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Short-weighting, species authentication, and labeling compliance of prepackaged frozen shrimp sold in grocery stores in Southern California

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ABSTRACT

Shrimp is the most-consumed seafood product in the United States; however, there is a lack of research into the extent of short-weighting and mislabeling of shrimp in the commercial marketplace. The objective of this study was to investigate frozen shrimp for Country of Origin Labeling (COOL) compliance, species authentication, acceptable market names, net weights, and percent glaze. A total of 106 frozen shrimp packages were purchased from grocery stores in Southern California. Samples were considered COOL compliant if both the procurement method and country of origin were reported at the point of sale. Species authentication and acceptable market names were determined by comparing the species identification based on DNA barcoding to the acceptable market names on the FDA Seafood List. Net weights and percent glaze were determined by recording the weight of each sample before and after deglazing according to AOAC methods. The measured net weight of each product was compared to the declared net weight to determine if samples had been short-weighted, taking into account the maximum allowable variation (MAV) by the National Institute of Standards and Technology (NIST). Overall, 94% of samples were compliant with COOL. The average percent glaze was 16.6%, with 26% of samples having >20% glaze. Short-weighting was detected in 37% of samples, with the greatest proportion of incidents recorded for the super/extra colossal shrimp category (57.1%). Species labeling errors were observed in 37% of samples due to conflicting market names, species substitution, and/or use of unacceptable market names. The results of this study indicate a high level of COOL compliance but suggest a need for increased scrutiny of species mislabeling and short-weighting of frozen shrimp.

1. Introduction

Shrimp is the top-consumed seafood in the United States, accounting for approximately one-fourth of the country's annual per capita seafood consumption (NMFS, 2020). Numerous species of shrimp are available on the U.S. commercial market, with the most common being whiteleg shrimp (*Penaeus vannamei* Boone, 1931), giant tiger prawn (*Penaeus monodon* Fabricius, 1798), and giant freshwater prawn (*Macrobrachium rosenbergii* De Man, 1879) (EMR, 2022). While there is a domestic fishery for wild-caught shrimp, over 90% of the shrimp consumed in the U.S. is farmed and imported from countries such as India, Ecuador, and Indonesia (Delaware Sea Grant, n.d.; NMFS, 2021). In 2020 alone, approximately 744 million kg of shrimp were imported to the U.S and 123 million kg of shrimp were domestically produced (NMFS, 2020).

Seafood is highly susceptible to fraud due to factors such as the similar appearance of many species, increasing global trade, and varying quality, supply, and demand (Silva et al., 2021). However, without distinct morphological indicators, it can be hard to visually determine whether a seafood product has been fraudulently labeled (Naaum & Hanner, 2016). Improper labeling of seafood products may lead to exposure to allergens, parasites or toxins, religious infringement, environmental impacts, and economic deception (Silva et al., 2021). To aid in the proper labeling of seafood, the U.S. Food and Drug Administration (FDA) established the Seafood List, which is FDA's guide to market names considered to be acceptable for seafood sold in U.S. interstate commerce (FDA, 2022). Seafood species can be determined with DNA barcoding, which utilizes DNA sequencing to aid in the identification of species in a given product (Eischeid et al., 2016; Handy et al., 2011). DNA barcoding for species determination combined with the enforcement of labeling regulations may help lower the percentage of mislabeled seafood both on a national and global scale.

The FDA Seafood List contains over 60 species that can be sold under

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the collective term "shrimp" on the U.S. market (FDA, 2022). Due to the high demand for shrimp and the range of species available at different price points, shrimp are highly vulnerable to deceptive labeling practices. For example, a U.S. market survey found that 30% of 143 shrimp samples were associated with species misrepresentation (Warner et at., 2014). In 2015, a North Carolina-based seafood processor and wholesale distributor pleaded guilty to falsely labeling imported farmed shrimp as wild-caught product of the United States (United States Department of Justice, 2015). Subsequently, Korzik et al. (2020) reported that 34% of shrimp samples sold at grocery retailers and seafood-specific markets in North Carolina, USA, and labeled as "local" were actually whiteleg shrimp (*P. vannamei*), an imported and predominantly farmed species.

In addition to the use of acceptable market names, unprocessed fresh and frozen seafood products sold in the U.S. must adhere to the Country of Origin Labeling law (COOL labeling for Fish and Shellfish, 7 C.F.R § 60). These regulations require Perishable Agricultural Commodities Act (PACA)-licensed retailers to notify their customers of the geographic origin and procurement information for applicable products at the point of sale (AMS, 2009). Imported fish and shellfish must also adhere to 19 C.F.R § 134.11 (Country of Origin Marking Required). In a previous U.S. market survey, 30% of 447 shrimp products visually surveyed from grocery retailers were missing information on country of origin and 29% lacked information on whether they were farm-raised or wild caught (Warner et al., 2014). These results indicate a lack of COOL compliance in shrimp products; however, further research is necessary to better understand the extent of noncompliant products among PACA-licensed retailers.

Additional concerns with frozen seafood are overglazing and short-weighting (Peterson et al., 2021). Glazing seafood is a common practice used in the industry that not only aids in reducing product weight loss by dehydration, but also prevents freezer burn by surrounding the product in a thin layer of ice. There is no industry standard for appropriate glaze levels; however, 5–10% glaze has been reported to be sufficient for most frozen seafood products (Mitchell & Archer, 2016) and 15–20% glaze has been determined to be a reasonable range for shrimp (Gonçalves & Gindri Junior, 2009). Excess use of glaze with frozen shrimp has been reported previously, with glazing as thick as 25–45% (Jacobsen & Fossan, 2001). However, according to the FDA, the net weight of frozen seafood may not include the weight of the glaze (ice) (FDA, 2009). In a previous study, Peterson et al. (2021) found that 7 out of 111 frozen fish fillets collected from grocery stores in Southern California were overglazed (>10% glaze) and 10 were short-weighted. Short-weighting occurs when the declared net weight on the label is less than the actual net weight and is outside of the maximum allowable variation (MAV) established by the National Institute of Standards and Technology (NIST, 2011).

The objective of this study was to investigate COOL compliance, species labeling, glazing, and short-weighting associated with frozen shrimp sold at grocery stores throughout Orange County, CA. This research is novel in that it is the first study to investigate commercially sold prepackaged frozen shrimp for short-weighting and overglazing, as well as the first combined assessment of glazing, species authentication, and COOL compliance in frozen shrimp.

