11-21-2022

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Recommended Citation

Kitch, C. J., Tabb, A. M., Marquis, G. E., & Hellberg, R. S. (2023). Species substitution and mislabeling of ceviche, poke, and sushi dishes sold in Orange County, California. *Food Control, 146*, 109525. https://doi.org/10.1016/j.foodcont.2022.109525

Title: Species Substitution and Mislabeling of Ceviche, Poke, and Sushi Dishes Sold in Orange County, California

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Declarations of interest: none

Abstract

Raw, ready-to-eat (RTE) seafood products have become increasingly popular globally, but they are vulnerable to species substitution and mislabeling. DNA barcoding allows for fish species identification by extracting, amplifying, and sequencing a standardized gene target. A wide variety of fish products have been studied with DNA barcoding, but little investigation of ceviche and poke has occurred in the United States. Sushi is known to be a target of mislabeling but has not been extensively studied in Orange County, CA. The objective of this study was to investigate species substitution and mislabeling of sushi, poke, and ceviche dishes sold at restaurants in Orange County, CA. A total of 105 raw, RTE seafood products were collected, including sushi (n = 35), poke (n = 35), and ceviche (n = 35). All samples were sequenced with DNA barcoding or mini-barcoding. The identified species were compared against the menu names, verbal declarations by restaurant staff, and the Food and Drug Administration (FDA) Seafood List to verify whether acceptable market names were used for each product. Of the 103 samples identified with DNA barcoding, species substitution was detected at a rate of 23.3% and unacceptable market names were found in 45.6% of samples. Overall, 63.1% of samples had some form of mislabeling. When the mislabeling rates were divided based on product category, ceviche had the highest overall mislabeling rate (85.3%), followed by poke (61.8%), and sushi (42.9%). Mislabeling of ceviche and poke was primarily driven by the use of unacceptable market names, while species substitution was more common in sushi dishes. These rates reveal widespread mislabeling among raw, RTE seafood products and suggest the need for outreach efforts to ensure proper labeling of fish using acceptable market names, as well as further research into mislabeling within the raw, RTE seafood supply chain.

Keywords: mislabeling; substitution; DNA barcoding; ready-to-eat; seafood

1. Introduction

Global annual per capita consumption of aquatic foods reached a record high of 20.5 kg in 2019 (FAO, 2022). In the United States in 2020, a total of 3.8 billion kg of seafood landings were recorded, valued at US$4.8 billion (NOAA, 2022). Due to the health benefits of seafood, the Dietary Guidelines for Americans recommends consuming at least 227 g of seafood per week (USDA, 2020). Live, fresh, and chilled products make up the largest share of seafood sold for direct human consumption (FAO, 2022). Some of the most widely consumed raw, ready-to-eat (RTE) seafood dishes in the U.S. include ceviche, poke, and sushi. Ceviche is a raw, marinated fish dish originating from Peru that is typically mixed with other ingredients, such as onions, peppers, and seasonings. The fish is cut into small pieces and marinated in acidic citrus juices, with the most common fish used in U.S. recipes being tilapia (Mathur & Schaffner, 2013). Poke is a cubed raw fish product originating from Hawaii that is mixed with seasonings such as soy sauce, onions, and peppers (Hospital & Beavers, 2014). Some of the most common fish used to make poke are tuna, salmon, and yellowtail. Sushi is a broad category of Japanese cuisine involving small cuts of seafood and/or vegetables served with rice. Numerous fish species are used in sushi, including tuna, salmon, halibut, and snapper (Warner et al., 2013).

Raw, RTE seafood products are particularly vulnerable to species substitution and mislabeling due to their high price points in the market and lack of morphological identifiers. Mislabeling of seafood can be intentional or accidental, with the former typically driven by economic motivation (Silva et al., 2021). Mislabeling can happen at any point between harvest and consumption; incorrect use of common names, lost product, or outright substitution of species can all contribute to species mislabeling. Complexity within the global seafood supply chain and varying labeling requirements across countries further increase the risk of seafood substitution and mislabeling (Silva et al., 2021).

Identifying seafood substitution and mislabeling within the seafood market is critical for safety, cultural significance, conservation measures, and protecting consumer interests. With regards to safety, the primary concerns surround allergies, contaminants and toxins that may be present (Silva et al., 2021). Seafood species substitution can be dangerous for consumers with allergies to fish or shellfish if the substituted species contains allergens that are not present in the declared species. Food safety is also a concern with species that contain toxins, such as gempylotoxin (oilfish), tetrodotoxin (pufferfish), or elevated levels of mercury (e.g., bigeye tuna) (Silva et al., 2021). The mislabeling of threatened species, such as substituting the endangered southern bluefin tuna (*Thunnus maccoyii*) for yellowfin tuna (*Thunnus alalunga*), can also impact conservation programs (Liou et al., 2020). Finally, the detection of seafood substitution and mislabeling is essential to protecting customer interests by ensuring that consumers receive what they paid for.

Due to the lack of morphological features in raw, RTE seafood, analytical methods are often required for species identification. DNA barcoding is a sequencing-based method that relies on the differentiation of species using a short, standardized genetic target (Hebert et al., 2003). The primary marker used with animal species, including fish, is a ~650 bp region of the gene coding for cytochrome c oxidase subunit I (COI). This genetic target is ideal for most instances of seafood species identification because it demonstrates relatively low intra-species variation and high inter-species variation. DNA barcoding of COI is widely used for the DNA-based identification of seafood and is utilized by the U.S. Food and Drug Administration (FDA) for regulatory testing of fish species (Handy et al., 2011). However, COI barcoding is frequently insufficient for species identification within the *Thunnus* genus due low genetic divergences (Pollack et al., 2018; Viñas & Tudela, 2009). In these cases, the mitochondrial control region (CR) is often used (Gordoa et al., 2017; Mitchell & Hellberg, 2016; Roungchun et al., 2022; Viñas & Tudela, 2009).

DNA barcoding has been used in several studies to reveal mislabeling of raw, RTE seafood, specifically ceviche (Velez-Zuazo et al., 2021) and sushi (Chang et al., 2021; Lowenstein et al., 2009; Roungchun et al., 2022; Velez-Zuazo et al., 2021; Warner et al., 2013; Willette et al., 2017). A study evaluating fish mislabeling in Southern California reported a mislabeling rate of 84% for sushi restaurants, including raw "white tuna" samples that were actually escolar (*Lepidocybium flavobrunneum*), which contains gempylotoxin (Warner et al., 2012, 2013). Another study investigating mislabeling in Los Angeles, CA, from 2012 to 2015 reported a mislabeling rate of 47%, with elevated mislabeling rates in sushi products labeled as halibut, red snapper, yellowfin tuna and yellowtail (Willette et al., 2017). Seafood mislabeling is a major issue globally as well (Pardo et al., 2016); for example, 17% of sushi samples were found to be mislabeled in a study in Taiwan (Chang et al., 2021), and a mislabeling rate of 26% was found in Japanese restaurants in Brazil (Staffen et al., 2017). Ceviche was previously reported to be mislabeled in 78% of samples in Peru; however, no studies have been conducted on ceviche mislabeling in the United States (Velez-Zuazo et al., 2021).

While relatively high levels of seafood mislabeling have been reported for sushi dishes sold in Southern California, there is a lack of research on mislabeling of ceviche dishes sold in the U.S. Furthermore, to the authors' knowledge, there are no studies focused specifically on mislabeling of poke dishes. Therefore, the objective of this study was to evaluate species substitution and mislabeling of ceviche, poke, and sushi products sold at restaurants in Orange

County, CA. Sushi was included in this study to allow for a direct comparison of mislabeling across the three categories of raw, RTE seafood.

2. Materials and Methods

2.1. Sample Collection

A total of 105 raw, RTE fish products marketed as sushi, poke, or ceviche were collected from restaurants (n = 67) across Orange County, CA. Equal numbers of samples were collected from each RTE category (i.e., 35 samples each of ceviche, poke, and sushi dishes). Additional details on the individual samples collected are provided in Table S1. The selection of seafood at each location was based on availability and each sample was unique (i.e., no duplicate samples from the same location). In cases of chain restaurants, only one location of the same chain restaurant was visited. The market name and menu description for each fish product was documented. In cases where dishes were labeled generically as “fish”, “white fish”, or “pescado” (a Spanish word for edible fish), verbal confirmation of the species was requested from staff and documented. The fish samples were then transported to the laboratory in a cooler with ice packs and stored in a freezer at –80°C or immediately processed for DNA extraction. To prepare for DNA extraction, a ~10 mg sample from the interior of the product was removed using sterile forceps and placed in a 1.5 mL sterile microcentrifuge tube (Handy et al., 2011). The microcentrifuge tubes containing sample tissue were stored at 4°C for up to 3 days until DNA extraction. This allowed for collection of a sufficient number of samples for a batch DNA extraction rather than extracting individual samples on each collection day. The remaining product was stored at -80°C.

