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Risks shift along seafood supply chains

David C. Love [a,b,*], Elizabeth M. Nussbaumer [a,b], Jamie Harding [a,b], Jessica A. Gephart [c], James L. Anderson [d,e], Frank Asche [d,f,g], Joshua S. Stoll [h], Andrew L. Thorne-Lyman [a,i], Martin W. Bloem [a,b]

[a] Johns Hopkins Center for a Livable Future, Johns Hopkins University, Baltimore, MD, 21202, USA
[b] Department of Environmental Health and Engineering, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, 21205, USA
[c] American University, Department of Environmental Science, 4400 Massachusetts Avenue NW, Washington, DC, 20016, USA
[d] Institute for Sustainable Food Systems, University of Florida, Gainesville, FL, 32611, USA
[e] Food and Resource Economics Department, University of Florida, Gainesville, FL, 32611, USA
[f] Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, Gainesville, FL, 32611, USA
[g] Department of Safety, Economics and Planning, University of Stavanger, Norway
[h] School of Marine Sciences, University of Maine, Orono, ME, 04469, USA
[i] Center for Human Nutrition, Department of International Health, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, 21205, USA

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ABSTRACT

Seafood is a highly traded commodity and 71% of the United States (U.S.) supply is imported. This study addresses questions about imported seafood safety and compares risks of outbreaks and recalls across countries of origin, species, and stages of the supply chain. We found that where seafood comes from does not play a major role in risk. Risk is a function of the activities happening at each stage of the supply chain, inherent riskiness of some products or processes, and "pass through" risks introduced at upstream and midstream stages of the supply chain. Dominant farmed species (shrimp, tilapia, catfish) became less risky as they move along the supply chain toward consumers. We recommend investments in agencies overseeing food safety and health, enhanced traceability within supply chains, and more open government datasets that support systems-level analyses.

1. Introduction

Seafood is a highly traded commodity with nearly 40% traded internationally (FAO 2020). About 71% of the United States (U.S.) supply is imported (Gephart et al., 2019; NOAA, 2020a), mainly from Asia (NOAA, 2020a). The proportion of seafood coming from imports has increased, and a growing share of imports have also come from aquaculture (i.e., farm raised) (Shamshak et al., 2019). Four of the five most consumed seafood species (shrimp, salmon, catfish, tilapia) in the U.S. are now primarily imported and farmed (Shamshak et al., 2019). U.S. consumers perceive imported seafood to be less safe than domestic products (Hicks et al., 2008; Wang et al., 2013). Our study considers available data about imported products, in order to evaluate comparative risks within imported seafood, and other food safety risks introduced during processing, distribution, preparation and consumption.

About 2% of imported seafood is inspected by U.S. federal agencies for filth, metals, microorganisms, product labeling, toxins, and veterinary drugs using risk-based criteria to best deploy limited resources (Love et al., 2011). From 2010 to 2015, the FDA found 5% of imported seafood samples (311 of 6112 samples) tested positive for veterinary drug residues (GAO 2017), which is related to the treatment of aquatic food animals on farms (Henriksson et al., 2018). However, it is impossible to extrapolate the violation rate to other imports due to FDA's targeted sampling strategy (Love et al., 2011). Roughly 3%–4% of the U.S. seafood supply is mislabeled, with a greater percentage of substituted products coming from imports (Kroetzet al., 2020), which further complicates the interpretation of import inspections. In retail studies, researchers routinely find antimicrobial resistant bacteria and low levels of drug residues in imported seafood products (Boinapally and Jiang 2007; Nawaz et al., 2012; Done and Halden 2015), which suggests that some risky products slip past inspectors at the port-of-entry and could cause problems further down the supply chain.

It is estimated that 9.4 million episodes of foodborne illness occur each year in the U.S. (Scallan et al., 2011). Seafood consumption is consistently one of the most common causes of foodborne disease outbreaks with known etiologies (Lynch et al., 2006; Painter et al., 2013;

* Corresponding author. Johns Hopkins Center for a Livable Future, Johns Hopkins University, Baltimore, MD, 21202, USA.
E-mail address: dlove8@jhu.edu (D.C. Love).

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Dewey-Mattia et al., 2018). While the number of outbreaks from imported foods are small relative to all foodborne outbreaks, seafood is the most common type of imported food linked to outbreaks, and the rate of imported seafood outbreaks is increasing (Gould et al., 2017). When seafood-related risks are uncovered, communicating the appropriate level of concern can be difficult. Consumers have trouble making decisions about balancing health risks and benefits (Uchida et al., 2017), and health advisories can have the unintended and negative consequence of suppressing seafood consumption (Shimshack and Ward 2010; Oken et al., 2012).

Consumer purchases are influenced by a number of factors such as taste preferences, cost, perceived nutritional value, healthfulness, and safety. Because so much seafood is imported and import inspection levels are low, the perceived food safety risks are high. U.S. consumers are skeptical of the safety of imported seafood (Hicks et al., 2008; Wang et al., 2013), and are willing to pay more for local and domestic-origin products (Campbell et al., 2014; Ortega et al., 2014; McClenachan et al., 2016; Garlock et al., 2020).

This study addresses lingering questions about the safety of imported seafood related to the risks by country of origin, species, and stages of the supply chain to give a more complete picture of risk.

2. Methods

2.1. Overview

To evaluate safety along U.S. seafood supply chains, we integrated data on seafood imports and inspections, domestic seafood supply and recalls, and consumption and seafood-related outbreaks, detailed below (Fig. 1; Supporting Information Table S1). New variables were added to harmonize datasets including the species names, species group name, and reason for the refusal, recall, or outbreak. We then compared the share of imports (by species and country) to the share of import refusals to evaluate relative risk. We also compared the relative share of seafood consumed (by species) to the share of those species implicated in recalls or outbreaks. Data were plotted in R Studio (v1.2) or Prism (v8, San Diego, CA), and mapped in ArcGIS (v10.7, Redlands, CA).

2.2. Imported seafood and inspections

Seafood trade data comes from the U.S. Customs and Border Protection and was downloaded for the years 2002–2019 (US Census Bureau 2020). Seafood import inspection data comes from the U.S. Food and Drug Administration (FDA) and the U.S. Department of Agriculture's Food Safety and Inspection Service (USDA FSIS). FDA provided counts of import refusals online for 2002 to 2019 (FDA 2020) and by Freedom of Information Act (FOIA) request for the value of import refusals for 2010 to 2018. USDA FSIS inspects only imported suliformes (i.e., catfish) and provides counts of import refusals online for mid-2016 to 2019 (USDA, 2020b). The reason for the shorter date range is that the USDA recently acquired the jurisdiction for inspecting catfish from the FDA. The USDA and FDA datasets were combined and include more than 28,000 counts of seafood import refusals (2002–2019) and over 16,000 import refusals reported by value (2010–2018).