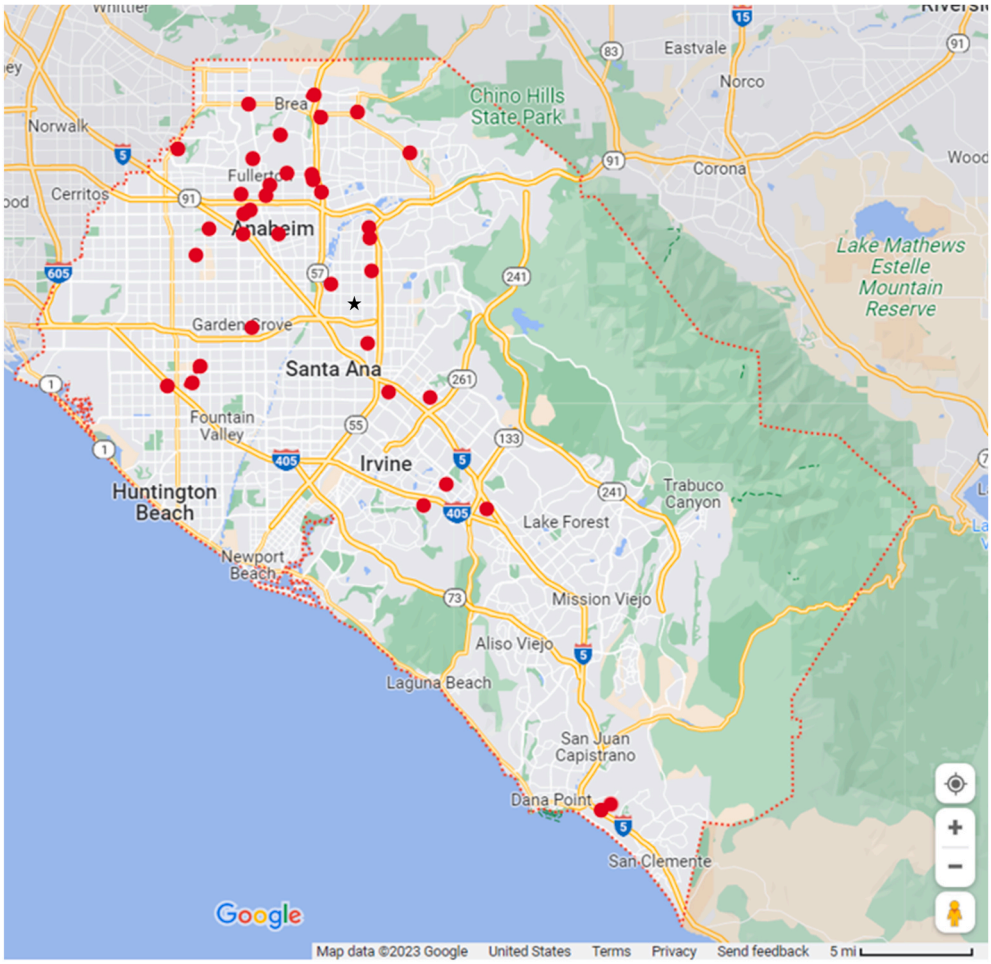

Fig. 1. Geographic sampling region targeted in this study. All products were collected within Orange County, CA, USA (designated by a dotted red border). Specific locations of PACA-licensed grocery retailers visited (n = 37) are indicated with red circles and Chapman University is indicated by a black star.

2. Materials and methods

2.1. Sample collection

A total of 106 samples of frozen uncooked shrimp (Table S1) were collected from 37 PACA-licensed grocery retailers located in Orange County, CA (Fig. 1). Selection was based on availability of products by the retailer and included the following subcategories based on the declared size descriptor: small (n = 10), medium (n = 15), large (n = 15), extra large (n = 15), jumbo (n = 17), extra jumbo (n = 13), colossal (n = 10), and extra/super colossal (n = 7). Four additional samples were collected in which the label listed a combination of sizes or listed a size that did not fit into the above categories: small/medium (n = 1), medium large (n = 1), extra large/jumbo (n = 1), and extra extra large (n = 1). In the absence of a declared size descriptor on the package, the declared count was used to determine the size category according to the chart provided in Rattray (2021). All samples were unique (i.e., no repeats of the same product in each subcategory). COOL compliance and species labeling for each product was determined by reviewing the provided labels found on the packaging, as well as any signs, labels, and/or tags available at each store at the time of purchase. Shrimp samples were transferred to the laboratory at Chapman University (Orange, CA) in a cooler containing ice packs and then stored at −20 °C until further processing.

2.2. Deglazing and net weight determination

The net weight of each shrimp product was determined following the AOAC International official method 963.18(a) for Individually Quick Frozen (IQF) shrimp and AOAC 967.13 for block frozen shrimp. All weights were recorded using an Ohaus Scout H-5853 Balance Scale (Ohaus Corp., Parsippany, NJ, USA), which was calibrated each day prior to sample testing. On the day of analysis, shrimp samples were removed from the −20 °C freezer and processed according to the appropriate AOAC method.

For AOAC 963.18(a), the contents of each package were transferred into an aluminum lined pan on a tared scale and weighed immediately to determine the glazed weight. The samples were run under a gentle flow of cold water to remove the ice glaze present, and then evenly distributed on a circular No. 8 sieve (Cole-Parmer, Mentor, OH, USA) and inclined at a 20° angle for 2 min to facilitate draining. A 20 cm diameter sieve was used for samples weighing 0.9 kg or less and a 30 cm diameter sieve was used for samples >0.9 kg. Next, the deglazed samples were immediately transferred into a previously tared pan and the net weights were recorded.

For AOAC 967.13, the entire container was weighed on the calibrated scale to determine the gross weight; the contents of each sample package were then placed in nylon mesh bags, in lieu of a wire mesh basket (NFI, 2017). The weight of the empty container and any plastic wrap used to seal the block frozen shrimp was subtracted from the gross weight to determine the glaze weight. The nylon mesh bags containing frozen shrimp were immersed in a >15 L pot of fresh water at 26 ± 3 °C (NFI, 2017) and water of the same temperature was introduced in a constant manner into the pot. Once the shrimp product was completely thawed, all materials were transferred and distributed evenly into a No. 8 sieve (Cole-Parmer), followed by draining and weighing as described above for AOAC 963.18(a).

The measured net weight of each product was compared to the declared net weight listed on the sample packaging. Samples with a measured net weight that exceeded the maximum allowable variation (MAV) according the National Institute of Standards and Technology (NIST) were considered short-weighted; the MAVs associated with the declared net weights of the collected samples are provided in Table 1 (NIST, 2011). The percent glaze of the product was calculated by $(1 - \frac{\text{net weight}}{\text{glaze weight}}) \times 100$. The number of individual shrimp in each package was counted and compared to the declared count-per-pound on the package, using the declared net weight to determine the expected number of shrimp in each package. Numerous steps were taken to prevent cross-contamination of DNA between samples, including sanitizing the workbench with DNA Away and changing gloves. Sieves, pots, pans, and tongs were washed in between each sample using dish soap and a sponge, followed by autoclaving at 121 °C for 15 min.

Table 1
Maximum Allowable Variations (MAVs) associated with the declared net weights of frozen shrimp packages collected in this study (NIST, 2011). Note: only categories relevant to the samples collected in this study are shown in the table.

Labeled Quantity (g)	Maximum Allowable Variation (g)
More than 209-263	13
More than 263-318	15
More than 318-381	16
More than 426-490	20
More than 490-572	22
More than 635-698	25
More than 852-971	32
More than 1350-1600	45
More than 1800-2100	55

2.3. DNA extraction of deglazed shrimp

Following deglazing, a 20–30 mg tissue sample was removed from the interior of an individual shrimp from each product using sterile forceps. DNA extraction of shrimp was conducted using a DNeasy Blood and Tissue kit (Qiagen, Valencia, CA, USA), Spin-Column protocol with modifications described in Eischeid et al. (2016), including use of one-fourth of the recommended manufacturer volumes. Lysis was carried out with an Eppendorf ThermoMixer C (Hamburg, Germany) set at 56 °C and 300 rpm for 3 h. DNA was eluted with 50 μL Buffer AE (Qiagen) and the extracted DNA was stored at −20 °C. Each batch of DNA extractions included a negative control (reagent blank) with no shrimp tissue added.

2.4. PCR and DNA sequencing

In order to maximize the potential for species identification of shrimp samples, a tiered approach was taken utilizing three different primer sets (Table 2). First, all samples underwent DNA barcoding of the 3′ cytochrome *c* oxidase subunit 1 (COI) region (475 bp) using primers described by Tong et al. (2000). Samples that failed to be identified with the 3' COI region were next tested with a 16S primer set (551 bp) described by Robles et al. (2006) and samples that continued to be unidentified underwent DNA mini-barcoding of the COI region using the SH-E primers (226 bp) described by Shokralla et al. (2015). Samples that failed to be identified with all three primer sets underwent a repeat DNA extraction, followed by PCR using the tiered approach described above. If a sample was unable to be identified with all three primer sets after the second DNA extraction, it was considered to have failed species identification.

