagi	*Anguilla anguilla*	Eel	No

[a] No FDA acceptable market name.

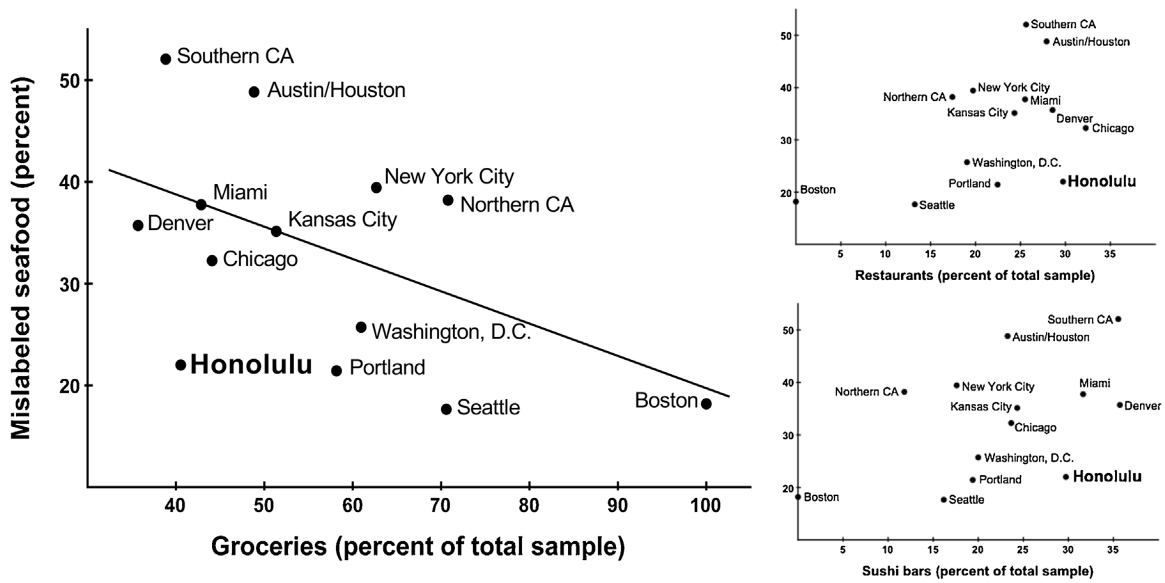

Fig. 1. Seafood mislabeling rates in Honolulu (this study) and other metropolitan areas in the U.S.A. (data from [10]) for groceries, restaurants, and sushi bars. The relationship between the proportion of samples in each study that were obtained from groceries and the total proportion of mislabeled seafood across cities was significant ($R^2 = 0.40$, $F_{(1, 10)} = 6.68$, $P = 0.0272$). Because they are proportional predictors, we did not test the significance of the proportion of non-grocery (restaurants and sushi bars) samples.

The phylogenetic analysis of the tuna D-loop sequences was consistent with the identifications from BLAST searches of the NCBI database, indicating that none of the tuna samples were mislabeled. Based on their position in the tree (Fig. S1), seven samples were identified as Yellowfin (*T. albacares*), six as Bigeye (*T. obesus*), and one as Southern bluefin (*T. maccoyii*) tuna. All were labeled as "Ahi," except one that was (correctly) labeled as "Bigeye."

4. Discussion

4.1. Seafood mislabeling in Hawaiʻi

Given that residents of the State of Hawaiʻi consume nearly twice as much seafood per capita as people in mainland U.S.A. [30], greater exposure and familiarity with seafood might lead to better seafood recognition by consumers. In turn, better seafood recognition by consumers could drive down the frequency of mislabeling. At face value, however, our data appear to indicate that the overall rate of seafood mislabeling in Honolulu is similar to mainland metropolitan areas. Although the overall mislabeling rate (21 %) for our samples fell outside the margin of error for the average rate (33 % $\pm$ 2.6%) on the mainland reported by Oceana in 2013 [10], it was the same rate (21 %) reported more recently in a smaller Oceana study in 2019 [25].

However, comparison of seafood mislabeling rates across all types of retailers can be misleading. Much of the geographic variation in mislabeling is driven in part by the proportion of samples obtained from different types of retailers (Fig. 1). Specifically, seafood substitutions tend to be less common at groceries than at restaurants and sushi bars [10,12,25], presumably because greater processing at restaurants and sushi bars allows less costly types of seafood to be more easily disguised as more expensive species. Not surprisingly, U.S. cities and regions with the highest overall mislabeling rates (Southern California, Austin/Houston, and New York City; 39–52 %) are those from which restaurant and sushi samples made up a relatively large proportion of the samples (37–61 %). In contrast, cities with the lowest overall rates of mislabeling (Seattle, Boston, and Portland; 18–21 %) have a relatively small proportion of samples from restaurant and sushi bars (0–29 %).