There are some limitations with federal inspection data. Federal agencies use a non-random, risk-based sampling approach that is not publicly disclosed, which makes it difficult to extrapolate the findings from some species or countries-of-origin back to all imports. Agencies did not provide the total number of inspections performed to establish a rate of violations or a rate of imports inspected. We were not able to track translocation of imports or repackaging after failed inspections, which is known to occur among some bad actors (Pramod et al., 2014). Lastly, priorities differ among agencies, which could influence testing outcomes.

2.3. Domestic seafood supply and recalls

Seafood supply data (i.e., domestic harvests plus imports minus exports) comes from the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA-NMFS) and is reported as raw, edible weight per capita (NOAA, 2020a). NOAA does not break out per capita supply by species, so we used per capita consumption data (described below) for species comparisons.

Seafood recall data come from the FDA's Center for Food Safety and Applied Nutrition, which manages an online database of food products being recalled by U.S. food companies. These data include both domestic and imported food and focuses at the U.S. wholesale, distribution, and retail stages of the supply chain. Some food recalls are voluntary while others are mandatory (FDA 2018; FDA 2020). It is important to note that there is likely underreporting of voluntary recalls. Food recall reports were available online for 2013 to 2019 (FDA 2020) and by FOIA request for 2003 to 2012. The USDA provides catfish recalls online from 2016 to 2019. The USDA and FDA datasets were combined and include over 2000 seafood recalls from 2002 to 2019.

2.4. Seafood consumption and seafood-related outbreaks

Seafood consumption was derived from the National Health and Nutrition Examination Survey (NHANES) conducted every 2 years by the Centers for Disease Control and Prevention (CDC), the Department of Agriculture, and the Department of Health and Human Services (CDC, 2020a; USDA, 2020c). We estimated total seafood consumption

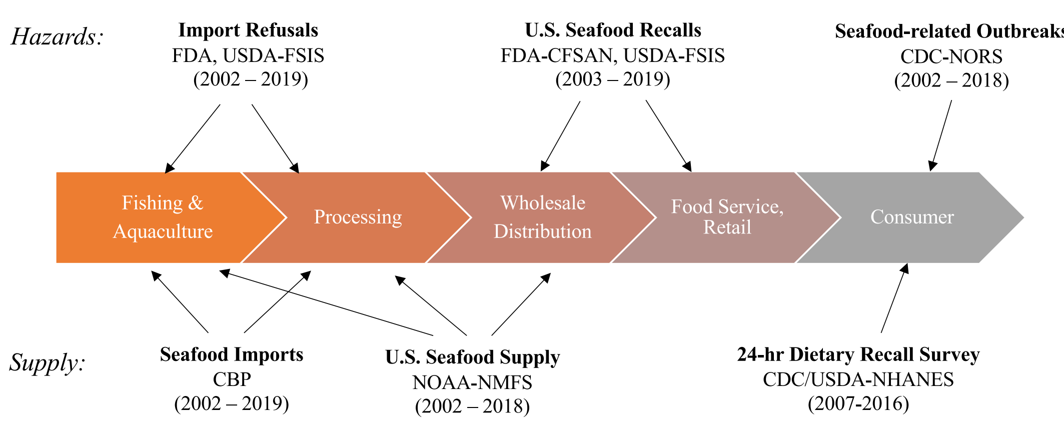

Fig. 1. Seafood supply chains and public datasets analyzed in this paper. Acronyms: CBP = U.S. Customs and Border Protection; FDA-CFSAN = U.S. Food and Drug Administration – Center for Food Safety and Applied Nutrition; USDA-FSIS = U.S. Department of Agriculture – Food Safety and Inspection Service; NOAA-NMFS = National Oceanic and Atmospheric Administration – National Marine Fisheries Service; CDC/USDA-NHANES = Centers for Disease Control and Prevention and U.S. Department of Agriculture– National Health and Nutrition Examination Survey; CDC-NORS = CDC National Outbreak Reporting System.

(including imported and domestic seafood) by species over five NHANES survey cycles (2007–2008, 2009–2010, 2011–2012, 2013–2014, and 2015–2016). NHANES data were joined with the USDA Food Patterns Equivalents Database (USDA, 2020a) to convert foods consumed by NHANES respondents into grams per type of seafood. We accounted for the complex sampling design within NHANES using primary sampling units, strata, and a 5-year weighted average variable to construct unbiased national estimates of seafood consumption. For more explanation of methods see (Love et al., 2020a). To estimate seafood consumption by state we used NHANES estimates of per capita consumption (g/day raw weight, edible portion) for regions of the country and coastal and non-coastal areas (EPA 2014) to develop county-level estimates, and then multiplied those estimates by the county population (US Census Bureau 2018). We then added all counties in each state to develop tons of seafood consumed per state per year.

Foodborne outbreaks are reported by state and local public health departments to the CDC, which are tracked by the National Outbreak Reporting System (NORS) (CDC, 2020b). We requested NORS data for all seafood-related outbreaks from 2002 to 2018, which included over 1000 outbreaks. NORS defines an outbreak as “two or more cases of similar illness associated with a common exposure” and includes enteric and non-enteric causes of illness. We limited our analysis to outbreaks linked only to seafood and not to multiple sources (i.e., fish, meat, vegetables) as recommended by CDC staff. One limitation with this data is that it favors reportable diseases that are required to be tracked, which means that non-reportable diseases would likely be underreported.

3. Results

3.1. Imported seafood and inspections

Over 170 countries export seafood to the U.S., and these exports are valued at $27.1 billion annually. Top exporting countries by value included Canada, China, Chile, India, Indonesia, and Vietnam (Fig. 2a, Supporting Information Table S2). Import inspections provide the first opportunity for U.S. government oversight of seafood arriving at U.S. ports. Mapping the value of import refusals alone (Fig. 2b) provides a distorted picture because it ignores trade volumes. To assess the relative risks, we compared the share of imports among all countries to the share of import refusals for those countries (Fig. 2c and d). With this analysis we see that China, Indonesia, Vietnam, Brazil, Malaysia, and Taiwan were risky exporters of seafood, while Canada, Chile, Norway, Mexico, Ecuador, and Japan were safer exporters. Overall, import refusals were 0.2% of total import value, and import refusals were a higher share (up to 2%) of the total value for some risky exporting countries. However, it is important to note that decisions related to inspections are based on risk, and not from a random sample, making it difficult to extrapolate overall risks of imported seafood. Additionally, if rejected seafood remains unspoiled, it can be resold to other countries as a way to recoup losses, or in some cases repackaged for attempted re-entry back into the U.S. (personal communication, unnamed industry expert).