PCR for the 3' COI and 16S regions was carried out using the following components: 3.44 μl molecular grade H_2O, 2.5 μl 10x PCR buffer, 12.5 μl 10% trehalose, 1.0 μl bovine serum albumin (BSA), 0.06 μl Platinum Taq DNA polymerase (Invitrogen, Carlsbad, CA), 2.5 μl 50 mM $MgCl_2$, 0.50 μl 10 mM dNTPs, 0.25 μl of each 10 μM primer, and 2.0 μl of DNA template for a total volume of 25.0 μl (Eischeid et al., 2016). Thermal cycling was carried out using an Eppendorf Mastercycler nexus gradient with the following conditions: 95 °C for 2 min; 35 cycles of 95 °C for 1 min, 50 °C for 1 min, and 72 °C for 1.5 min; and a final extension at 72 °C for 10 min (Eischeid et al., 2016). PCR for the SH-E primers was carried out using the following components: 8.5 μl molecular grade H_2O, 11.5 μl HotStarTaq Plus Master Mix (Qiagen), 0.5 μl of

Table 2
DNA barcoding primers used in this study.

Genetic target	Primer direction	Sequence[a]	Sequence length (bp)	Reference
COI (3′ end)	Forward	CACGACGTTGTAAAACGACTATTATTAGACAAGAATCTGGTAAA	475 bp	Tong et al. (2000)
COI (3′ end)	Reverse	GGATAACAATTTCACACAGGAGGAAATGTTGAGGGAAGAAAGTAA		
16S	Forward	CACGACGTTGTAAAACGACCGCCTGTTTATCAAAAACAT	551 bp	Robles et al. (2006)
16S	Reverse	GGATAACAATTTCACACAGGCCGGTCTGAACTCAGATCACGT		
COI (SH-E mini-barcode)	Forward	CACGACGTTGTAAAACGACACYAAICAYAAAGAYATIGGCAC	226 bp	Shokralla et al. (2015)
COI (SH-E mini-barcode)	Reverse	GGATAACAATTTCACACAGGCTTATRTTRTTTATICGIGGRAAIGC		

[a] Underlined segment indicates M13 tails.

each 10 μM SH-E primer, and 2.0 μl of DNA template, for a total reaction volume of 23.0 μl (Kitch et al., 2023). The cycling conditions were: 95 °C for 15 min; 35 cycles of 94 °C for 40 s, 46 °C for 1 min, and 72 °C for 30 s; and a final extension at 72 °C for 5 min (Shokralla et al., 2015). Each PCR run included a non-template negative control (NTC) with water in place of DNA template. All primers were synthesized by Integrated DNA Technologies (Coralville, IA, USA) and included M13 tails (Table 2).

PCR products were confirmed using pre-cast 2% agarose E-Gels run on an E-Gel™ Simple Runner Electrophoresis Device (Invitrogen) (Kitch et al., 2023). Each well was loaded with 10 μl of sterile water and 10 μl PCR product to achieve a total of 20 μl. Gels were visualized using an E-Gel Imager combined with GelCapture software (ThermoFisher Scientific, Waltham, MA, USA). PCR products were prepared for sequencing with ExoSAP-IT (ThermoFisher Scientific) according to the manufacturer's instructions. Bi-directional sequencing with M13 tails was carried out at Eurofins Genomics (Louisville, KY, USA) using a BigDye Terminator v3.1 Cycle Sequencing Kit and a 3730xl Genetic Analyzer (Applied Biosystems, Santa Clara, CA, USA).

2.5. DNA sequence analysis

The raw data obtained from sequencing was assembled and trimmed using Geneious Pro version 7 (Biomatters, Ltd., Auckland, New Zealand). Consensus sequences with <2% ambiguous bases that were ≥76% of the target length were considered to pass quality control (Pollack et al., 2018). The resulting DNA sequences for each sample are available in Table S1. All sequences were queried against GenBank using the nucleotide Basic Local Alignment Search Tool (BLASTn; http://blast.ncbi.nlm.nih.gov/Blast.cgi) to determine the top species match. In situations where the species could not be resolved with BLASTn, the sequences were aligned with reference sequences from previous studies (Eischeid et al., 2016; Garcia-Machado et al., 1996; Kaur et al., 2021; Zhong et al., 2019) using the MUSCLE alignment default settings in Geneious Pro and an unweighted pair group method with arithmetic mean (UPGMA) tree was generated using the parameters described in Eischeid et al. (2016). The species identified for each sample was compared to the FDA Seafood List to determine whether it was correctly labeled (FDA, 2022). Current scientific names for each species were determined using the World Register of Marine Species (WoRMS Editorial Board, 2023).

2.6. Statistical analysis

Short-weighting, overglazing, and species mislabeling of samples were compared across size categories using a test of equal proportions, with a significance level of $p < 0.05$. Size categories containing only one sample were excluded from the analyses (i.e., small/medium, extra large/jumbo, medium large, and extra extra large). All statistical analysis was carried out with R Studio version 4.2.3 (2022).

3. Results and discussion

3.1. COOL compliance

The majority of products (94.3%) were determined to be COOL compliant (Table S1). Of the six products that were noncompliant with COOL, three had conflicting countries of origin listed on the packaging/placard, two did not state the procurement method, and one had a retail sticker/price tag applied to the back of the packaging that covered the country of origin and procurement method declared on the product insert. Of the 37 retailers, only four (10.8%) were found to be noncompliant with COOL, with two of the five noncompliant products purchased from the same store.

Among the products with conflicting countries of origin, one stated that it was a product of Bangladesh on the packaging and a product of India on the placard, one was labeled as product of India on the packaging and product of Indonesia on the placard, and a third sample declared product of Ecuador on the packaging and product of Mexico on the placard. This practice is not only noncompliant with COOL, but also causes confusion among consumers and does not allow them to make informed purchasing decisions based on country of origin. The inconsistent labeling observed for these products may have been a result of the grocery retailer not checking the placards when placing a new product or a product with an updated country of origin into the display case.

Of the two products that did not state the procurement method, one was completely missing the information on both the product package and the product placard. However, the product package had three stickers applied to it that may have been covering the procurement method statement. Improper placement of production or retail stickers prevents consumers from getting all necessary COOL information when making their purchases. Another product did not have any procurement information on the placard and stated "naturally grown in mangrove forests" on the packaging. While this product mentioned shrimp farming and mangrove conservation on the back of the packaging, it did not use the COOL-required labeling terms of "farmed" or "farm-raised".

The high level of COOL compliance (94%) observed for frozen shrimp in this study is consistent with several previous studies showing high COOL compliance (90–99%) for fresh/frozen seafood sold at retail (K. Becker, personal communication, June 21, 2017; Lagasse et al., 2014; Peterson et al., 2021). In contrast, Liou et al. (2020) observed a lower rate of COOL compliance (77%) in fresh/thawed fish sold at grocery store seafood counters in Southern California, while Warner et al. (2014) reported an even lower rate of COOL compliance (41%) among fresh/frozen shrimp products sold at grocery retailers throughout the United States. The higher rate of COOL compliance observed for the current study as compared to the previous study on shrimp (Warner et at., 2014) is likely due to the focus on prepackaged products, in which the label containing the COOL information is typically applied at the processing facility as opposed to the retail level. Furthermore, Warner et al. (2014) visited a variety of retailers, including national/regional supermarket chains as well as smaller chains and markets, some of which may not have been PACA-licensed. This likely contributed to the reduced rate of COOL compliance observed, as smaller retailers and fish markets are exempt from COOL (USDA, 2023).