2.2. DNA Extraction

The spin column DNA extraction protocol outlined in Handy et al. (2011) was performed on each tissue sample using a DNeasy Blood and Tissue Kit (Qiagen, Germany). Lysis was carried out using an Eppendorf ThermoMixer C (Germany) set at 56°C with a mixing speed of 300 rpm for 2 h. DNA was eluted in 100 µL of pre-heated (37ºC) Buffer AE (DNeasy Blood and Tissue Kit). The extracted DNA underwent PCR immediately or was stored at –80°C for future use. Each set of DNA extractions included a negative control with no fish tissue (i.e., reagent blank).

2.3. PCR and DNA Sequencing

COI DNA barcoding was conducted on all samples using the primers and cycling conditions described in Handy et al. (2011). To prepare the samples for PCR, 9 µL of sterile water, 11.5 µL of HotStarTaq Plus Master Mix (Qiagen), 0.25 µL of each 10 µM primer and 2 µL of DNA template were added to each reaction tube. Each PCR run included a negative control with sterile water instead of template DNA (i.e., non-template control). All samples labeled as tuna were also tested with the CR mini-barcode primers and cycling conditions described in Mitchell and Hellberg (2016) to facilitate species discrimination. For CR mini-barcoding, each reaction tube contained 7 µL sterile water, 11.5 µL HotStarTaq Plus Master Mix, 0.5 µL of each 10 µM primer, and 3 µL DNA template. Samples that could not be identified with COI DNA barcoding or CR mini-barcoding (in the case of tuna) were tested with COI mini-barcoding using the SH-E primers and cycling conditions described in Shokralla et al. (2015). For COI mini-barcoding, each reaction tube contained 8.5 µL sterile water, 11.5 µL HotStarTaq Plus Master Mix, 0.5 µL of each 10 µM primer, and 2 µL DNA template.

PCR products were confirmed with agarose gel electrophoresis as described previously (Roungchun et al. 2022). Gels were visualized with an E-Gel Imager (ThermoFisher Scientific, USA) containing a UV base and universal filter. All PCR products were purified with ExoSAP-IT (ThermoFisher Scientific) according to the manufacturer's instructions and sent to Eurofins Genomics (USA) for sequencing. Bidirectional sequencing was carried out with a BigDye Terminator v3.1 cycle Sequencing Kit (Applied Biosystems, USA) and a 3730xl DNA Analyzer (Applied Biosystems).

Geneious R7 (Biomatters, Ltd., New Zealand) was utilized to assemble and edit the raw sequence data. The sequences were trimmed to the target regions for the respective barcode targeted. The QC parameters described in Handy et al. (2011) were applied to the COI DNA barcodes and the QC parameters described in Pollack et al. (2018) were applied to the COI and CR mini-barcodes. The resulting DNA barcode consensus sequences associated with each sample can be found in Table S1.

COI DNA barcode and mini-barcode sequences were queried against the Barcode of Life Database (BOLD), Public Records. CR mini-barcode sequences were queried against GenBank utilizing the Basic Local Alignment Search Tool (BLAST). Each species that was identified was compared against the species that was advertised and checked for the use of an acceptable market name based on guidance provided in *The Seafood List* (FDA, 2022).

2.4. Statistical Analysis

The mislabeling rates of raw, RTE seafood products were compared across the three product categories (i.e., poke, ceviche, and sushi) using a Fisher's exact test with a Bonferroni correction for multiple tests. This test was used to compare the rates of species substitution, use of unacceptable market names, and overall mislabeling across the three product categories. Price was examined as a potential factor affecting mislabeling (i.e., species substitution, unacceptable market names, and overall mislabeling) within each product category using a Kruskal-Wallis H test. Three ceviche samples were missing price data and therefore were excluded from the analysis (Table S1). Mislabeling rates (i.e., species substitution, unacceptable market names, and overall mislabeling) of chain and independent stores were also compared across the combined data set using Fisher's exact test. Statistical analysis was performed using R Studio version 4.0.2 (RStudio, PBC, USA) (R Core Team, 2020).

3. Results

3.1. DNA Barcoding

Of the 105 raw, RTE seafood samples tested in this study, 103 passed DNA sequencing quality control and were identified with at least one of the DNA barcoding methods utilized (Fig. 1). Among the COI DNA barcoding methods, the standard COI barcode allowed for identification of 91 samples and the COI mini-barcode identified 10 samples (Table S1). The 10 samples that failed COI DNA barcoding and were instead identified with COI mini-barcodes were found to be Atlantic salmon (*Salmo salar*; n = 2), Atlantic mackerel (*Scomber scombrus*; n = 2), buri (*Seriola quinqueradiata*; n = 1), walleye pollock (*Gadus chalcogrammus*; n = 1), walleye pollock/Arctic cod (*Gadus chalcogrammus*/*Boreogadus saida*; n = 1), whiteleg shrimp (*Litopenaeus vannamei*; n = 2), and yellowtail (*Seriola lalandi*; n = 1). CR mini-barcoding allowed for identification of an additional two samples that failed COI DNA barcoding, as well as species confirmation for 29 samples that were also sequenced with the COI DNA barcode (results discussed in section 3.2).

A poke sample labeled as albacore tuna failed assembly for the COI DNA barcode and failed quality control for the CR mini-barcode due to having 2.3% ambiguities. The sample was identified as albacore tuna with 96.8% identity in GenBank. However, due to the relatively high number of ambiguities (>2%), this identification is not considered reliable and was not used in the determination of species labeling. The other sample that did not pass quality control was a ceviche dish labeled as "fish". This sample failed assembly for the COI DNA barcode and failed quality control for the COI mini-barcode due to its short sequence length (125 bp). This sequence was poor quality with 0% high quality bases and multiple overlapping peaks, indicating the possibility of a species mixture.

When comparing DNA barcoding success across the three raw, RTE product categories, the ceviche samples had the lowest success rate (82.9%) for COI DNA barcoding, with five samples identified with COI mini-barcoding instead and one sample that was unable to be identified with COI DNA barcoding or mini-barcoding (Table S1). The poke and sushi categories showed a slightly higher success rate (88.6%) for COI DNA barcoding, with four samples each that could not be identified with COI DNA barcoding. Of the four poke samples that could not be identified with COI DNA barcoding, two were identified with COI mini-barcoding, one was identified with CR mini-barcoding, and one sample could not be identified. Of the four sushi samples that could not be identified with COI DNA barcoding, three were identified with COI mini-barcoding and one was identified with CR mini-barcoding. The preparation methods used for these dishes, which include soaking the fish in citrus juices/citric acid (ceviche), as well as the use of acidic sauces (poke and sushi), may have contributed to DNA degradation. However, the results of this study show that the use of smaller target sequences, such as the COI mini-barcode (Shokralla et al., 2015), can alleviate this issue.

3.2. Species Identification

All 101 of the samples identified with COI DNA barcoding or mini-barcoding had one or more top species matches in BOLD with > 98% similarity and the 31 samples identified with CR mini-barcoding had one or more top species matches in GenBank with > 95% identity. These results are consistent with previous studies, which have reported > 98% similarity for COI species matches and > 95% identity for CR mini-barcode species matches (Liou et al., 2020; Mitchell & Hellberg, 2016). The CR genetic marker typically shows lower levels of intraspecies similarity compared to COI due to its greater rate of divergence (Roungchun et al., 2022). Among the 31 tuna samples collected in this study, CR mini-barcoding confirmed the species level identifications obtained with COI DNA barcoding in 15 samples and produced species-level identifications for the remaining 16 samples that either failed COI DNA barcoding (n = 2) or were only identified to the genus level with COI DNA barcoding (n = 14). The tuna species identified in this study included albacore tuna (*Thunnus alalunga*; n = 11), yellowfin tuna (*Thunnus albacares*; n = 10), southern bluefin tuna (*Thunnus maccoyii*; n = 5), and bigeye tuna (*Thunnus obesus*; n = 5).

When taking into account the combined results for COI and CR barcoding, 94 samples were identified to the species level (i.e., showed a top genetic match to a single species), eight samples were identified to the genus level (i.e., showed equivalent top genetic matches to multiple species from the same genus), and one had equivalent top genetic matches to species from multiple genera within the same family (Fig. 1). One sushi sample labeled as seabream had equivalent genetic matches to both madai (*Pagrus major*) and Nile tilapia (*Oreochromis niloticus*). However, upon further inspection it was found that the Nile tilapia identification was likely due to an erroneous sequence (Accession ID MT525054) in the database and the sample was therefore determined to be madai.