3.2. Risks by state

Eighty percent of imported seafood (by value) moves through six

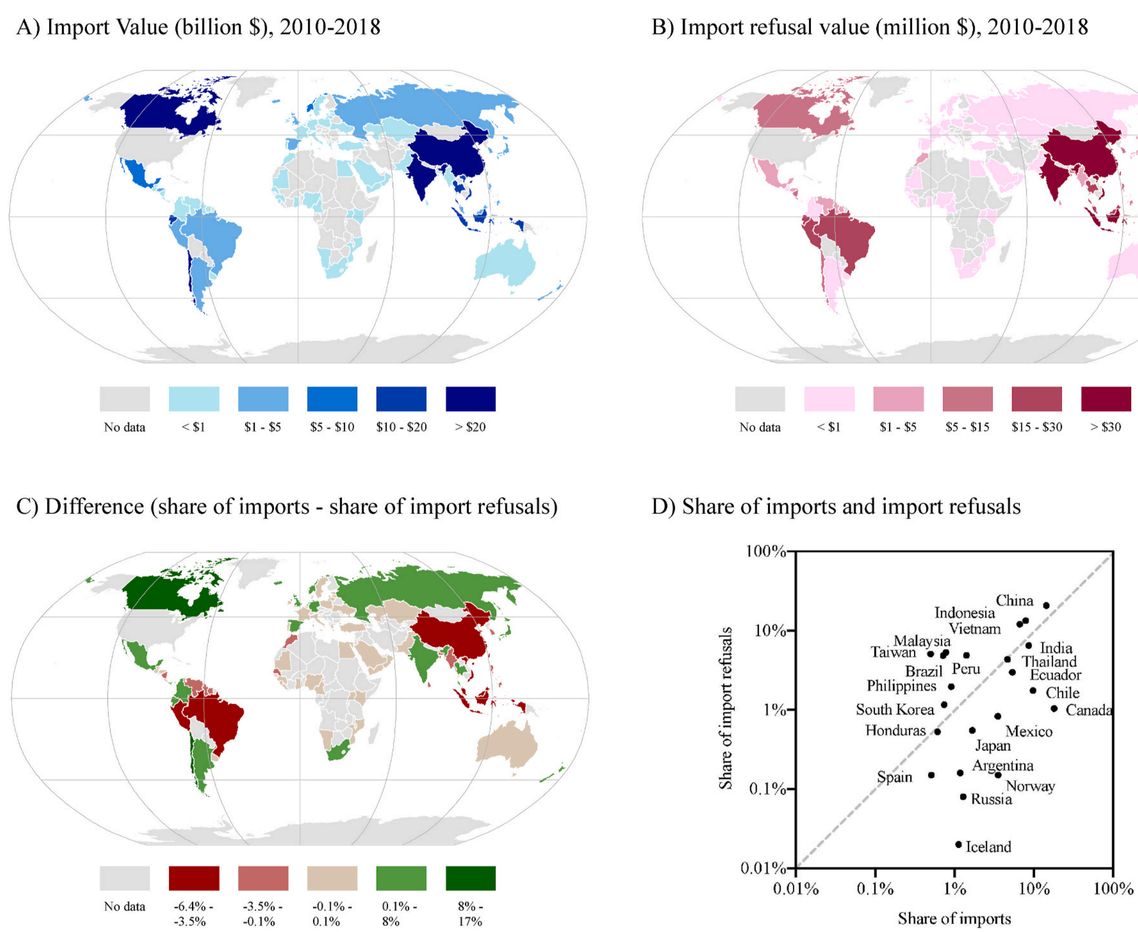

Fig. 2. Seafood A) imports and B) refusals by value and country of origin (total, 2010 to 2018). C) Relative risk as the difference between the share of imports to the share of import refusals, and D) graphed for the top-30 countries on a $\log_{10}$ scale. Data sources (US Census Bureau 2020): and FDA by Freedom of Information Act request. Values reported in Supporting Information Table S2.

ports-of-entry in the U.S. (New York City, NY, Los Angeles, CA, Miami, FL, Portland, ME, Seattle, WA, and Boston, MA). Many of these ports also refuse large numbers of seafood shipments (Fig. 3b), but the rate of refusals is fairly similar across the major ports-of-entry, ranging from one to five refusals per $10 million import value (Fig. 3c). Some ports-of-entry inspect products destined for other states, which makes state-to-state comparisons more challenging.

Once products enter the U.S. supply chain, another means of tracking risk is by monitoring domestic seafood recalls. Recalls are voluntary notices or mandatory orders for U.S. wholesalers, distributors, and retailers to call back unsafe products. Overall, there were 27.7 seafood recalls per 10,000 tons of seafood consumed in the U.S. Seafood recalls were most often issued by companies in New York, California, Washington State, Florida, New Hampshire, Massachusetts, and Oregon (Fig. 3d); these states that are generally known to import, process, and/or distribute more seafood than other states. Once products are distributed, they are shipped widely across the U.S. as seen by domestic trade flow networks for recalled products (Fig. 4) and the destination state for recalls (Fig. 3e), which can make tracebacks and recalls a challenge. States receiving the greatest rate of recalled seafood (based on total consumption by state) were the District of Columbia, Rhode Island, Maine, Wyoming, New Hampshire Nevada, and Connecticut (Fig. 3f). As an aside, domestic trade flows for recalled seafood (Fig. 4) could serve as a proxy for interstate seafood trade since these data are not currently available at this resolution.