3.2. Shrimp size category

While there is currently no industry-wide standard established for the labeling of shrimp size categories, a guideline adopted by the National Conference for Weights and Measures (NCWM) states that if size

descriptor terms are used on the shrimp packages, advertisements, or on signs when offering shrimp for sale from bulk, a statement of count-per-pound, if sold by pound, should be included next to the descriptor (Butcher et al., 2022). Out of the 106 collected products, 14 (13.2%) listed only the size descriptor term on the package, with no accompanying count-per-pound statement (Table S2). Four of these products provided the count-per-pound on the retail price tag, but not on the package. Of the remaining products, 49 listed only the count-per-pound with no size descriptor on the package and 43 listed both a size descriptor and a count-per-pound. Two of the products that only listed the count-per-pound on the package had a retail price tag that listed both the count-per-pound and a size descriptor. A significant proportion of products (28.3%) used size descriptor terms that did not align with the declared count-per-pound according to the size chart in Rattray (2021). This is due to the lack of an industry standard for the use and definition of size descriptor terms. Establishment of a standard nomenclature for categorizing shrimp that defines the various size descriptor terms and requires the corresponding count to be clearly stated on a product's packaging is recommended to help avoid confusion for consumers.

Of the 96 products that declared a count-per-pound on the package or retail price tag, 87 (90.6%) had an actual shrimp count that was in-range with the declared count (Table S2). Two products had declared counts that were lower than the actual number of shrimp and seven products had declared counts that were higher than the actual number of shrimp. For example, one product declared 51–60 shrimp per pound, but contained only 30 shrimp per pound, while another product declared 31–35 shrimp per pound, but contained 46 shrimp per pound. Three of the products outside of the declared count-per-pound range were also short-weighted, one was overweight, and four were overglazed.

3.3. Glaze levels

The glaze levels in the 106 frozen shrimp samples ranged from 0.58% to 63.67%, with an overall average of 16.58 ± 8.74% (Table S2). As shown in Fig. 2, 33 samples were within the 15–20% glaze recommended by Gonçalves and Gindri Junior (2009) for frozen shrimp, while 10 samples were within the recommended range of 5–10% for seafood in general (Mitchell & Archer, 2016). A total of 28 samples were determined to be overglazed (i.e., >20% glaze). Of these overglazed samples, 24 were also determined to be short-weighted (discussed in section 4.3). There were no significant differences when comparing the rates of overglazing across shrimp size categories based on an equality of proportions test ($p > 0.05$).

Overglazing was associated with 17 of the 43 commercial brands analyzed in the study, indicating that it is a widespread practice. This practice was found to be slightly more prevalent in domestic samples than imported samples, with rates of 28.6% (n = 4/14) and 26.1% (n = 24/92), respectively. Overglazing was also slightly higher in farm-raised products (27.5%; n = 22/80) as compared to wild-caught products (25.0%; n = 6/24). The wide range in glaze levels and the prevalence of overglazing is likely due to the lack of a standardized glaze range for frozen shrimp. Furthermore, glaze levels may vary due to factors such as application of glaze at multiple points in the supply chain, as well as the method of glazing (Peterson et al., 2021). To prevent overglazing and maintain consistency in the marketplace, an industry-wide standard range for percent glaze on frozen shrimp is recommended.

3.4. Short-weighting

Short-weighting was detected in 39 (36.8%) of the 106 frozen shrimp samples based on NIST standards, with 24 of these samples also overglazed (NIST, 2011). Out of the 11 size categories of shrimp tested, eight had at least three short-weighted samples (Fig. 3). The average deglazed weight among short-weighted samples was 91.8 ± 3.5% of the declared net weight. In comparison, the average deglazed weight for the 63 samples that were within the MAV was 99.5 ± 1.7% of the declared net weight. Among the 39 short-weighted products, consumers were overcharged an average of US$1.76/kg, with a range of US$0.61-US $3.41/kg (Table S2). The most extreme instance of short-weighting was observed in a bag of extra jumbo Argentine red shrimp that had a declared net weight of 907 g and a deglazed weight of only 773.2 g

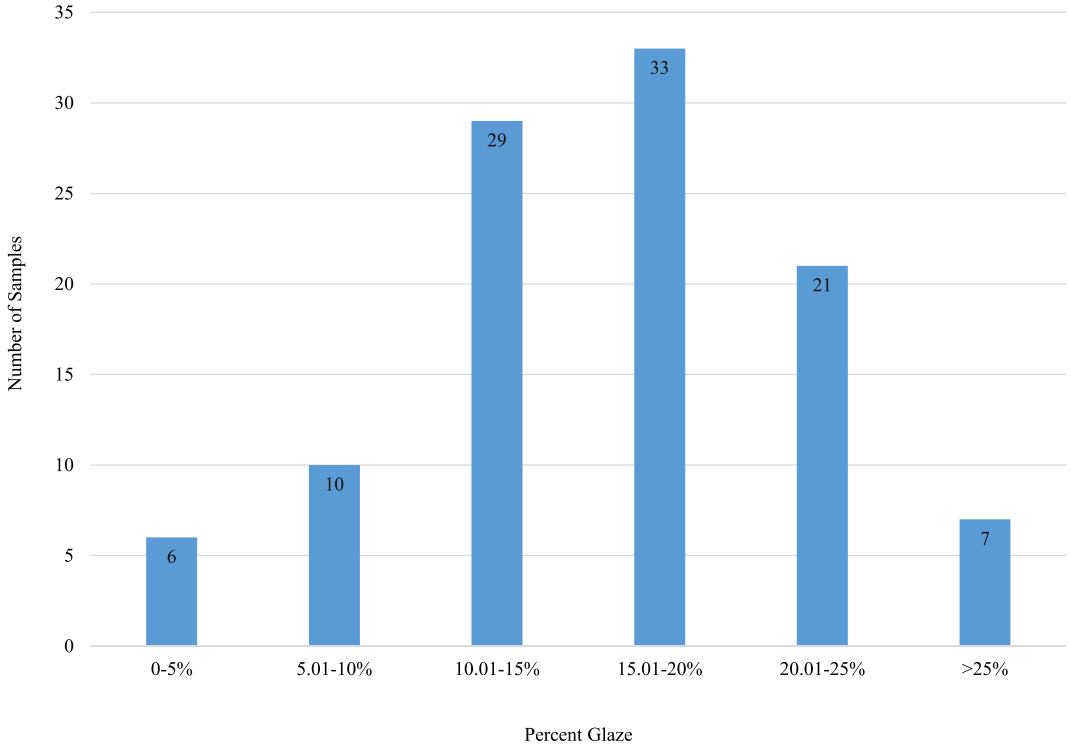

Fig. 2. Percent glaze measured for prepackaged frozen raw shrimp examined in this study (n = 106).