Our Honolulu survey contained a relatively high proportion of samples from restaurants (30 %) and sushi bars (30 %). Yet, because mislabeling rates at Honolulu restaurants, sushi bars, and groceries are all similar, the overall rate of mislabeling in our study falls below most cities with similar proportions of these three types of retailers (Fig. 1). As in most metropolitan areas, seafood mislabeling in Honolulu peaked at sushi bars (27 %), but sushi mislabeling in our study was substantially lower than recent studies on the mainland, which often report >50 % mislabeled sushi (e.g., [12,44]).

The mislabeling was likely driven primarily by economic incentives because the majority of the mislabeled seafood involved substitutions of less expensive species for more expensive species (Table S2). Most of the apparent substitutions were also probable aquaculture products

Fig. 2. Inadequately-labeled Escolar (*Lepidocybium flavobrunneum*) in Honolulu, HI. To the best of our knowledge, “Fresh Fish” is not a name that local residents associate with Escolar, often marketed as “White tuna.”.

mislabeled as fish that are wild-caught, such as Carp sold as “Bangamary,” Tilapia sold as “Marlin,” and Swai sold as “Mahi-mahi,” “Basa,” and “Red snapper.”

In addition to the 16 samples we considered mislabeled, 19 other samples in our study were not labeled with acceptable market names actually on the FDA seafood list. However, we did not consider these 19 samples mislabeled given the common and vernacular names under which these species were sold provided “an appropriate, non-misleading statement of identity.”[3] Those common or vernacular names for species in our survey included “Blue cod” for Sandperch (*Parapercis colias*), “Butterfish” for Sablefish (*Anoplopoma fimbria*), “Shutome” for Swordfish (*Xiphias gladius*), and “Ahi” for Tuna (*Thunnus*). The use of some of these vernacular names is largely limited to Hawaiî (e.g., “Shutome” and “Butterfish”) but others are widely used on the mainland and elsewhere (e.g., “Ahi”). Within Hawaiî, none cause confusion among consumers and did not represent attempts to mislead consumers.

Several other species in our samples are not in the *The Seafood List*, but we did not consider these mislabeled. *Platycephalus indicus*, sold under the name “Flathead”, is not listed in the FDA’s list, but “Flathead” is an acceptable name for other congeneric species. *Taractichthys steindachneri* is also not in *The Seafood List* but the name it was sold under (“Monchong”) was not considered mislabeled in the Hawaiî seafood market. We also did not consider our sample of *Venerupis* (*Ruditapes) philippinarum* sold as “Manila clams” as mislabeled even though the FDA list only considers “Littleneck clam” as acceptable for this species. Although “Littleneck” is used widely in the U.S.A. for *Mercenaria mercenaria*, the acceptable FDA market name for all species of *Mercenaria* is “Clam” or “Quahog.”

4.2. Generic names, consumer risk, and endangered species

Much of the seafood in our study was labeled with generic names (see [14]), including “Salmon,” “Shrimp,” and “Squid.” Although these ambiguous names are valid market names in the U.S.A., they provide incomplete information for consumers and can conceal potential health risks associated with consuming some species of seafood. For example, one sample obtained in an open-air market labeled as “Fresh Fish” (Fig. 2) was Escolar (*Lepidocybium flavobrunneum*). Escolar contains high wax esters that frequently cause gastrointestinal illness in consumers; sale of this species has been banned in some countries [10,22,45–48]. We also found Chilean sea bass (*Dissostichus eleganoides*) sold in a restaurant as “Sea bass.” Because this fish was sold in a tourist area (Waikk, see Table 1) we speculate that a more generic name was likely used by the retailer because “Sea bass” does not explicitly indicate that the fish was imported. Ambiguous generic names also facilitate the sale of aquaculture species in a market where many consumers probably expect to find wild-caught fish. Based on the species’ identities, one-quarter of the samples we purchased were likely aquaculture products.