Finally, we mapped consumption of all seafood (including imported and domestic) (Fig. 3g), seafood-related outbreaks (Fig. 3h), and the rate of outbreaks (Fig. 3i). From 2002 to 2018, a total of 1062 reported outbreaks were linked to seafood consumption, and these caused 7697 cases of illness, 544 hospitalizations, 10 deaths. Overall, there were 0.37 outbreaks per 10,000 tons consumed, but reported outbreaks represent the "tip of the iceberg" of the total burden of disease. The highest rates of outbreaks were in Hawaii, Alaska, Washington State, Minnesota, Florida and Oregon. Large numbers of outbreaks in Hawaii were related to ciguatera and scombroid toxins and could be specific to diets that include more tropical and marine fish. Multi-state outbreaks were not reported in the maps and made up 2% of all outbreaks but caused a disproportionally higher share (15%) of total illnesses.

3.3. *Risks by species and stage of the supply chain*

We explored relative risks of top-consumed species at different stages of the supply chain (Fig. 5). Relative risk was calculated as the share of violations, recalls, and outbreaks by species relative to the share imported or consumed by species. Risky species at multiple stages of the supply chain were anchovies, clams, eel, mackerel, octopus, oysters, and

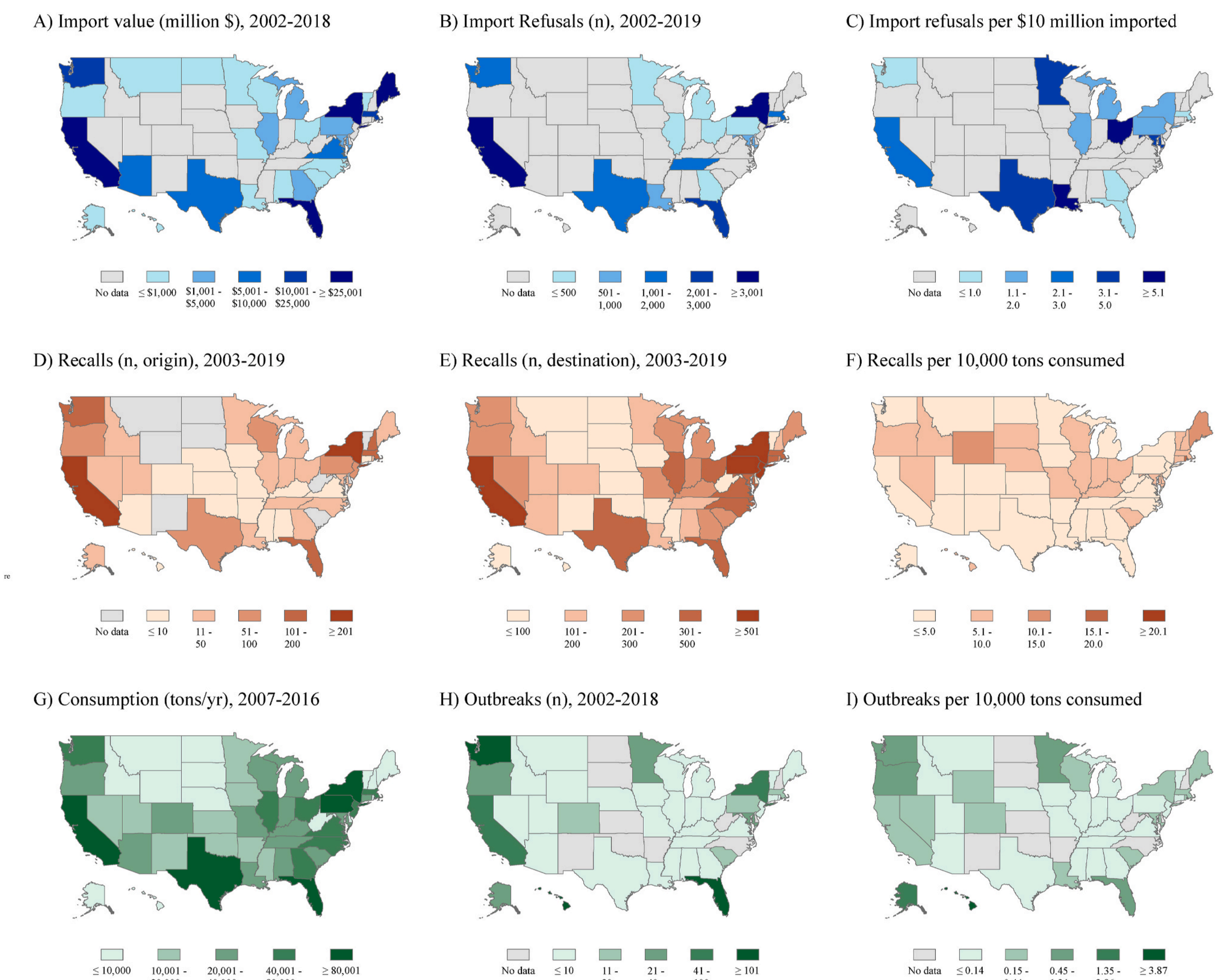

Fig. 3. Seafood imports, domestic supply, and consumption and risks by state. A) total seafood import value, b) total seafood import refusals, c) seafood import refusals per $10 million import value, d) total seafood recalls by origin, e) total seafood recalls by destination, f) rate of refusals per 10,000 tons consumed, g) seafood consumption (tons/yr), h) total seafood-related outbreaks, i) rate of outbreaks per 10,000 tons of seafood consumed. Data sources: (CDC, 2020b; FDA 2020, US Census Bureau 2020; USDA, 2020b).