The eight samples identified to the genus level showed equivalent top matches to multiple tilapia species (*Oreochromis* sp.), primarily Nile tilapia (*Oreochromis niloticus*), blue tilapia (*Oreochromis aureus*), and Mozambique tilapia (*Oreochromis mossambicus*). Tilapia species are often cross-bred, and the resulting hybrids cannot be differentiated with mitochondrial DNA (Liou et al., 2020; Peterson et al., 2021). However, the identification of tilapia to the genus level is sufficient for confirming samples labeled as "tilapia" and is consistent with previous studies that have used COI barcoding methodologies (Liou et al., 2020; Peterson et al., 2021).

The one sample with a family level match (Gadidae) was a ceviche dish that showed equivalent top genetic matches to walleye pollock (*Gadus chalcogrammus*) and Arctic cod (*Boreogadus saida*). Among the top 100 genetic matches to the query sequence for this sample, 97 entries were associated with walleye pollock and only three entries were associated with Arctic cod. All three entries for Arctic cod were associated with the same published study that performed COI DNA barcoding on fish larvae and juveniles (Bouchard et al., 2021), which can be especially difficult to differentiate (Wildes et al., 2022). Furthermore, Wildes et al. (2022) reported that walleye pollock is frequently misidentified as Arctic cod based on morphological features. Taken together, it is possible that the genetic matches to Arctic cod were associated with walleye pollock specimens that were morphologically misclassified as Arctic cod. In this case the use of additional genetic markers, such as microsatellites or other mitochondrial targets, would be helpful to determine whether the sample is indeed walleye pollock (Wildes et al., 2022). However, the identification of this sample to the family level of Gadidae was considered sufficient in the current study to confirm that the species on the label was different from the identified species (discussed in section 4.1.1).

4. Discussion

4.1. Species Substitution

Species substitution was detected in 24 of the 103 raw, RTE seafood samples identified in this study (Table 1). These results include six samples that were listed as "fish" or "white fish" on the menu, but were verbally declared by staff to be halibut, sea bass, tilapia, or snapper. While several cases of species substitution were associated with economic motivation (discussed in the following subsections), instances of substitution resulting from verbal declarations of restaurant staff may have been due to a lack of communication among restaurant staff and managers regarding fish species. Among the 67 restaurants sampled in this study, 20 had at least one case of species substitution. Interestingly, the species substitution rate found in this study for raw, RTE seafood (23.3%) is higher than rates of species substitution reported previously in the Southern California region for fresh or thawed fish fillets (13.3%) sold at grocery stores (Liou et al., 2020) and pre-packaged frozen fish fillets (1.8%) sold at grocery stores (Peterson et al., 2021). When the results were separated based on product category (Fig. 2), the highest rate of species substitution was observed with sushi samples at 28.6% (10/35), followed by ceviche samples at 23.5% (8/34), and then poke samples at 17.6% (6/34). These differences were not statistically significant ($p > 0.017$), according to Fisher's exact test of independence with the Bonferroni correction.

Products declared to be yellowtail were the most frequently detected targets of substitution (11/12), followed by those declared (verbally or on the menu) to be halibut (4/5), various types of snappers (3/3), tilapia (2/6), sea bass (2/2), and amberjack (1/1). Previous studies conducted in the United States and globally also reported relatively high rates of substitution for sea bass, yellowtail, snapper and halibut (Filonzi et al., 2010; Hanner et al., 2011; Hu et al., 2018; Liou et al., 2020; Pardo et al., 2016; Warner et al., 2013; Willette et al., 2017).

4.1.1. Yellowtail and Halibut Substitution

Among the 12 samples labeled as yellowtail (*Seriola lalandi*), 11 were identified as buri (*Seriola quinqueradiata*). While these species share amberjack as an acceptable market name, yellowtail is not an acceptable market name for buri (FDA, 2022). This form of species substitution was observed across all three product categories (ceviche, sushi, and poke). The high rate of substitution found in yellowtail (91.7%) is consistent with Warner et al. (2013), who reported that 100% of sushi samples collected nationwide labeled as yellowtail or hamachi were actually buri (n = 23). While this particular species substitution is common, it is believed to be unintentional and possibly due to issues in foreign name translation (Warner et al., 2013). However, the detection of this substitution event in ceviche and poke is a novel finding that indicates this is a pervasive labeling error that is not limited to sushi dishes. An additional substitution event associated with the *Seriola* genus was the substitution of amberjack (*Seriola* sp.) for white trevally (*Pseudocaranx dentex*) in a sample of sushi. This substitution may have been accidental or due to a lack of product supply, as white trevally has a high commercial value and is utilized in sushi dishes (Agawa et al., 2022). Similarly, Wallstrom et al. (2020) previously reported the mislabeling of white trevally as another species of jack in a sushi sample.

Of the five dishes declared to be halibut in this study, only one was verified as halibut, with an identification of Pacific halibut (*Hippoglossus stenolepis*) for a ceviche dish. The remaining samples were found to be substituted with other species, specifically two sushi samples were identified as olive flounder (*Paralichthys olivaceus*), one sushi sample was identified as almaco jack (*Seriola rivoliana*), and one ceviche sample showed equivalent top matches to walleye pollock (*Gadus chalcogrammus*) and Arctic cod (*Boreogadus saida*). Halibut is a highly valued species and there are economic incentives to substituting it with other species. According to federal regulations (21 CFR §102.57), the term “halibut” is reserved for Atlantic halibut (*Hippoglossus hippoglossus*) and Pacific halibut (*Hippoglossus stenolepis*). However, the findings of the current study combined with previous studies (Filonzi et al., 2010; Liou et al., 2020; Wallstrom et al., 2020; Warner et al., 2013; Willette et al., 2017), indicate that halibut substitution is a consistent problem, with flounders often mislabeled as halibut in sushi products. Consistent with the current study, Willette et al. (2017) also reported the mislabeling of olive flounder sushi as halibut. The use of undeclared raw olive flounder is problematic because this species has been associated with a myxosporean parasite, *Kudoa septempunctata*, which causes gastroenteritis in humans (Kawai et al., 2012).

4.1.2. Snapper, Sea Bass, and Tilapia Substitution

Two instances of substitution involving snappers were detected in sushi products: red snapper (*Lutjanus campechanus*) substituted with tilapia (*Oreochromis* sp.) and black snapper (*Apsilus dentatus*) substituted with gilthead bream (*Sparus aurata*). These results are similar to snapper substitution events reported in Warner et al. (2013), in which snapper sushi was substituted with tilapia and bream, among other species. Similarly, studies conducted in Canada have reported a high frequency of red snapper/snapper substituted with tilapia (Hanner et al., 2011; Hu et al., 2018). The substitution of red snapper sushi with tilapia is likely economically motivated, as red snapper is a highly valued species while tilapia is generally inexpensive (Hu et al., 2018; Isaacs & Hellberg, 2020; Khaksar et al., 2015; Willette et al., 2017). Bream is often referred to as genuine snapper in sushi culture, and there does not appear to be an economic motivation for mislabeling it as black snapper (Hu et al., 2018). One sample of ceviche was labeled on the menu as fish and declared by staff to be snapper but was identified as catfish.

Two ceviche samples declared to be sea bass in this study were instead identified as Sutchi catfish (*Pangasianodon hypophthalmus*) and tilapia (*Oreochromis sp.*). *The Seafood List* includes 16 species listed that are acceptable to be marketed as sea bass, none of which are from the *Oreochromis* or *Pangasianodon* genera (FDA, 2022). Sea bass is a highly valued species that is frequently substituted with other species, as reported in previous studies conducted in the United States and globally (Hanner et al., 2011; Hu et al., 2018; Khaksar et al., 2015; Velez-Zuazo et al., 2021; Warner et al., 2013). The ceviche sample identified as Sutchi catfish was described as "fish" on the menu and verbally declared to be "sea bass" by the staff, while the ceviche sample identified as tilapia specifically declared "sea bass" on the menu.

Of the three substituted ceviche samples declared to be tilapia, two were identified as whiteleg shrimp (*Litopanaeus vannamei*) and the other was identified as Sutchi catfish (*Pangasianodon hypophthalmus*). These samples were described as "fish" or "white fish" on the menu but declared by restaurant staff to be "tilapia". Species substitution in products labeled as tilapia is not a common occurrence, as tilapia is a relatively low-value species. Of note, both of the restaurants that sold undeclared shrimp also had "shrimp ceviche" dishes on their menus. Although these substitution events appear to be accidental, individuals with shellfish allergies could be greatly impacted by the undeclared presence of shrimp due to the potential for anaphylactic shock. These substitutions also have cultural impacts, as the consumption of shellfish is prohibited in those with kosher diets.