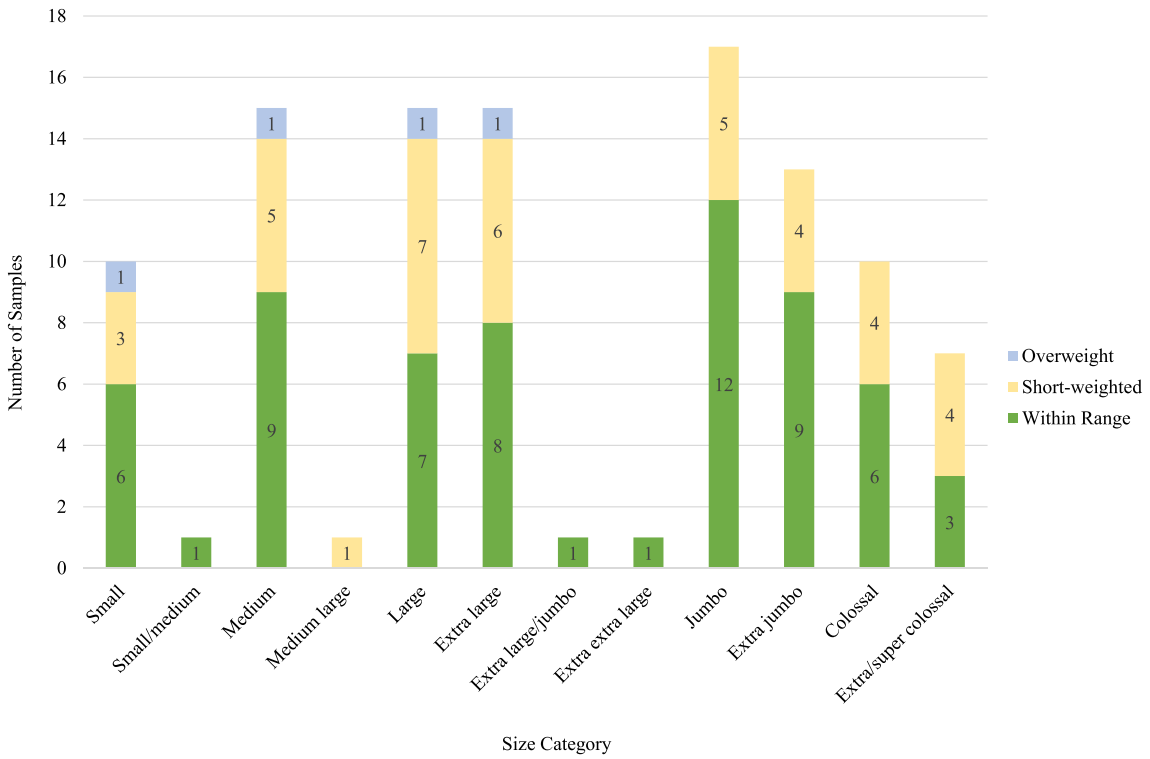

Fig. 3. Net weight determination results separated by size category for frozen raw shrimp products (n = 106), including those found to be overweight, short-weighted, and within the maximum allowable variation range according to NIST.

(85.2% of the declared net weight). The product was sold for US $22.04/kg, meaning that consumers overpaid US$3.26/kg. The extra/-super colossal shrimp size category had the highest rate of short-weighting at 57.1% (n = 4/7), followed by the large size category (46.7%; n = 7/15). There were no significant differences when comparing short-weighting across size categories based on an equality of proportions test ($p > 0.05$).

Short-weighting was observed in 23 of the 43 commercial brands analyzed in the study. The greatest number of short-weighted products was observed for farm-raised shrimp from Indonesia (n = 25/35), at a rate of 71%. However, short-weighting was also observed in a high proportion of domestic shrimp, with 36% of the wild-caught shrimp from the United States determined to be short-weighted (n = 5/14). Farm-raised shrimp were short-weighted more often than wild-caught shrimp, with rates of 40% (n = 32/80) and 29% (n = 7/24), respectively. Short-weighting was found in similar proportions for imported (n = 34/92) and domestic (n = 5/14) products, at 37% and 36% respectively, suggesting that this is a widespread issue of concern for frozen shrimp, regardless of origin.

Four products were considered overweight because their deglazed weights were greater than the declared weight by an amount that exceeded the MAV (Table S2). These samples were overweight by an average of 106 ± 2.8% when comparing the deglazed weight to the declared net weight. The four samples were each from a different size category, with two from the same brand. Consumers were undercharged up to US$2.64/kg for these overweight products, which could result in a considerable loss of profit for the manufacturer if this is a common practice at the processing facility.

The degree of short-weighting observed in the current study (36.8%) was much higher than that reported previously by Peterson et al. (2021) for frozen fish (9%), indicating that this practice is more common in frozen shrimp. Similarly, the proportion of overglazed shrimp samples in the current study (26.4%) was high compared with the proportion of overglazed fish samples (6.3%) reported by Peterson et al. (2021). In both studies, the majority of short-weighted samples were also overglazed, indicating that overglazing is used as a means to artificially inflate the weight of the product. Overall, these results point to a need for increased scrutiny and regulatory oversight with regards to short-weighting of frozen shrimp to protect consumers from over-paying for these products.

3.5. DNA sequencing results

A total of 100 shrimp samples were identified with the tiered DNA sequencing approach used in this study (Table 3). Most samples (n = 60) were identified using the 3′ COI primers; 11 samples were identified using the 16S primers; and 29 samples were identified with COI mini-barcoding (SH-E primers). The majority (96%) of samples had at least one top species match in GenBank with ≥98% genetic similarity. Numerous sequences (n = 54) showed equivalent E values and >99% genetic identity to more than one species in GenBank. In many cases, a sample matched multiple entries from a single species in GenBank, but also showed an equivalent genetic match to a single entry from a different species. These sequences were resolved to the species level by considering the results of BLAST combined with UPGMA analysis (Fig. S1-S3). For example, 50 samples that were labeled as “Shrimp” or “Whiteleg Shrimp” and sequenced with the 3’ COI primers showed top genetic matches to 5–7 whiteleg shrimp entries in GenBank, as well as to one Indian prawn (*Penaeus indicus* H. Milne Edwards, 1837) entry (Accession no. KF192816) and 1–2 giant tiger prawn (*P. monodon*) clone sequences (Accession nos. EF646193 and EF646198). These samples grouped within the whiteleg shrimp clade when analyzed with a UPGMA tree (Fig. S1) and were therefore determined to be whiteleg shrimp.

An additional four samples (A008, A012, A028, and A046) sequenced with the 16S primers showed equivalent 100% genetic identity matches in GenBank to 20 whiteleg shrimp entries and one jinga shrimp (*Metapenaeus affinis* H. Milne Edwards, 1837) entry. However, the GenBank entry for jinga shrimp (Accession no. GU324140) states “commercial purchased sample; source organism represents species

Table 3
Summary of the DNA barcoding results for frozen shrimp products identified in this study (n = 100). Species were identified based on the results of BLAST, unless otherwise noted. Values are displayed as the number count.

Identified species	Total number of samples	Identified using 3′ COI full barcoding	Identified using 16S barcoding	Identified using COI mini-barcoding	Samples with species mislabeling
Whiteleg shrimp (*P. vannamei*)	75	50[a]	4	21	28
White shrimp (*P. setiferus*)	7	3	3	1	–
Argentine red shrimp (*P. muelleri*)	6	1	3	2	5
Pink shrimp (*Penaeus* spp. (subgen. *Farfantepenaeus*))	3	3[a]	–	–	1
Giant freshwater prawn (*M. rosenbergii*)	3	–	–	3 (1[b])	–
Giant tiger prawn (*P. monodon*)	2	2	–	–	2
Brown shrimp (*F. aztecus*),	2	–	–	2	–
Blue shrimp (*P. stylirostris)*	2	1[a]	1	–	1
Overall	100	60	11	29	37

[a] Identified using a combination of BLAST and UPGMA tree.
[b] Identified as giant freshwater prawn/hairy river prawn (*M. rude*) using a combination of BLAST and UPGMA trees.

indicated on label", indicating that the authors reported the species based on the commercial label without morphological verification. Therefore, the jinga shrimp GenBank entry was determined to be unreliable. These samples grouped within the whiteleg shrimp clade when analyzed with a UPGMA tree (Fig. S2) and were therefore determined to be whiteleg shrimp.