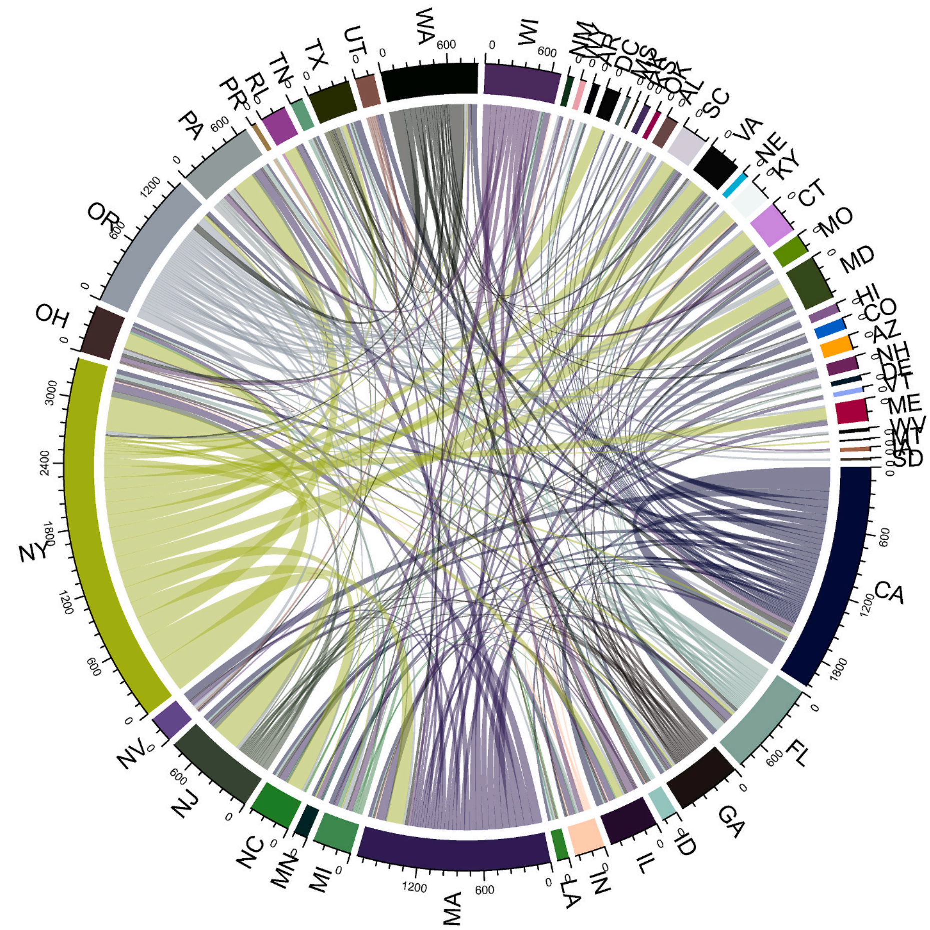

Fig. 4. Trade flows for U.S. seafood recalls (total, 2003–2019). Data sources: (FDA 2020; USDA, 2020b). State-to-state trade routes with 10 or more recalls were mapped. State names are reported as two letter acronyms. The color indicates the state of origin. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

tuna. Oysters, which are primarily a domestic-origin product, became riskier as they moved down the supply chain. Safer species at multiple stages of the supply chain were catfishes (including pangasius and U.S. farmed catfish), cod, crab, crawfish, lobster, perch, salmon, sardines, scallops, sea bass, shrimp, squid, and tilapia. Imported shrimp, tilapia, catfishes, and cod became less risky as these products moved down the supply chain. Notably, several top aquaculture species (catfishes, shrimp, tilapia, and salmon — except for smoked salmon) were among the safest of all products. Smoked salmon is commonly recalled for Listeria monocytogenes contamination in products or in processing facilities.

We observed "pass-through" risks introduced during upstream (import) and midstream (distribution) stages of the supply chain that were later associated with downstream risks for consumers. For example, improperly recalled seafood in the distribution and retail stages was associated with over 50 seafood outbreaks (or 5% of the total) (Supporting Information Fig. S1). Imported seafood was implicated in nearly 150 seafood outbreaks (or 14% of the total). Removing these "pass-through" risks would prevent nearly one-fifth of seafood outbreaks.

New risks were introduced during food preparation. Contamination of seafood during preparation was a contributing factor in 9% of seafood outbreaks and 2% of outbreaks were thought to be caused by food workers. Assessing outbreaks by the location where seafood was consumed, we see that 57% occurred at restaurants and other away-from-home venues while 33% occurred at home (and 10% at undisclosed locations) (data not shown).

3.4. Risks by hazard type and stage of the supply chain

Filth and microbes were consistently top reasons for violations, recalls, or outbreaks along the supply chain (Fig. 6). Missing or improper labels were also a frequent reason for violation on both the import and domestic supply sides (Fig. 6a and b). In some cases, hazards such as veterinary drugs were more frequently detected at upstream compared to downstream stages. There were shifts in the types of hazards and hazard-species group pairs that emerge as products move down the supply chain from raw materials to finished goods that are prepared and eaten. This is consistent with the idea that some hazards are removed while new hazards are introduced at each stage of the supply chain.

4. Discussion

U.S. consumers perceive that imported seafood is more risky than domestic products (Hicks et al., 2008; Wang et al., 2013) and are willing to pay more for local and domestic-origin products (Campbell et al., 2014; Ortega et al., 2014; McClenachan et al., 2016; Garlock et al., 2020). This paper used multiple datasets that span the seafood supply chain to addresses questions about the safety of imported seafood. We found that imports are not as risky as consumer perceptions suggest (Hicks et al., 2008; Wang et al., 2013), and that risks shift as products move from raw materials to finished goods.

Imported shrimp, pangasius, tilapia and farmed salmon, largely farmed commodities, make up about half of U.S. seafood consumption (Knapp 2014; Shamshak et al., 2019; NOAA, 2020a), and these products are relatively safe compared to other products across multiple stages of