The use of generic names also provides a way for overfished and threatened species to reach the marketplace [14,49]. Our survey included three samples of two species considered “Critically Endangered” by the International Union for Conservation of Nature (IUCN)[4] . First, among three samples sold as either “Unagi” or “Eel”, one individual possessed a *co1* sequence that identified it as an American eel (*A. rostrata*) but the other two had *co1* sequences that matched the European eel (*A. anguilla*), a Critically Endangered species on the IUCN Red List [50]. Hybrids between *A. anguilla* and *A. rostrata* have been found in nature but rarely outside Iceland [51,52]. Given that only a single export of *Anguilla* from Iceland has been reported in the past 10 years[5], (also see [53]).

European eels can be legally imported in the U.S.A despite a European Union (EU) export ban. Juveniles are caught by non-EU countries, shipped to aquaculture facilities in China [54], and then exported to the U.S.A. as a “Product of China.” Although the name “Unagi” originated in Japan for *Anguilla japonica*, the name is widely used at sushi bars and groceries in North America to refer to any eel in the genus *Anguilla*. Given the complexity of the supply chain, the acceptable FDA market name for all species of *Anguilla* is “Eel” (or “Freshwater eel”) provides insufficient information for consumers that would choose to avoid eating *A. anguilla*. Country of Origin Labeling (COOL) laws in the U.S.A.[6] cannot help

[4] https://www.iucnredlist.org.
[5] https://trade.cites.org.
[6] https://www.ams.usda.gov/rules-regulations/cool.

consumers avoid European eels for two reasons. First, if caught in the Atlantic but shipped to farms in China, COOL only requires that China be listed as the country of origin. Second, most Freshwater eel is purchased in the U.S.A. but restaurants are exempt from COOL.

The most common generic name in our study was "Ahi," a name used in Hawaiʻi and elsewhere for both Bigeye and Yellowfin tuna (Table S2, Fig. S1). Although Bigeye prices can be substantially higher than for Yellowfin, there is enough quality overlap between these species that causes retailers to often sell both as "Ahi" [47,55,56]. However, the *co1* sequence from another sample in our study that was labeled as "Ahi" was placed with Southern bluefin tuna (*T. maccoyii*), a Critically Endangered species on the IUCN Red List [50]. This instance of mislabeling is unusual given that together, all three species of bluefin make up ~1% of all tuna caught worldwide [57]. Bigeye and Yellowfin tuna can be difficult to distinguish morphologically, but Southern bluefin is unlikely confused by fishers and dealers with other sympatric species of tuna. If the quality of the Southern bluefin individual was low, the fish that this sample originated from may have sold at a lower price, eventually being sold in Hawaiʻi as "Ahi." Introgression and/or retention of ancestral mtDNA polymorphisms has been documented in several other species of tuna [58], albeit not for Southern bluefin and either Yellowfin and Bigeye, the two most common species of ʻAhi available in Hawaiʻi.

4.3. Conclusions

Seafood fraud is prevalent worldwide [13,59–61] and we found a mislabeling rate of 21 % (16 of 75 samples) in the greater Honolulu area. Most of the mislabeled seafood involved less expensive species sold under the names of more expensive species, suggesting intentional species substitutions for profit. Our study detected several significant consumer hazards caused by mislabeling, including overpayment for the wrong species (e.g., Swai sold as "Mahi-mahi), health risks (Escolar sold as "Fresh fish"), and consumption of endangered species (e.g., European eels sold as "Eel").

We also found numerous examples (19 of 75 samples or 25 %) of species sold under vernacular names that are not on *The Seafood List*. None of these were considered mislabeled because the names are established in the local consumer culture and provide as much specificity as the market names on *The Seafood List*. Although some of these vernacular names are used widely across the U.S.A. and elsewhere, others are rarely used on the mainland, making them unacceptable for inter-state commerce. Nevertheless, none of these names cause confusion among consumers within Hawaiʻi.

An obvious solution for these problems is to require that seafood in the U.S.A. be labelled with latin scientific names, in addition to commercial names [62]. Although the vernacular or commercial name is often how consumers currently identify their seafood, scientific names are the most accurate and unambiguous way to identify individual species. Mandated use of scientific names alongside commercial names, from ocean (or farm) to plate, would allow consumers to make more informed choices and prevent seafood fraud in an increasingly complex globalized seafood supply chain.

Declaration of Competing Interest

The authors report no declarations of interest.

CRediT authorship contribution statement

Michael A. Wallstrom: Data curation, Writing - original draft. **Kevin A. Morris:** Conceptualization, Data curation. **Laurie V. Carlson:** Writing - review & editing. **Peter B. Marko:** Conceptualization, Data curation, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fsir.2020.100154.

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