Among the four samples that had <98% genetic identity to the top species matches in GenBank, three (A064, A067, and A068) were identified as *Penaeus* spp. (subgen. *Farfantepenaeus*) using the 3′ COI primers. These samples showed equivalent 95.16% genetic matches to pink shrimp (*Penaeus duorarum* Burkenroad, 1939) and Southern pink shrimp (*Penaeus notialis* Pérez Farfante, 1967). The sequences also grouped closest to pink shrimp and Southern pink shrimp in the UPGMA tree (Fig. S1). Previous research has reported that pink shrimp and Southern pink shrimp are morphologically very similar and show little to no genetic variation based on COI (Ramirez et al., 2021; Timm et al., 2019). While it was previously suggested that they may be the same species (Timm et al., 2019), further analysis suggested the presence of two clades – one containing only Southern pink shrimp and another containing both pink shrimp and Southern pink shrimp (Ramirez et al., 2021). The relatively low genetic match of the sequences in the current study to pink shrimp and Southern pink shrimp combined with their high sequence quality (95–100% high quality bases) suggests that they may belong to a related species with no representative 3' COI sequence currently in GenBank. A fourth sample (A100) was identified as belonging to the *Macrobrachium* genus using COI mini-barcoding, with equivalent genetic matches (97.35% identity) to giant freshwater prawn (*M. rosenbergii*) and hairy river prawn (*Macrobrachium rude* Heller, 1862). This sequence grouped most closely with giant freshwater prawn in the UPGMA tree (Fig. S3); however, there was no available hairy river prawn reference sequence for comparison. This sequence was the expected length for the COI mini-barcode (226 bp) but had slightly lower quality (i.e., 85.5% high quality bases and 1.3% ambiguities), which may explain why a stronger genetic match was not obtained.

3.6. Species authentication and acceptable market names

Species labeling errors were observed in 37 of the 100 samples identified with DNA barcoding (Table 4). Species substitution was observed in a total of 21 products: 11 were substituted due to errors found on the packaging/processing stickers, nine were substituted due to errors on the retail price tag, and one was substituted due to errors on both the package and the retail price tag. Products with errors on the packaging/processing stickers were purchased from 11 different brand names, while products with retail price tag errors were purchased from four different retailers. Of the 21 substituted products, 19 were labeled

Table 4
Products with species labeling errors (n = 37) according to the FDA Seafood List (FDA, 2022).

Product description	Expected species	Number of samples	Identified species	Acceptable market name (other than common name)	Type of mislabeling
White shrimp	White shrimp (*P. setiferus*)	9[a], 9[b], 1[c]	Whiteleg shrimp (*P. vannamei*)	Shrimp	Species substitution
American shrimp (*Litopenaeus* ssp. [sic])	*Penaeus* spp. (subgen. *Litopenaeus*)	1[b]	Pink shrimp (*Penaeus* spp. (subgen. *Farfantepenaeus*))	Shrimp	Species substitution
Blue shrimp	Blue shrimp (*P. stylirostris*)	1[b]	Whiteleg shrimp (*P. vannamei*)	Shrimp	Species substitution
Argentinian red shrimp; Red Argentine shrimp; Red Argentine wild shrimp; Red shrimp	Argentine red shrimp (*P. muelleri*)	3[b], 2[c]	Argentine red shrimp (*P. muelleri*)	Shrimp	Unacceptable market name
Black tiger shrimp (*Penaeus monodon)*	Giant tiger prawn (*P. monodon)*	1[b], 1[c]	Giant tiger prawn (*P. monodon)*	Shrimp	Unacceptable market name
Blue Mexican shrimp; Prawn	Blue shrimp (*P. stylirostris*) or Various species of prawn	1[c]	Blue shrimp (*P. stylirostris*)	Shrimp	Unacceptable market name
WHT shrimp	White shrimp (*P. setiferus)*	3[a]	Whiteleg shrimp (*P. vannamei*)	Shrimp	Unacceptable market name
Vanme shrimp	Whiteleg shrimp (*P. vannamei*)	1[a]	Whiteleg shrimp (*P. vannamei*)	Shrimp	Unacceptable market name
White shrimp; shrimp (*Litopenaeus vannamei*)	White shrimp (*P. setiferus*) or whiteleg shrimp (*P. vannamei*)	3[b], 1[c]	Whiteleg shrimp (*P. vannamei*)	Shrimp	Conflicting species names

[a] Mislabeled due to errors on retail price tag.
[b] Mislabeled due to errors on packaging.
[c] Mislabeled due to errors on both retail price tag and packaging.

as "White Shrimp" but identified as whiteleg shrimp. Although "Shrimp" is considered an acceptable market name for whiteleg shrimp, "White Shrimp" refers to a separate species (*Penaeus setiferus* Linnaeus, 1767) (FDA, 2022). The substitution of white shrimp with whiteleg shrimp may have been intentional, as white shrimp is a domestic species that is known to be desired by consumers, while whiteleg shrimp is a predominantly imported and farmed species (Korzik et al., 2020). In a related study, Korzik et al. (2020) reported that 34% of shrimp samples collected in North Carolina, USA, labeled as "local" were identified as whiteleg shrimp. While there are incentives for mislabeling whiteleg shrimp as white shrimp, substitution cases based on the retail price tag alone may have been due to confusion in labeling and/or word limits for retail price tags. Additionally, details regarding proper species labeling may be overlooked or missed as the information is passed along through the supply chain.

One case of species substitution was observed in a sample that declared to be a wild-caught blue shrimp product of Mexico but was identified as whiteleg shrimp (Table 4). The product stated "Shrimp" on the front of the package and in the ingredients list, but declared "Premium Blue Shrimp" on a sticker applied to the back of the package. There does not appear to be an economic incentive for this substitution event, as blue shrimp (*Penaeus stylirostris* Stimpson, 1871) is typically lower in value than whiteleg shrimp (Pascoal et al., 2011). It is possible that the two species were co-mingled during harvest due to their similar appearance and overlapping geographic regions (Pascoal et al., 2011). Of note, another "Blue Shrimp" product from the same brand was authenticated as blue shrimp. However, additional sampling would be needed to determine the frequency of mislabeling associated with this product.

In another case of species substitution, a product labeled as "American Shrimp (*Litopenaeus* ssp. [sic])" on the back of the packaging and as "Shrimp (*Litopenaus* [sic] spp.)" in the ingredients list was identified as pink shrimp/Southern pink shrimp (*Penaeus* (subgen. *Farfantepenaeus*); Table 4). This sample was labeled as a wild-caught product of the USA. Of note, some *Penaeus* (subgen. *Litopenaeus*) species have overlapping geographic regions with pink shrimp/Southern pink shrimp (e.g., Gulf of Mexico) (Monterey Bay Aquarium, 2017) and it is possible that co-mingling of species during harvest may have occurred.

A total of four products had conflicting market names on the packaging (Table 4). These products declared "White Shrimp" on the front packaging, but the back of the packaging or a sticker applied to the packaging declared "Shrimp (*Litopenaeus vannamei*)". One of these products also declared "White Shrimp" on the retail price tag. All four products were identified as whiteleg shrimp with DNA barcoding. Of note, all four products were from the same brand and were purchased at four different stores.