4.2. Unacceptable market names

Use of the common name or acceptable market name(s) for a fish species as provided in *The Seafood List* is recommended by the FDA in order to provide a clear representation of a product to the consumer (FDA, 2022). Of the 103 samples identified with DNA barcoding, 47 (45.6%) did not have common names or acceptable market names on the menu (Table 2). Among the 67 restaurants sampled in this study, 43 had at least one unacceptable market name on the menu. Six of the products with unacceptable market names were also determined to be substituted based on the verbal declarations of restaurant staff (discussed above). Among the three product categories (Fig. 2), ceviche had the greatest rate of unacceptable market names at 79.4% (27/34), followed by poke at 44.1% (15/34), and sushi at 14.3% (5/35). These three rates were found to be significantly different from each other using Fisher's exact test of independence with the Bonferroni correction ($p < 0.017$). However, there were no significant differences in the rates of unacceptable market names based on price within each product category (Kruskal Wallis H test, $p > 0.05$) or when comparing independent vs. chain restaurants (Fisher's exact test, $p > 0.05$).

4.2.1. Ceviche

Ceviche's high mislabeling rate was driven primarily by restaurants referring to their product using generic terms such as "fish" (n = 22), "pescado" (n = 4), or "white fish" (n = 2), none of which are acceptable market names for fish sold in the United States. These generically labeled samples were identified as a wide variety of species, including Atlantic salmon, tilapia, Sutchi catfish, whiteleg shrimp, yellowtail, and widow rockfish. When the restaurant staff were asked for clarification regarding the species in the dish, their answers were uninformative for 67.9% of samples and resulted in species substitution for 21.4% of samples (discussed above). However, in three instances (10.7%), the restaurant staff were able to provide an accurate market name (swai or tilapia) that was confirmed with DNA barcoding. These results are similar to a study conducted in Chile, which indicated that 64% of salespeople were unable to identify the species in sushi products (Prida et al., 2020). In comparison, a U.S. study on tuna sushi reported that 32% of species descriptions declared by restaurant staff were incorrect and 9% were uninformative for generically labeled tuna sushi samples (Lowenstein et al., 2009).

4.2.2. Poke and Sushi

Unacceptable market names among poke products were driven by incorrectly labeled tuna and salmon samples. Four poke samples labeled as "ahi" or "ahi tuna" were identified as yellowfin tuna (*Thunnus albacares*) and one was identified as southern bluefin tuna (*Thunnus maccoyii*). The term "ahi poke" is often used to describe poke containing yellowfin tuna or bigeye tuna (Hospital & Beavers, 2014). However, "ahi" is considered a vernacular name and is not an acceptable market name for any species according to *The Seafood List* (FDA, 2022). The mislabeling of southern bluefin tuna with a vernacular term for yellowfin or bigeye tuna is potentially a case of "reverse substitution", in which the highly valuable bluefin tuna is illegally overfished and sold as a lesser species (Gordoa et al., 2017). Reverse substitution involving bluefin tuna has been reported previously in studies conducted in the United States (Liou et al., 2020) and Spain (Gordoa et al., 2017).

Ten poke samples and four sushi samples with unacceptable market names were associated with improper labeling of salmon. These samples were labeled as "salmon" and identified as Atlantic salmon (*Salmo salar*). While labeling of Atlantic salmon generically as "salmon" is a commonly observed practice (Khaksar et al., 2015; Liou et al., 2020), it should be referred to as "Atlantic salmon" according to *The Seafood List* (FDA, 2022). The specification is important because Atlantic salmon is a farmed species, whereas the majority of Pacific salmon are wild-caught (Cline, 2012). Therefore, designating Atlantic salmon generically as "salmon" does not provide consumers with sufficient information to make informed purchasing decisions. The remaining sushi sample with an unacceptable market name was labeled as "izumidai" and identified as tilapia. While izumidai is used in sushi culture to refer to tilapia, it is not a recommended market name according to *The Seafood List* (FDA, 2022).

4.3. Overall mislabeling rates

When the instances of species substitution and use of unacceptable market names were combined, the overall mislabeling rate was found to be 63.1% (65/103; Fig. 2). Among the 67 restaurants where samples were collected, 55 had at least one instance of species substitution or use of unacceptable market names. The overall mislabeling rate reported here for raw, RTE seafood (63.1%) is similar to the rate of 61% reported by Velez-Zuazo et al. (2021) for mislabeling at ceviche and sushi restaurants in Peru, and within the range of previous studies conducted globally on sushi which have reported 12-84% species mislabeling (Gordoa et al., 2017; Hu et al., 2018; Khaksar et al., 2015; Liu et al., 2022; Lowenstein et al., 2009; Prida et al., 2020; Wallstrom et al., 2020; Warner et al., 2013; Willette et al., 2017). However, it is difficult to make direct comparisons among mislabeling rates reported in other studies due to differences in sampling methods and the way in which mislabeling is determined (e.g., species substitution versus unacceptable market names).

When the overall mislabeling rates were separated based on product category, the rate for ceviche (85.3%, 29/34) was significantly higher ($p < 0.017$) than the rate for sushi (42.9%, 15/35), according to a Fisher's exact test of independence with the Bonferroni correction. On the other hand, the overall rate of poke mislabeling (61.8%, 21/34) was not significantly different from the rates for ceviche or sushi mislabeling. Mislabeling in ceviche and poke was primarily due to the use of unacceptable market names, whereas species substitution was more common in sushi dishes (Fig. 2). This is likely due to differences in how the products are marketed to consumers – ceviche dishes are often generically labeled as "fish" and poke restaurants tend to offer a small range of fish choices (i.e., yellowtail, tuna, and salmon). On the other hand, sushi restaurants tend to offer a larger range of fish choices at various price points depending on the fish species listed on the menu.

5. Conclusion

This study highlights several challenges with species substitution and mislabeling of raw, RTE seafood. Ceviche mislabeling is not well documented in the United States, and the results of this study indicate a relatively high mislabeling rate, primarily due to the use of unacceptable market names. There were six instances where the species that was verbally declared by restaurant staff resulted in cases of species substitution. These occasions speak to the challenges of relying on adequate communication among restaurant staff and managers regarding fish species and suggest potential for improvement in this area. Two instances of shellfish being present in samples sold as finfish present concerns for public safety. While the substitution was likely accidental, ingestion of shellfish in those with allergies can result in anaphylactic shock, leading to hospitalization or death. This study presents the first reports of poke mislabeling, which was due to a combination of unacceptable market names and species substitution. In combination with previous studies, the current study demonstrates that sushi species substitution continues to be problematic, with yellowtail, halibut, sea bass, and snapper samples being consistently mislabeled. While mislabeled products were observed at the retail level in this study, it is likely that a portion of these products were originally mislabeled earlier in the supply chain. Further research into mislabeling within the seafood supply chain and a determination of where and why mislabeling is occurring is warranted. Additionally, greater outreach efforts at the retail level to improve menu descriptions of raw, RTE seafood are suggested, as well as requiring the use of species names or acceptable market names according to *The Seafood List*.

Acknowledgements

This research was supported by internal funding from Chapman University.

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Table 1. Instances of species substitution (n = 24) in raw, RTE seafood samples based on menu description or verbal declaration.

Menu Description	**Expected Species[a]**	**Identified Species**	**Product Category**	**No. of Samples**
Yellowtail	Yellowtail (*Seriola lalandi*)	Buri (*Seriola quinqueradiata*)	Sushi	4
			Poke	6
			Ceviche	1
Halibut	Atlantic halibut (*Hippoglossus hippoglossus*) or Pacific halibut (*Hippoglossus stenolepis*)	Olive flounder (*Paralichthys olivaceus*)	Sushi	2
		Almaco jack (*Seriola rivoliana*)	Sushi	1
Fish (halibut[b])	Atlantic halibut (*Hippoglossus hippoglossus*) or Pacific halibut (*Hippoglossus stenolepis*)	Walleye Pollock (*Gadus chalcogrammus)*/Arctic cod (*Boreogadus saida*)	Ceviche	1
Sea bass	Sea bass (range of species from 6 genera)	Tilapia (*Oreochromis sp.*)	Ceviche	1
Fish (sea bass[b])	Sea bass (range of species from 6 genera)	Sutchi Catfish (*Pangasianodon hypophthalmus*)	Ceviche	1
Red snapper	Red snapper (*Lutjanus campechanus*)	Tilapia (*Oreochromis sp.*)	Sushi	1
Black snapper	Black snapper (*Apsilus dentatus*)	Gilthead bream (*Sparus aurata*)	Sushi	1
Fish (snapper[b])	Snapper (range of species from 12 genera)	Sutchi Catfish (*Pangasianodon hypophthalmus)*	Ceviche	1
Amberjack	Amberjack (*Seriola* sp.)	White trevally (*Pseudocaranx dentex*)	Sushi	1
White fish (tilapia[b])	Tilapia (*Oreochromis sp., Sarotherodon sp.* or *Tilapia* sp.)	Sutchi Catfish (*Pangasianodon hypophthalmus*)	Ceviche	1
Fish (tilapia[b])	Tilapia (*Oreochromis sp., Sarotherodon sp.* or *Tilapia* sp.)	Whiteleg Shrimp (*Panaeus vannamei*)	Ceviche	2