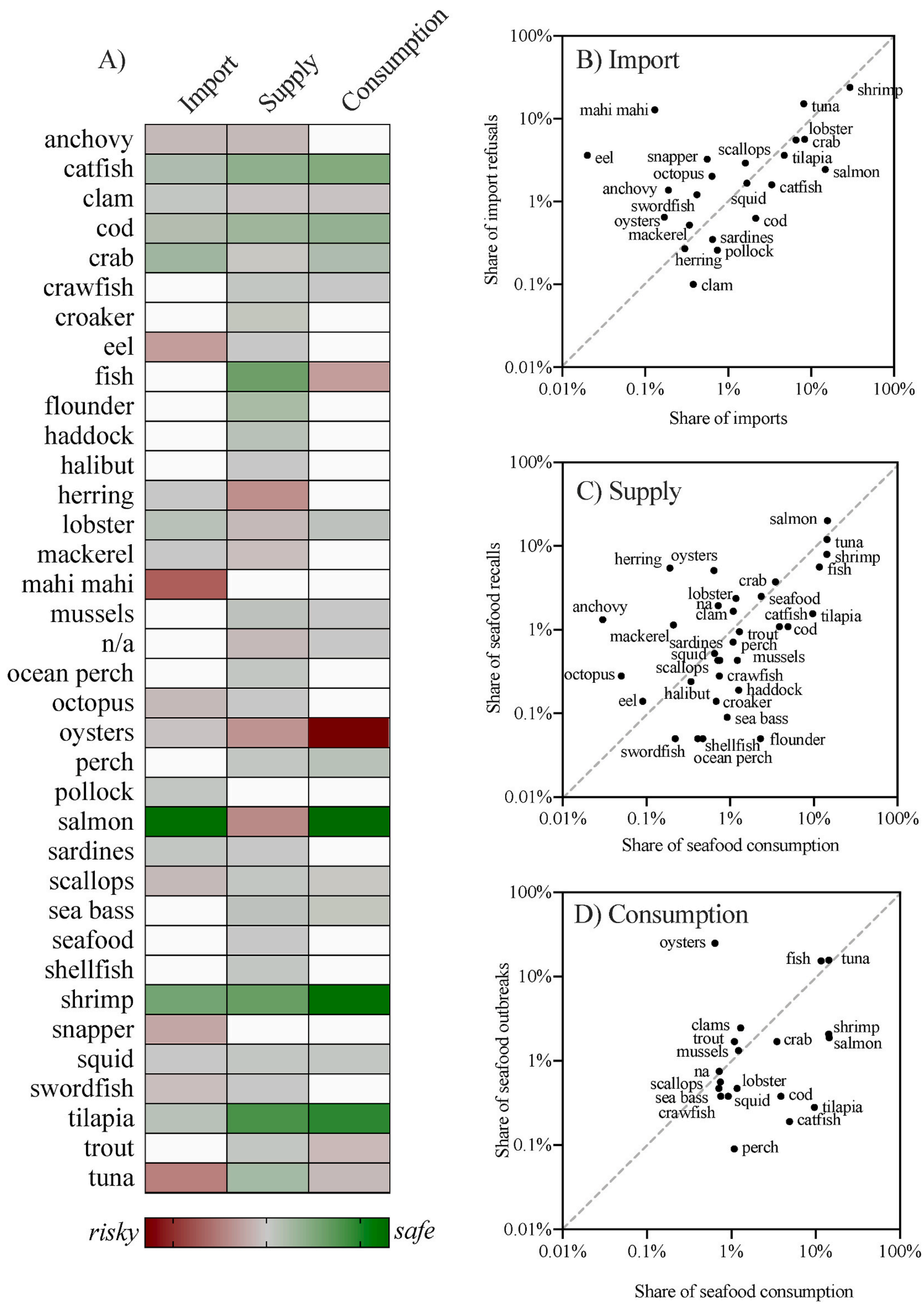

Fig. 5. Seafood safety by species and stage of the supply chain. B-D) Plotted on a $\log_{10}$ scale. Data sources: (CDC, 2020b; FDA 2020, US Census Bureau 2020; USDA, 2020b). Values reported in Supporting Information Table S3.

the supply chain. In fact, shrimp, tilapia, and catfishes become less risky as they move along the supply chain. These findings call for destigmatizing imported farmed seafood as has been noted by others (Little et al., 2012). One caveat is that this study can only comment on food safety and not environmental, labor, or economic issues related to imported seafood. We also recognize that seafood import monitoring needs to be strengthened and modernized (Willette and Cheng 2018) and veterinary drug residues remain a challenge for farmed products (Love et al., 2011; GAO 2017).

Seafood risks are less about country of origin and more a function of the activities happening at each stage of the supply chain, inherent riskiness of some products and types of processing, and some "pass through" risks introduced at upstream and midstream stages of the supply chain. For example, L. monocytogenes and Clostridium botulinum were common reasons for seafood recalls among many types of processed and ready-to-eat seafood items in this study, and as noted by

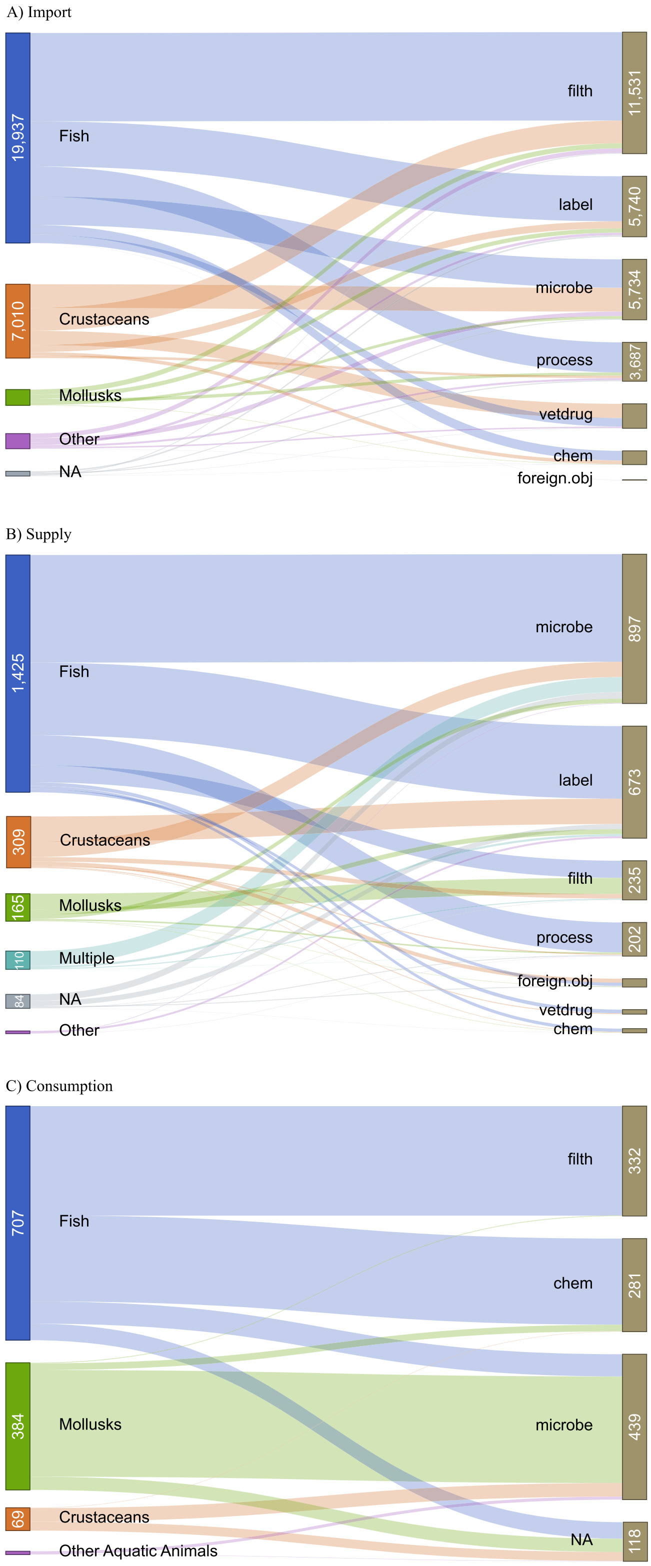

Fig. 6. IFSAC species groups and reason for a) seafood import refusals (total, 2002–2019), b) U.S. seafood recalls (total, 2003–2019), and c) seafood-related outbreaks (total, 2002–2018). Data sources: (CDC, 2020b; FDA 2020; USDA, 2020b). Terms: filth = filthy, insanitary conditions or products, time and temperature abuse, etc.; labeling = missing or incorrect labels on packages, microbe = bacteria, virus, parasite; process = issues related to HACCP, improper processing of low acid or salted foods, failing lids or seals, or missing forms; vet drug = veterinary drugs; foreign obj = glass or metal fragments in food; chem = chemicals, toxic substances; pesticides.