Of the 12 products found to contain unacceptable market names (Table 4), five samples identified as Argentine red shrimp (*Pleoticus muelleri* Spence Bate, 1888) were sold under the names "Argentinian Red Shrimp", "Red Argentine Shrimp", "Red Argentine Wild Shrimp", and "Red Shrimp" on the retail tag and/or the product's packaging. According to the FDA Seafood List, this species of shrimp should be labeled as either "Argentine Red Shrimp" or simply "Shrimp" (FDA, 2022). Additionally, while the term "Wild" can be listed to satisfy COOL requirements, it should be used outside of the product's market name. Three samples identified as whiteleg shrimp had an unacceptable market name of "WHT Shrimp" on the retail price tag. This is concerning, as the abbreviation of "WHT" may mislead consumers into thinking the product contains white shrimp. Two samples were labeled as "Black Tiger Shrimp" on the retail price tag and/or packaging, with the species listed on the packaging as *P. monodon*. However, the common name for *P. monodon* according to the FDA Seafood List is "Giant Tiger Prawn" and the only other acceptable market name is "Shrimp" (FDA, 2022).

A product identified as blue shrimp (*P. stylirostris*) was declared to be "Blue Mexican Shrimp" on the product packaging and "Prawn" on the retail price tag, neither of which are acceptable market names for this species. While the use of a geographic location to describe a product is acceptable if it is truthful and not misleading, it should be used either before or after the acceptable market name. An additional product identified as whiteleg shrimp was labeled as "Vanme Shrimp" on the retail price tag, which is not an acceptable market name for the species.

Species labeling errors were found in all shrimp size categories containing more than one sample. The extra large shrimp category had the highest rate of labeling errors, at 60.0% (n = 9/15), followed by large (46.7%; n = 7/15). No significant differences were found when comparing species labeling errors across size categories based on an equality of proportions test ($p > 0.05$). Notably, the majority (97%) of species labeling errors occurred with imported shrimp products (n = 36/88), with only one domestic product found to have a labeling error (n = 1/12). Species labeling errors were observed at similar rates in farm-raised (35.5%; n = 27/76) and wild-caught (36%; n = 8/22) shrimp products.

Products with species labeling errors were purchased from 17 grocery retailers (16 chain-owned and one independent retailer). While most of the retailers had ≤3 products with species labeling errors, one retailer had six products with conflicting species names and/or species substitution. Labeling errors on the retail price tags (n = 15) were likely due to a lack of communication along the supply chain, a need to abbreviate product names on retail price tags, and/or inadequate training to ensure proper species labeling. Labeling errors on the product packaging (n = 21) and/or stickers applied to the packaging (n = 4) indicate that proper training and communication along the supply chain is also a concern for processing facilities.

The overall rate of species labeling errors in this study (37%) is similar to previous market surveys conducted on shrimp mislabeling in the United States, which reported species mislabeling rates of 30–34% (Korzik et al., 2020; Warner et al., 2014). The current study is the first to focus on species labeling of shrimp collected in Southern California and indicates that erroneous or unclear labeling of shrimp species is a persistent issue in the United States.

3.7. Products with multiple labeling errors

Seventeen products were found to have multiple labeling errors associated with COOL noncompliance, short-weighting, and/or species labeling. Four products were noncompliant with COOL and had species labeling errors, either due to species substitution, conflicting species names, or use of an unacceptable market name. One product was noncompliant with COOL, had a species labeling error due to species substitution, and was short-weighted. An additional 12 products were both short-weighted and had a species labeling error, either due to species substitution or use of an unacceptable market name.

4. Conclusion

This is the first study to present information on COOL compliance, short-weighting, overglazing, and species labeling of frozen shrimp sold in Southern California. Taken together, the results of the current study illustrate the various ways in which labeling errors undermine the fair trading of products and consumer protection. A high level of COOL compliance (94.3%) was observed; however, overglazing and short-weighting of samples were both higher than expected, with rates of 26% and 37%, respectively. These results suggest that some shrimp processors may be artificially increasing the weight of their product through overglazing, and that consumers are unknowingly paying for extra ice while receiving less product than advertised. Species substitution was detected in 21% of products identified with DNA barcoding, meaning that consumers are not always receiving the species they intended to buy. Use of the name "white shrimp" to erroneously describe the predominantly farmed and imported whiteleg shrimp was found to be a prevalent practice. The results of this study indicate a need for increased scrutiny with regards to short-weighting and species

mislabeling to decrease the occurrence of shrimp fraud in the United States. Industry-wide training and outreach on the importance of proper labeling of seafood throughout the supply chain is also recommended. Additionally, implementation of a standardized glaze range for frozen shrimp may assist in lowering the rate of overglazing and short-weighting, while also preventing the dehydration of frozen shrimp for both block frozen and IQF shrimp products. Further research into overglazing, short-weighting, and species mislabeling of frozen shrimp and other shellfish is needed globally to better understand the extent of these practices.

CRediT authorship contribution statement

McKenna C. Rivers: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Alexia B. Campbell:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – review & editing. **Chris Haneul Lee:** Investigation, Methodology, Writing – review & editing. **Pragati Kapoor:** Investigation, Methodology, Writing – review & editing. **Rosalee S. Hellberg:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Project administration, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shared the data as Supplementary Material.

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Appendix A. Supplementary data

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References

AMS. (2009). Mandatory country of origin labeling of Beef, Pork, Lamb, Chicken, Goat Meat, Wild and farm-raised fish and shellfish, Perishable agricultural Commodities, Peanuts, Pecans, Ginseng, and Macadamia Nuts. Final Rule *Federal Register, 74*(10) https://www.regulations.gov/document?D=AMS-LS-07-0081-0815.

Butcher, T., Sefcik, D., Warfield, L., Bowers, S., & Lippa, K. (2022). *Uniform laws and regulations in the areas of legal metrology and fuel quality*. Gaithersburg, MD): National Institute of Standards and Technology. https://doi.org/10.6028/NIST.HB.130-2023. NIST Handbook (HB) NIST HB 130-2023.

Delaware Sea Grant. (n.d.). Seafood Health Facts. https://www.seafoodhealthfacts.org/?s=shrimp.

Eischeid, A. C., Stadig, S. R., Handy, S. M., Fry, F. S., & Deeds, J. (2016). Optimization and evaluation of a method for the generation of DNA barcodes for the identification of crustaceans. *LWT, 73*, 357–367. https://doi.org/10.1016/j.lwt.2016.06.033

EMR. (2022). *Expert market research: United States shrimp market: By environment: Farming, processing; by species; by product category; by distribution channel; by production and imports; historical market and forecast (2018-2028); market dynamics; value chain analysis; trade data analysis; competitive landscape; industry events and developments.* https://www.expertmarketresearch.com/reports/united-states-shrimp-market.

FDA. (2009). *Guidance for industry: 1991 letter to seafood manufacturers regarding the fraudulent practice of including glaze (ice) as part of the weight of frozen seafood.* https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-1991-letter-seafood-manufacturers-regarding-fraudulent-practice-including-glaze.

FDA. (2022). *Guidance for industry: The seafood list.* U.S. Food and Drug Administration. https://www.cfsanappsexternal.fda.gov/scripts/fdcc/?set=SeafoodList

Garcia-Machado, E., Dennebouy, N., Suarez, M. O., Mounolou, J. C., & Monnerot, M. (1996). Partial sequence of the shrimp Penaeus notialis mitochondrial genome. *Comptes Rendus de l'Academie Des Sciences. Serie III, Sciences de La Vie, 319*(6), 473–486.