[a]Expected species were determined based on acceptable market names listed in *The Seafood List* (FDA, 2022)
[b]Verbal declaration by restaurant staff

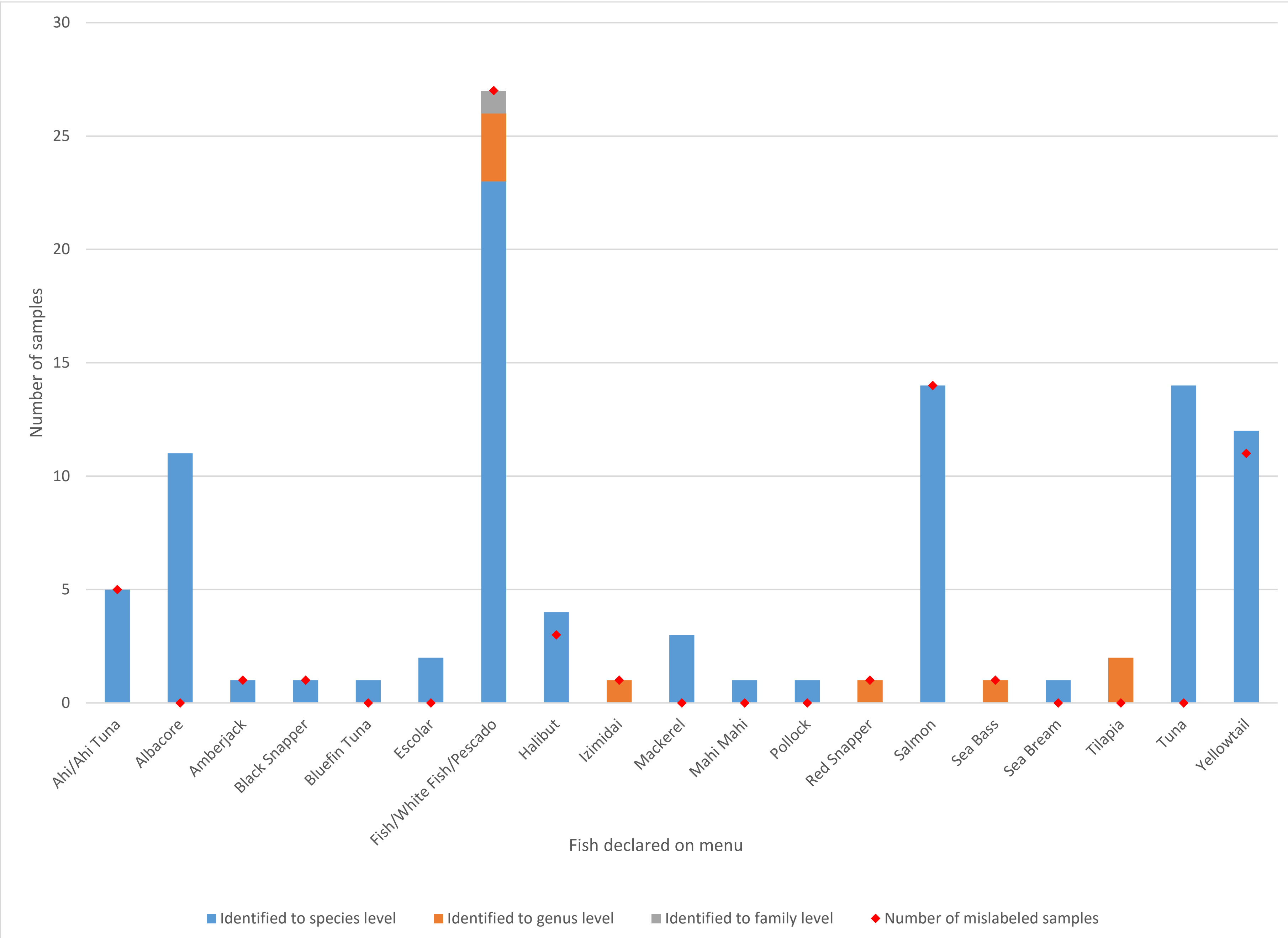
Table 2. Samples found to have unacceptable market names (n = 47) according to *The Seafood List* (FDA, 2022). Note: The common name may be used as the market name unless prohibited by regulation or law.

Product Category	Menu Description	Number of Samples	Identified Species	Acceptable market name(s)
Ceviche	Fish/white Fish/pescado	15	Sutchi catfish (*Pangasianodon hypophthalmus*)	Swai, Sutchi, Striped Pangasius, or Tra
	Fish/pescado	5	Tilapia *(Oreochromis sp.)*	Tilapia
	Fish	1	Walleye pollock *(Gadus chalcogrammus)*	Pollock
	Fish	1	Walleye pollock *(Gadus chalcogrammus)*/Artic cod (*Boreogadus saida*)	Pollock/Cod
	Fish	1	Atlantic salmon *(Salmo salar)*	Atlantic salmon
	Fish	1	Yellowtail *(Seriola lalandi)*	Amberjack or Yellowtail
	Fish	1	Widow rockfish *(Sebastes entomelas)*	Rockfish
	Fish	2	Whiteleg shrimp (*Litopenaeus vannamei*)	Shrimp
Poke	Salmon	10	Atlantic salmon *(Salmo salar)*	Atlantic salmon
	Ahi/ahi tuna	4	Yellowfin tuna *(Thunnus albacares)*	Tuna
	Ahi tuna	1	Southern Bluefin Tuna *(Thunnus maccoyii)*	Tuna
Sushi	Salmon	4	Atlantic salmon *(Salmo salar)*	Atlantic salmon
	Izimidai	1	Tilapia *(Oreochromis sp.)*	Tilapia

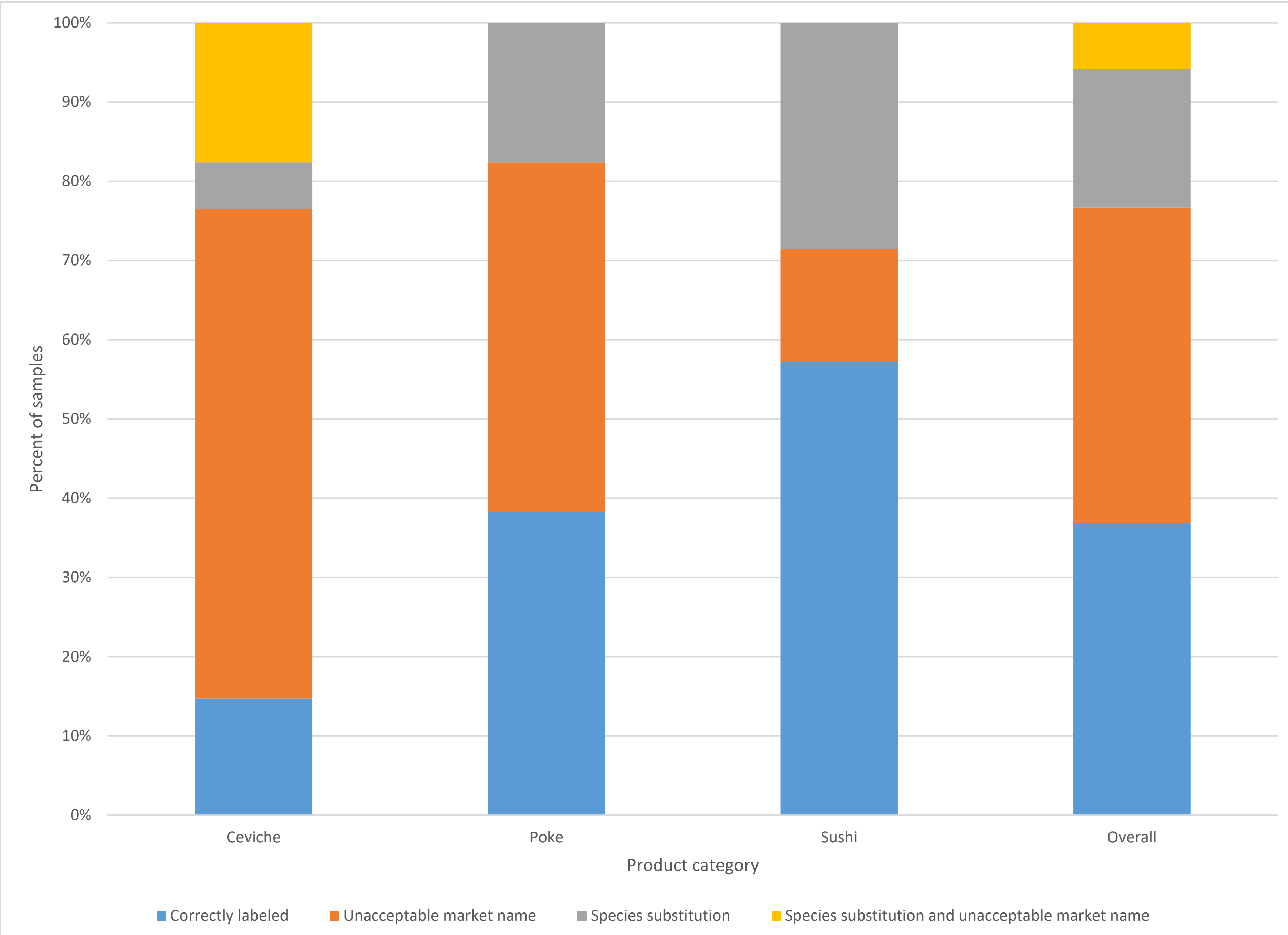
Figure captions

Figure 1. Combined results of DNA barcoding and mini-barcoding for raw, RTE seafood samples identified in this study (n = 103). The number of mislabeled samples refers those with unacceptable market names and/or species substitution.