others (Lianou and Sofos 2007; Rasetti-Escargueil et al., 2020). Food preparation was another important contributor to risk in this study, and has been noted elsewhere (Angelo et al., 2017). Food preparation risks can be controlled by safe food handling practices and focusing on food worker health, hygiene, and paid sick leave (Angelo et al., 2017; Hsuan et al., 2017). Oysters were the largest share of seafood-related outbreaks in this study, and these products are mainly sourced from within the U.S. (NOAA, 2020a). We found that Vibrio-related outbreaks in oysters are increasing, which is linked to climate change (Vezzulli et al., 2016; Deeb et al., 2018) and magnified by eating raw oysters (Froelich and Noble 2016). Other species appear to be riskier, but only when mishandled. If tuna, mahi, mackerel, and marlin have time and temperature abuse, then histamine forming bacteria that live in the gills and gastrointestinal tract of these fish will proliferate. These bacteria produce a toxin called histamine or scombroid toxin (Feng et al., 2016), which was a common feature of import refusals, recalls, and outbreaks. These risks can be reduced by using time and temperature sensors for seafood distribution (Love, Lane et al. 2019; Love et al., 2020b,c), which are being used to varying degrees at all stages of the supply chain.

Our study raises several issues that can be best addressed by policy changes. We have several recommendations that would improve the safety of the U.S. seafood supply.

First, without robust government datasets this work would not have been possible. However, the ease of accessing and using these data were decidedly mixed. Some records were only available by FOIA, other data were buried on agency websites, and metadata was at times poor or not available (Supporting Information Table S1). A continued focus on "open government data" is desperately needed (Ubaldi 2013), which can benefit governments when these data are compiled and analyzed in ways that break down agency silos (Love et al., 2017). We see some signs of hope, for example www.FoodSafety.gov maintained by the US Department of Health and Human Services, is a good resource for the public, and this level of transparency can lead to a safer food supply. Second, there needs to be continued investment in federal, state and local agencies overseeing food safety and public health. Given limited budgets, our findings can help agencies better target resources to particular regions, species, or hazards, but without robust institutions we cannot have a safe food supply that is resilient to shocks. Third, government and industry need to solve seafood traceability from 'farm-to-plate', which can be a win-win for the environment and human health. NOAA introduced the Seafood Import Monitoring Program (SIMP) in 2018 to require chain-of-custody documentation for 13 imported species (NOAA, 2020b). Risky exporting countries in our study were located in regions of the world with higher rates of illegal, unreported, and unregulated (IUU) fishing (Petrossian 2015). SIMP could have the dual benefit of reducing IUU fishing (Fang and Asche 2019) and pinpointing the origins of seafood safety issues, and this program could be expanded to all species.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2020.100476.

References

Angelo, K., Nisler, A., Hall, A.J., Brown, L., Gould, L., 2017. Epidemiology of restaurant-associated foodborne disease outbreaks, United States, 1998–2013. Epidemiol. Infect. 145 (3), 523–534.

Boinapally, K., Jiang, X., 2007. Comparing antibiotic resistance in commensal and pathogenic bacteria isolated from wild-caught South Carolina shrimps vs. farm-raised imported shrimps. Can. J. Microbiol. 53 (7), 919–924.

Campbell, L.M., Boucquey, N., Stoll, J., Coppola, H., Smith, M.D., 2014. From vegetable box to seafood cooler: applying the community-supported agriculture model to fisheries. Soc. Nat. Resour. 27 (1), 88–106.

CDC, 2020a. National health and nutrition examination survey. " from. https://www.cdc.gov/nchs/nhanes/index.htm.

CDC, 2020b. National outbreak reporting system (NORS). from. https://wwwn.cdc.gov/norsdashboard/.

Deeb, R., Tufford, D., Scott, G.I., Moore, J.G., Dow, K., 2018. Impact of climate change on Vibrio vulnificus abundance and exposure risk. Estuar. Coast 1–15.

Dewey-Mattia, D., Manikonda, K., Hall, A.J., Wise, M.E., Crowe, S.J., 2018. Surveillance for foodborne disease outbreaks—United States, 2009–2015. MMWR Surveillance Summaries 67 (10), 1.

Done, H.Y., Halden, R.U., 2015. Reconnaissance of 47 antibiotics and associated microbial risks in seafood sold in the United States. J. Hazard Mater. 282, 10–17.

EPA, 2014. Estimated Fish Consumption Rates for the U.S. Population and Selected Subpopulations (NHANES 2003-2010). EPA-820-R-14-002.

Fang, Y., Asche, F., 2019. Can US Import Regulations Reduce IUU Fishing and Improve Production Practices in Aquaculture? Agricultural and Applied Economics Association, Atlanta, Georgia. No. 291058.

Fao, U., 2020. The state of world fisheries and aquaculture 2020.

FDA, 2018. Questions and Answers Regarding Mandatory Food Recalls: Guidance for Industry and FDA Staff.

FDA, 2020a. Enforcement reports. from. https://www.accessdata.fda.gov/scripts/ires/index.cfm - tabNav_advancedSearch.

FDA, 2020b. Guidance for Industry: Product Recalls, Including Removals and Corrections.

FDA, 2020c. Import refusal report. from. https://www.accessdata.fda.gov/scripts/importrefusals/index.cfm?action=main.default.

Feng, C., Teuber, S., Gershwin, M.E., 2016. Histamine (scombroid) fish poisoning: a comprehensive review. Clin. Rev. Allergy Immunol. 50 (1), 64–69.