Gonçalves, A. A., & Gindri Junior, C. S. G. (2009). The effect of glaze uptake on storage quality of frozen shrimp. *Journal of Food Engineering, 90*(2), 285–290. https://doi.org/10.1016/j.jfoodeng.2008.06.038

Handy, S. M., Deeds, J. R., Ivanova, N. V., Hebert, P. D. N., Hanner, R. H., Ormos, A., Weigt, L. A., Moore, M. M., & Yancy, H. F. (2011). A single-laboratory validated method for the generation of DNA barcodes for the identification of fish for regulatory compliance. *Journal of AOAC International, 94*(1), 201–210. https://doi.org/10.1093/jaoac/94.1.201

Jacobsen, S., & Fossan, K. M. (2001). Temporal variations in the glaze uptake on individually quick frozen prawns as monitored by the CODEX standard and the enthalpy method. *Journal of Food Engineering, 48*(3), 227–233. https://doi.org/10.1016/S0260-8774(00)00162-X

Kaur, R. A., Uppal, G. K., & Sawant, T. M. (2021). The molecular characterization and phylogenetic reconstruction of penaeid shrimps from Mumbai Coast, Maharashtra. *International Journal of Fisheries and Aquatic Studies, 9*(6), 328–334. https://doi.org/10.22271/fish.2021.v9.i6d.2619

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*, Article 109525. https://doi.org/10.1016/j.foodcont.2022.109525

Korzik, M. L., Austin, H. M., Cooper, B., Jasperse, C., Tan, G., Richards, E., Spencer, E. T., Steinwand, B., Fodrie, F. J., & Bruno, J. F. (2020). Marketplace shrimp mislabeling in North Carolina. *PLoS One, 15*(3), Article e0229512. https://doi.org/10.1371/journal.pone.0229512

Lagasse, L. P., Love, D. C., & Smith, K. C. (2014). Country-of-Origin labeling prior to and at the point of purchase: An exploration of the information environment in Baltimore city grocery stores. *Ecology of Food and Nutrition, 53*(1), 58–80. https://doi.org/10.1080/03670244.2014.854605

Liou, P., Banda, A., Isaacs, R. B., & Hellberg, R. S. (2020). Labeling compliance and species authentication of fish fillets sold at grocery stores in Southern California. *Food Control, 112*, Article 107137. https://doi.org/10.1016/j.foodcont.2020.107137

Mitchell, M., & Archer, M. (2016). *Glaze*. www.seafish.org/document/?id= 0dab3bd5-d2aa-470f-b9e2-ae57593f9ff7.

Monterey Bay Aquarium. (2017). *Seafood watch*. https://prod.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_mexicoshrimpreport.pdf.

Naaum, A., & Hanner, R. (2016). Seafood authenticity and traceability: A DNA-based perspective. In *Seafood authenticity and traceability: A DNA-based perspective* (pp. 47–76). Elsevier.

NFI. (2017). *Industry guidance of best practices for addressing seafood fraud*. National Fisheries Institute. https://www.aboutseafood.com/wp-content/uploads/2018/05/BSB-Best-Practice-Guidance-November-2017.pdf.

NIST. (2011). *Maximum allowable variation for packages. Handbook 133. Checking net contents of packaged goods*. National Institute of Standards and Technology. https://www.nist.gov/document/hb133-13-finalpdf.

NMFS. (2020). *Fisheries of the United States, 2020*. U.S. Department of Commerce, NOAA Current Fishery Statistics. No. 2020 https://www.fisheries.noaa.gov/resource/document/fisheries-united-states-2020.

NMFS. (2021). *FUS foreign trade 2021* [Trade Report] https://www.fisheries.noaa.gov/foss/f?p=215:18.

Pascoal, A., Barros-Velázquez, J., Ortea, I., Cepeda, A., Gallardo, J. M., & Calo-Mata, P. (2011). Molecular identification of the black tiger shrimp (*Penaeus monodon*), the white leg shrimp (*Litopenaeus vannamei*) and the Indian white shrimp (*Fenneropenaeus indicus*) by PCR targeted to the 16S rRNA mtDNA. *Food Chemistry, 125*(4), 1457–1461. https://doi.org/10.1016/j.foodchem.2010.10.053

Peterson, A. M., McBride, G. E., Jhita, S. K., & Hellberg, R. S. (2021). An investigation into country of origin labeling, species authentication and short weighting of commercially sold frozen fish fillets. *Heliyon, 7*(4), Article e06713. https://doi.org/10.1016/j.heliyon.2021.e06713

Pollack, S. J., Kawalek, M. D., Williams-Hill, D. M., & Hellberg, R. S. (2018). Evaluation of DNA barcoding methodologies for the identification of fish species in cooked products. *Food Control, 84*, 297–304. https://doi.org/10.1016/j.foodcont.2017.08.013

Ramirez, J. L., Simbine, L., Marques, C. G., Zelada-Mázmela, E., Reyes-Flores, L. E., López, A. S., Gusmão, J., Tavares, C., Galetti, P. M., & Freitas, P. D. (2021). DNA barcoding of penaeidae (Decapoda; Crustacea): Non-Distance-Based species delimitation of the most economically important shrimp family. *Diversity, 13*(10). https://doi.org/10.3390/d13100460. Article 10.

Rattray, D. (2021). Shrimp counts per pound and how much to serve. *The Spruce Eats*. https://www.thespruceeats.com/shrimp-counts-per-pound-and-serving-sizes-3054059.

Robles, R., Schubart, C. D., Conde, J. E., Carmona-Suárez, C., Alvarez, F., Villalobos, J. L., & Felder, D. L. (2006). Molecular phylogeny of the american callinectes stimpson,

1860 (Brachyura: Portunidae), based on two partial mitochondrial genes. *Marine Biology, 150*(6), 1265–1274. https://doi.org/10.1007/s00227-006-0437-7

Shokralla, S., Hellberg, R. S., Handy, S. M., King, I., & Hajibabaei, M. (2015). A DNA mini-barcoding system for authentication of processed fish products. *Scientific Reports, 5*(1). https://doi.org/10.1038/srep15894. Article 1.

Silva, A. J., Hellberg, R. S., & Hanner, R. H. (2021). Seafood fraud. In R. S. Hellberg, K. Everstine, & S. A. Sklare (Eds.), *Food fraud: A global threat with public health and economic consequences* (pp. 109–137). San Diego: Academic Press/Elsevier.

R Studio. (2022). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Timm, L., Browder, J. A., Simon, S., Jackson, T. L., Zink, I. C., & Bracken-Grissom, H. D. (2019). A tree money grows on: The first inclusive molecular phylogeny of the economically important pink shrimp (Decapoda : Farfantepenaeus) reveals cryptic diversity. *Invertebrate Systematics, 33*(2), 488–500. https://doi.org/10.1071/IS18044

Tong, J. G., Chan, T.-Y., & Chu, K. H. (2000). A preliminary phylogenetic analysis of metapenaeopsis (Decapoda: Penaeidae) based on mitochondrial DNA sequences of selected species from the indo-west pacific. *Journal of Crustacean Biology, 20*(3), 541–549. https://www.jstor.org/stable/1549395.

United States Department of Justice. (2015). *North Carolina seafood processor and distributor sentenced for mislabeling shrimp*. https://www.justice.gov/opa/pr/north-carolina-seafood-processor-and-distributor-sentenced-mislabeling-shrimp.

USDA. (2023). *Country of origin labeling (COOL) frequently asked questions | agricultural marketing service*. https://www.ams.usda.gov/rules-regulations/cool/questions-answers-consumers.

Warner, K., Golden, R., Lowell, B., Disla, C., Savitz, J., & Hirschfield, M. (2014). Shrimp: Oceana reveals misrepresentation of America's favorite seafood. *Ocean*. https://oceana.org/reports/news-media-shrimpfraud/.

WoRMS Editorial Board. (2023). *World register of marine species*. VLIZ. https://doi.org/10.14284/170. https://www.marinespecies.org

Zhong, S., Zhao, Y., & Zhang, Q. (2019). The complete mitochondrial genome of Metapenaeus affinis (Decapoda: Penaeidae). *Mitochondrial DNA Part B, 4*(1), 225–226. https://doi.org/10.1080/23802359.2018.1546146