Figure 2. Proportion of ceviche (n = 34), poke (n = 34), and sushi (n = 35) samples with unacceptable market names and/or species substitution. The "species substitution and unacceptable market name" category applies to samples that had an unacceptable market name on the menu and were substituted due to a verbal declaration by restaurant staff. The "overall" category represents all samples combined (n = 103).



30
25
20
15
10
5
0
Number of samples
Ahi/Ahi Tuna
Albacore
Amberjack
Black Snapper
Bluefin Tuna
Escolar
Fish/White Fish/Pescado
Halibut
Izimidai
Mackerel
Mahi Mahi
Pollock
Red Snapper
Salmon
Sea Bass
Sea Bream
Tilapia
Tuna
Yellowtail
Fish declared on menu
Identified to species level
Identified to genus level
Identified to family level
Number of mislabeled samples



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of samples
Ceviche
Poke
Sushi
Overall
Product category
Correctly labeled
Unacceptable market name
Species substitution
Species substitution and unacceptable market name

Number for sorting	Sample Number	Product category	Menu Declaration	Verbal Declaration by Staff
1	Q1	Sushi/sashimi	Salmon	N/A
2	Q2	Sushi/sashimi	Tuna	N/A
3	Q3	Sushi/sashimi	Salmon	N/A
4	Q4	Sushi/sashimi	Tuna	N/A
5	Q5	Poke	Tuna	N/A
6	Q6	Poke	Yellowtail	N/A
7	Q7	Poke	Tuna	N/A
8	Q8	Poke	Salmon	N/A
9	Q9	Sushi/sashimi	Tuna	N/A
10	Q10	Sushi/sashimi	Yellowtail	N/A
11	Q11	Sushi/sashimi	Yellowtail	N/A
12	Q12	Sushi/sashimi	Tuna	N/A
13	Q13	Sushi/sashimi	Tuna	N/A
14	Q14	Sushi/sashimi	Salmon	N/A
15	Q15	Sushi/sashimi	Tuna	N/A
16	Q16	Sushi/sashimi	Yellowtail	N/A
17	Q17	Poke	Albacore	N/A
18	Q18	Poke	Salmon	N/A
19	Q19	Sushi/sashimi	Albacore	N/A
20	Q20	Sushi/sashimi	Yellowtail	N/A
21	Q21	Sushi/sashimi	Tuna	N/A
22	Q22	Sushi/sashimi	Salmon	N/A
23	Q23	Sushi/sashimi	Tuna	N/A
24	Q24	Sushi/sashimi	Albacore	N/A
25	Q25	Poke	Salmon	N/A
26	Q26	Poke	Tuna	N/A
27	Q27	Poke	Salmon	N/A
28	Q28	Poke	Ahi tuna	N/A
29	Q29	Poke	Salmon	N/A
30	Q30	Poke	Ahi	N/A
31	Q31	Ceviche	Fish	No additional informa
32	Q32	Poke	Tuna	N/A
33	Q33	Poke	Salmon	N/A
34	Q34	Poke	Tuna	N/A
35	Q35	Poke	Salmon	N/A
36	Q36	Sushi/sashimi	Albacore	N/A
37	Q37	Sushi/sashimi	Mackerel	N/A
38	Q38	Sushi/sashimi	Mackerel	N/A
39	Q39	Sushi/sashimi	Escolar	N/A
40	Q40	Sushi/sashimi	Halibut	N/A
41	Q41	Sushi/sashimi	Red snapper	N/A
42	Q42	Poke	Salmon	N/A
43	Q43	Poke	Yellowtail	N/A
45	Q45	Poke	Salmon	N/A
46	Q46	Poke	Yellowtail	N/A
47	Q47	Poke	Salmon	N/A

48	Q48	Poke	Tuna	N/A
49	Q49	Sushi/sashimi	Albacore	N/A
50	Q50	Sushi/sashimi	Izimidai	N/A
51	Q51	Sushi/sashimi	Mackerel	N/A
52	Q52	Sushi/sashimi	Albacore	N/A
53	Q53	Sushi/sashimi	Halibut	N/A
54	Q54	Sushi/sashimi	Black snapper	N/A
55	Q55	Sushi/sashimi	Amberjack	N/A
56	Q56	Sushi/sashimi	Escolar	N/A
57	Q57	Sushi/sashimi	Albacore	N/A
58	Q58	Sushi/Sashimi	Halibut	N/A
59	Q59	Sushi/Sashimi	Sea bream	N/A
60	Q60	Ceviche	Pescado	No additional informa
61	Q61	Ceviche	Mahi mahi	N/A
63	Q63	Ceviche	Fish	No additional informa
64	Q64	Ceviche	Fish	No additional informa
65	Q65	Ceviche	White fish	No additional informa
66	Q66	Ceviche	Fish	No additional informa
68	Q68	Ceviche	Sea bass	N/A
69	Q69	Ceviche	Pescado	No additional informa
71	Q71	Ceviche	Fish	Halibut
72	Q72	Ceviche	Fish	Tilapia
73	Q73	Ceviche	Halibut	N/A
75	Q75	Ceviche	Pescado	No additional informa
77	Q77	Ceviche	Fish	Swai
79	Q79	Ceviche	Pollock	N/A
80	Q80	Ceviche	Tilapia	N/A
83	Q83	Ceviche	Fish	White fish
84	Q84	Ceviche	Fish	White fish
86	Q86	Ceviche	Fish	Sea bass
88	Q88	Ceviche	Fish	White fish
89	Q89	Ceviche	Fish	White fish
90	Q90	Ceviche	Yellowtail	N/A
95	Q95	Ceviche	Fish	Tilapia
96	Q96	Ceviche	Fish	Tilapia
98	Q98	Ceviche	Fish	Tilapia
99	Q99	Ceviche	Fish	Snapper
101	Q101	Poke	Ahi Tuna	N/A
103	Q103	Poke	Ahi Tuna	N/A
106	Q106	Poke	Albacore	N/A
107	Q107	poke	Yellowtail	N/A
111	Q111	Poke	Albacore	N/A
114	Q114	Poke	Albacore	N/A
123	Q123	Poke	Albacore	N/A
127	Q127	Poke	Ahi tuna	N/A
133	Q133	Poke	Albacore	N/A
134	Q134	Poke	Bluefin tuna	N/A
145	Q145	Ceviche	Fish	No additional informa
146	Q146	Ceviche	Pescado	No additional informa

184	Q184	Ceviche	White Fish	Tilapia
186	Q186	Ceviche	Fish	No additional informa
187	Q187	Ceviche	Fish	No additional informa
188	Q188	Ceviche	Fish	No additional informa
189	Q189	Ceviche	Tilapia	N/A
190	Q190	Ceviche	Fish	No additional informa
191	Q191	Ceviche	Fish	No additional informa
193	Q193	Poke	Yellowtail	N/A
194	Q194	Poke	Yellowtail	N/A
195	Q195	Poke	Yellowtail	N/A

Price (USD)	Type of Restaurant (Independent or Chain)	Barcode used for Species ID
$10.45	Independent	Full Barcode
$11.45	Independent	Full Barcode and CR
$10.99	Independent	Full Barcode
$11.99	Independent	Full Barcode and CR
$9.99	Independent	Full Barcode and CR
$9.99	Independent	Full Barcode
$12.99	Independent	Full Barcode and CR
$12.99	Independent	Full Barcode
$15.95	Independent	Full Barcode and CR
$15.95	Independent	Full Barcode
$14.95	Independent	Full Barcode
$14.95	Independent	Full Barcode and CR
$3.99	Independent	Full Barcode and CR
$3.99	Independent	COI Mini-Barcode
$3.79	Independent	CR (full barcode identified genus)
$4.29	Independent	Full Barcode
$12.99	Chain	CR (full barcode identified genus)
$12.99	Chain	Full Barcode
$7.99	Chain	CR (full barcode identified genus)
$7.99	Chain	Full Barcode
$12.95	Independent	CR (full barcode identified genus)
$12.95	Independent	Full Barcode
$6.99	Independent	Full Barcode and CR
$6.99	Independent	CR (full barcode identified genus)
$13.95	Chain	Full Barcode
$13.95	Chain	CR (full barcode identified genus)
$13.95	Chain	Full Barcode
$13.95	Chain	CR (full barcode identified genus)
$14.00	Independent	Full Barcode
$14.00	Independent	Full Barcode and CR
$15.34	Independent	Full Barcode
$9.99	Independent	CR (full barcode identified genus)
$9.99	Independent	Full Barcode
$13.95	Independent	CR (full barcode identified genus)
$13.95	Independent	Full Barcode
$15.95	Independent	CR (full barcode identified genus)
$13.99	Independent	Full Barcode
$15.95	Independent	COI Mini-Barcode
$15.95	Independent	Full Barcode
$6.95	Independent	Full Barcode
$4.95	Independent	Full Barcode
$8.95	Independent	Full Barcode
$8.95	Independent	Full Barcode
$8.99	Independent	COI Mini-Barcode
$8.99	Independent	Full Barcode
$11.75	Chain	Full Barcode

$11.75	Chain	Full Barcode and CR
$3.99	Independent	CR (full barcode identified genus)
$3.99	Independent	Full Barcode
$3.69	Independent	COI Mini-Barcode
$3.69	Independent	Full Barcode and CR
$8.00	Independent	Full Barcode
$8.00	Independent	Full Barcode
$8.00	Independent	Full Barcode
$7.00	Independent	Full Barcode
$7.00	Independent	CR
$16.00	Independent	Full Barcode
$18.00	Independent	Full Barcode
$4.50	Independent	Full Barcode
$18.00	Independent	Full Barcode
$16.50	Independent	Full Barcode
$4.35	Chain	Full Barcode
$17.95	Independent	Full Barcode
$5.45	Independent	COI Mini-Barcode
$14.50	Independent	Full Barcode
$8.49	Chain	Full Barcode
$10.39	Independent	COI Mini-Barcode
$17.50	Chain	Full Barcode
$19.00	Chain	Full Barcode
N/A - missing data	Independent	Full Barcode
$13.99	Independent	Full Barcode
$15.00	Independent	Full Barcode
$8.00	Chain	Full Barcode
N/A - missing data	Independent	Full Barcode
$9.14	Independent	Full Barcode
$14.95	Independent	Full Barcode
N/A - missing data	Independent	Full Barcode
$14.00	Independent	Full Barcode
$17.00	Chain	Full Barcode
$7.00	Independent	COI Mini-Barcode
$7.99	Independent	COI Mini-Barcode
$14.46	Independent	Full Barcode
$15.00	Independent	Full Barcode
$11.99	Chain	CR (Full barcode identified genus)
$11.85	Independent	CR (Full barcode identified genus)
$8.95	Independent	N/A (did not get an ID with DNA barcoding
$8.95	Independent	Full Barcode
$8.95	Independent	Full Barcode and CR
$9.99	Independent	CR
$13.99	Chain	Full Barcode and CR
$9.95	Independent	Full Barcode and CR
$13.00	Independent	CR (Full barcode identified genus)
$12.35	Chain	Full Barcode and CR
$15.00	Chain	COI Mini-Barcode
$11.95	Independent	Full Barcode

	$19.00	Chain	Full Barcode
	$16.50	Independent	Full Barcode
	$13.00	Independent	Full Barcode
	$11.25	Independent	Full Barcode
	$9.99	Independent	Full Barcode
	$10.99	Chain	N/A (did not get an ID with DNA barcodin
	$9.99	Independent	Full Barcode
	$10.19	Independent	Full Barcode
	$10.50	Chain	Full Barcode
	$10.50	Chain	COI Mini-Barcode

Species ID	Level of Genetic Match	Labeling Status
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Bigeye tuna (Thunnus obesus)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Southern bluefin tuna (Thunnus maccoyii)	Species	Correctly Labeled
Southern bluefin tuna (Thunnus maccoyii)	Species	Correctly Labeled
Yellowtail (Seriola lalandi)	Species	Correctly Labeled
Southern bluefin tuna (Thunnus maccoyii)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Bigeye tuna (Thunnus obesus)	Species	Correctly Labeled
Buri (Seriola quinqueradiata)	Species	Species substitution
Buri (Seriola quinqueradiata)	Species	Species substitution
Bigeye tuna (Thunnus obesus)	Species	Correctly Labeled
Bigeye tuna (Thunnus obesus)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Correctly Labeled
Buri (Seriola quinqueradiata)	Species	Species substitution
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Albacore tuna (Thunnus alalunga)	Species	Correctly Labeled
Buri (Seriola quinqueradiata)	Species	Species substitution
Yellowfin tuna (Thunnus albacares)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Bigeye tuna (Thunnus obesus)	Species	Correctly Labeled
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Unacceptable Market Name
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Unacceptable Market Name
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Correctly Labeled
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Atlantic mackerel (Scomber scombrus)	Species	Correctly Labeled
Atlantic mackerel (Scomber scombrus)	Species	Correctly Labeled
Escolar (Lepidocybium flavobrunneum)	Species	Correctly Labeled
Almaco jack (Seriola rivoliana)	Species	Species substitution
Tilapia (Oreochromis sp.)	Genus	Species substitution
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Buri (Seriola quinqueradiata)	Species	Species substitution
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name
Buri (Seriola quinqueradiata)	Species	Species substitution
Atlantic salmon (Salmo salar)	Species	Unacceptable Market Name

Yellowfin tuna (Thunnus albacares)	Species	Correctly Labeled
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Tilapia (Oreochromis sp.)	Genus	Unacceptable Market Name
Atlantic mackerel (Scomber scombrus)	Species	Correctly Labeled
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Olive flounder (Paralichthys olivaceus)	Species	Species Substitution
Gilthead bream (Sparus aurata)	Species	Species Substitution
White trevally (Pseudocaranx dentex)	Species	Species Substitution
Escolar (Lepidocybium flavobrunneum)	Species	Correctly Labeled
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Olive flounder (Paralichthys olivaceus)	Species	Species Substitution
Madai (Pagrus major) (also matched Nile tilap	Species	Correctly Labeled (sea bream is
Tilapia (Oreochromis sp.)	Genus	Unacceptable Market Name
Dolphinfish (Coryphaena hippurus)	Species	Correctly Labeled
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Walleye pollock (Gadus chalcogrammus)	Species	Unacceptable Market Name
Tilapia (Oreochromis sp.)	Genus	Species Substitution
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Walleye pollock (Gadus chalcogrammus)/Artic	Family/Multi-Genus	Species Substitution (verbal) an
Mozambique tilapia (Oreochromis mossambic	Species	Unacceptable Market Name (bu
Pacific halibut (Hippoglossus stenolepis)	Species	Correctly Labeled
Nile tilapia (Oreochromis niloticus)	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name (bu
Walleye pollock (Gadus chalcogrammus)	Species	Correctly labeled
Tilapia (Oreochromis sp.)	Genus	Correctly labeled
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Species Substitution (verbal) an
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Buri (Seriola quinqueradiata)	Species	Species Substitution
Whiteleg shrimp (Penaeus vannamei (synonyr	Species	Species Substitution and Unacc
Whiteleg shrimp (Penaeus vannamei (synonyr	Species	Species Substitution and Unacc
Tilapia (Oreochromis sp.)	Genus	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Species Substitution (verbal) an
Yellowfin tuna (Thunnus albacares)	Species	Unacceptable Market Name
Yellowfin tuna (Thunnus albacares)	Species	Unacceptable Market Name
N/A	N/A	N/A (not identified with barcod
Buri (Seriola quinqueradiata)	Species	Species Substitution
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Southern Bluefin Tuna (Thunnus maccoyii)	Species	Unacceptable Market Name
Albacore (Thunnus alalunga)	Species	Correctly Labeled
Southern bluefin tuna (Thunnus maccoyii)	Species	Correctly Labeled
Yellowtail (Seriola lalandi)	Species	Unacceptable Market Name
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name

Sutchi catfish (Pangasianodon hypophthalmus	Species	Species Substitution (verbal) an
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Tilapia (Oreochromis sp.)	Genus	Unacceptable Market Name
Widow rockfish (Sebastes entomelas)	Species	Unacceptable Market Name
Tilapia (Oreochromis sp.)	Genus	Correctly Labeled
N/A	N/A	N/A (not identified with barcod
Sutchi catfish (Pangasianodon hypophthalmus	Species	Unacceptable Market Name
Buri (Seriola quinqueradiata)	Species	Species substitution
Buri (Seriola quinqueradiata)	Species	Species substitution
Buri (Seriola quinqueradiata)	Species	Species substitution

Full COI Barcode Consensus Sequence	COI (SH-E) Mini-Barcode Consensus Sequence	CR Mini-Barcode Consensus Sequence
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATATCTATATATAGACCATATACAGTAATGTTCTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATATCTATATATCGACCATACATAATAATGCTTTAGGACATATAT(
CCTCTATCTAGTATTCGGTGCA	N/A	ATATTTATATATTGACCATATATAATAATGCTTTAGGACATATATG
CCTCTATCTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATATTTATATATTGACCATATATAATAATGCTTTAGGACATATATG
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATATTTATATATGAACCATATACAGTAATGTTCTAGGACATATAT(
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
AACTTAGTCAACCCGGTGCTC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATATCTATATATGAACCATATACAATAATGTTCTAGGACATATAT(
CCTCTATCTAGTATTCGGTGCA	N/A	ATATTTATATATGGACCATATACAATAATGTTCTAGGACATATAT(
Full barcode did not pass QC	CCTCTATTTAGTATTTG(	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATAATCATATTTGAAACATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
TCTATCTAGTATTCGGTGCATG	N/A	ATAACTATATTTGAAACATATATAATAATGCTTTAGGACATACAT(
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATATCTATATATAGACCATATACAGTAATGTTCTAGGACATATAT(
CCTCTATCTAGTATTCGGTGCA	N/A	ATAACTATATTTGAAACATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATTTAGTATTTGGGTGC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATAACTATATTTGAAACATACATAATAATGCTTTAGGACATACAT(
TACGTAGTATTTGGTGCATGAT	N/A	N/A
Full barcode did not pass QC	CCTCTACCTAGTATTTG	N/A
CCTGTATCTCGTATTCGGTGCA	N/A	N/A
CCTTTATCTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTCTATTTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
Full barcode did not pass QC	CCTCTATTTAGTATTTG(	N/A
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
CCTCTATTTAGTATTTGGTGCC	N/A	N/A

CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTCTATCTAGTATTCGGTGCA	N/A	ATAACTATATTTGAAACATATATAATAATGCTTTAGGACATGTAT(
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
Full barcode did not amplify i	CCTCTACCTAGTATTTG	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATAACTATATTTCAAACATATATAATAATGCTTTAGGACATATAT(
CCTCTATCTCGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTTGGTGCT	N/A	N/A
CCTATATCTAGTATTTGGTGCT	N/A	N/A
CCTGTATCTCGTATTCGGTGCA	N/A	N/A
Full barcode did not pass QC	N/A	ATAACTATATTTAAAACATATATAATAATGCTTTAGGACATATAT(
CCTCTATCTCGTATTTGGTGCC	N/A	N/A
CCTTTATCTTGTATTTGGTGCT	N/A	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTTTATTTAATTTTCGGTGTC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
Full barcode did not amplify i	CCTTTATCTCGTATTTG(	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
Full barcode did not pass QC	CCTTTATCTCGTATTTG(	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTCTATCTCGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTCGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
Full barcode did not pass QC	ATTATACTTTATCTTCG(	N/A
Full barcode did not pass QC	ATTATACTTTATCTTCG(	N/A
CCTCTATCTAGTATTTGGNTGC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTTTATCTAGTATTCGGTGCA	N/A	ATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT(
CCTTTATCTAGTATTCGGTGCA	N/A	CATACTCATATATCGACCATATATAATAATGCTTTAGGACATATAT
Full barcode did not pass QC	N/A	CR mini-barcode did not pass QC
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
CCTCTATCTAGTATTCGGTGCA	N/A	ATAACTATATTTAAAACATATATAATAATGCTTTAGGACATATAT(
Full barcode did not pass QC	N/A	ATAACTATATTTAAAACATATATAATAATGCTTTAGGACATATAT(
CCTCTATCTAGTATTTGGTGCA	N/A	ATAACTATATTTGAAACATATATAATAATGCTTTAGGACATATAT(
CCTCTATCTAGTATTCGGTGCA	N/A	ATACTTATATATCGACCATACATAATAATGCTTTAGGACATATAT(
CCTCTATCTAGTATTCGGTGCA	N/A	ATAACTATATTTTAAACATATATAATAATGCTTTAAGACATGTATG
CCTCTATCTAGTATTCGGTGCA	N/A	ATACTTATATATCGACCATACATAATAATGCTTTAGGACATATAT(
Full barcode did not pass QC	CCTCTATCTAGTATTTG(	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A

CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
CCTTTATCTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTAGTATTTGGTGCT	N/A	N/A
Full barcode did not pass QC	SH-E mini-barcode did	N/A
CCTCTACCTAGTATTTGGTGCC	N/A	N/A
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
CCTCTATCTGGTATTCGGTGCC	N/A	N/A
Full barcode did not amplify i	CCTCTATCTGGTATTCG	N/A

GTATTAAAACCATTACTAGTACTAAACCATTCATATATCAACAAACAATGAAGACTTACATAAACCATACAGATATATTCC

GTATTAAAACCATTACTAGTATTAAACCATTCATATGTCAACAAACAACGAAGATTTACATAAACCATGCAGATAAACTCC
GTATTAAAACCATTACTAGTATTAAACCATTCATATGTCAACAAACAACGAAGATTTACATAAACCATGCGAATAAATTCT

GTATTAAAACCATTACTAGTATTAAACCATTCATATGTCAACAAACAACGAAGATTTACATAAACCATGCGAATAAGTTCT

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGACTTACATAAACCATACAGATATATCCT

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGACTTACATAAACCATACGAATATACTCC
GTATTAAAACCATTACTAGTACTAAACCATTCATATATCAACAAACAATGAAGACTTACACAAACCATACAGATATATTCC

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGACTTACATAAACCATACAGATATATCTT

GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGATTTACATAAAACATAACAACCATCTCT

GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGACTTACATAAGACATAACAACCATCCCC

GTATTAAAACCATTACTAGTACTAAACCATTCATATATCAACAAACAATGAAGATTTACATAAACCATACAGATATATCTT

GTATTAAAACCATTACTAGTACTAAACCATTCATATATCAACAAACAATGAAGACTTACATAAACCATACAGATATATTCC
GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGGTTTGCATAAGACATATCAATCACCTTT

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGGTTTACATAAACCATACAAATATATCTT

GTATTAAAACCATTACTAGTATTAAACCATTCATATGTCAACAAACAATGAAGATTTACATAAACCATACAGATATATCTT

GTATTAAAACCATTACTAGTACTAAACCATTCACATGTCAACAAACAATGAAGATTTACATAAACCATACAGATATATCTT

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCGAATAAACAATGAAAATTTACATAAACCATACAGATATATCT

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGACTTACATAAACCATACAGATATATCCT

GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGACTTACATAAGACATAACAACCATCTCC

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGATTTACATAAACCATACAAATATATCTTA
GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGACTTACATAAAACATAGCAACCATCTCCC

GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGACTTACATAAAACATAACAATCATCCCTC

GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACACATCATGAAGGTTTGCATAAGACATATTAATCATCTCTC

GTATTAAAACCATTACTAGTACTAAACCATTCATATGTCAACAAACAATGAAGATTTACATAAACCATACAAATATATCTTA
TGTATTAAAACCATTACTAGTACTAAACCATTCATATATCAACAAACAATGAAGACTTACATAAACCATACAAATATATCTT

GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGGTTTGCATAAGACATATCAATCACTTCTC
GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGACTTACATAAAACATAGCAACCATCTCCC
GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAARACTTACATAAAACATAACAATCATTCCCC
GTATTAAAACCATTGCTAGTACTAAACCATTCATATGTCAACAAATAACGAAGATTTACATAAACCATACAGATAAACTTCA
GTATTAAAACCATAACTAGTATTTAACCATTCATATGTCAACATATCATGAAGGTTTGCATAAAACATATGAACCATCCTTC
GTATTAAAACCATTACTAGTATTAAACCATTCATATGTCAACAAACAACGAAGATTTACATAAACCATATAGACAAACTTCA

AACATTCAAGTTAAGCCAAGTAATTAAACGAGATTTAAGACCTACCACAAACACTAAATCGTCTAAGCCATACCAAGTCT

AACATTCTCTTAAATTCAAGTAACTAAACGAAATTTAAGACCTAACACAAATCTAAATCGTCTAAGCCATACCAAGTCTCC
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AACATTCTCTCGAGTTCAGGTAATTAAACGAGATTTAAGACCTAACACAAACCTAAATCGTCTAAGCCATACCAAGTCCC

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