Froelich, B.A., Noble, R.T., 2016. Vibrio bacteria in raw oysters: managing risks to human health. Phil. Trans. Biol. Sci. 371 (1689), 20150209.

Gao, 2017. Imported Seafood Safety: FDA and USDA Could Strengthen Efforts to Prevent Unsafe Drug Residues, pp. 17–443.

Garlock, T., Nguyen, L., Anderson, J., Musumba, M., 2020. Market potential for Gulf of Mexico farm-raised finfish. Aquacult. Econ. Manag. 24 (2), 128–142.

Gephart, J.A., Froehlich, H.E., Branch, T.A., 2019. Opinion: to create sustainable seafood industries, the United States needs a better accounting of imports and exports. Proc. Natl. Acad. Sci. Unit. States Am. 116 (19), 9142–9146.

Gould, L.H., Kline, J., Monahan, C., Vierk, K., 2017. Outbreaks of disease associated with food imported into the United States, 1996–2014. Emerg. Infect. Dis. 23 (3), 525.

Henriksson, P.J., Rico, A., Troell, M., Klinger, D.H., Buschmann, A.H., Saksida, S., Chadag, M.V., Zhang, W., 2018. Unpacking factors influencing antimicrobial use in global aquaculture and their implication for management: a review from a systems perspective. Sustain. sci. 13 (4), 1105–1120.

Hicks, D., Pivarnik, L., McDermott, R., 2008. Consumer perceptions about seafood–an Internet survey. J. Foodserv. 19 (4), 213–226.

Hsuan, C., Ryan-Ibarra, S., DeBurgh, K., Jacobson, D.M., 2017. Association of paid sick leave laws with foodborne illness rates. Am. J. Prev. Med. 53 (5), 609–615.

Knapp, G., 2014. Estimating US Salmon Consumption, Paper Presented at IIFET,. Brisbane, Australia.

Kroetz, K., Luque, G.M., Gephart, J.A., Jardine, S.L., Lee, P., Moore, K.C., Cole, C., Steinkruger, A., Donlan, C.J., 2020. In: Consequences of Seafood Mislabeling for Marine Populations and Fisheries Management. Proceedings of the National Academy of Sciences.

Lianou, A., Sofos, J.N., 2007. A review of the incidence and transmission of Listeria monocytogenes in ready-to-eat products in retail and food service environments. J. Food Protect. 70 (9), 2172–2198.

Little, D.C., Bush, S.R., Belton, B., Phuong, N.T., Young, J.A., Murray, F.J., 2012. Whitefish wars: pangasius, politics and consumer confusion in Europe. Mar. Pol. 36 (3), 738–745.

Love, D.C., Asche, F., Conrad, Z., Young, R., Harding, J., Nussbaumer, E.M., Thorne-Lyman, A.L., Neff, R., 2020a. Food sources and expenditures for seafood in the United States. Nutrients 12 (6), 1810.

Love, D.C., Gorski, I., Fry, J.P., 2017. An analysis of nearly one billion dollars of aquaculture grants made by the US federal government from 1990 to 2015. J. World Aquacult. Soc. 48 (5), 689–710.

Love, D.C., Kuehl, L.M., Lane, R.M., Fry, J.P., Harding, J., Davis, B.J., Clancy, K., Hudson, B., 2020b. Performance of cold chains and modeled growth of Vibrio parahaemolyticus for farmed oysters distributed in the United States and internationally. Int. J. Food Microbiol. 313, 108378.

Love, D.C., Lane, R.M., Davis, B.J., Clancy, K., Fry, J.P., Harding, J., Hudson, B., 2019. Performance of cold chains for Chesapeake Bay farmed oysters and modeled growth of Vibrio parahaemolyticus. J. Food Protect. 82 (1), 168–178.

Love, D.C., Lane, R.M., Kuehl, L.M., Hudson, B., Harding, J., Clancy, K., Fry, J.P., 2020c. Performance and conduct of supply chains for United States farmed oysters. Aquaculture 515, 734569.

Love, D.C., Rodman, S., Neff, R.A., Nachman, K.E., 2011. Veterinary drug residues in seafood inspected by the European Union, United States, Canada, and Japan from 2000 to 2009. Environ. Sci. Technol. 45 (17), 7232–7240.

Lynch, M., Painter, J., Woodruff, R., Braden, C., 2006. Surveillance for Foodborne-Disease Outbreaks: United States, 1998-2002.

McClenachan, L., Dissanayake, S.T., Chen, X., 2016. Fair trade fish: consumer support for broader seafood sustainability. Fish Fish. 17 (3), 825–838.

Nawaz, M., Khan, S., Tran, Q., Sung, K., Khan, A., Adamu, I., Steele, R., 2012. Isolation and characterization of multidrug-resistant Klebsiella spp. isolated from shrimp imported from Thailand. Int. J. Food Microbiol. 155 (3), 179–184.

NOAA, 2020a. Fisheries of the United States, 2018, National Marine Fisheries Service Office of Science and Technology. Current Fishery Statistics No. 2017.

NOAA, 2020b. Seafood import monitoring program. from. https://www.fisheries.noaa.gov/international/seafood-import-monitoring-program.

Oken, E., Choi, A.L., Karagas, M.R., Mariën, K., Rheinberger, C.M., Schoeny, R., Sunderland, E., Korrick, S., 2012. Which fish should I eat? Perspectives influencing fish consumption choices. Environ. Health Perspect. 120 (6), 790–798.

Ortega, D.L., Wang, H.H., Olynk Widmar, N.J., 2014. Aquaculture imports from Asia: an analysis of US consumer demand for select food quality attributes. Agric. Econ. 45 (5), 625–634.

Painter, J.A., Hoekstra, R.M., Ayers, T., Tauxe, R.V., Braden, C.R., Angulo, F.J., Griffin, P.M., 2013. Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998–2008. Emerg. Infect. Dis. 19 (3), 407.

Petrossian, G.A., 2015. Preventing illegal, unreported and unregulated (IUU) fishing: a situational approach. Biol. Conserv. 189, 39–48.

Pramod, G., Nakamura, K., Pitcher, T.J., Delagran, L., 2014. Estimates of illegal and unreported fish in seafood imports to the USA. Mar. Pol. 48, 102–113.

Rasetti-Escargueil, C., Lemichez, E., Popoff, M.R., 2020. Public health risk associated with botulism as foodborne zoonoses. Toxins 12 (1), 17.

Scallan, E., Hoekstra, R.M., Angulo, F.J., Tauxe, R.V., Widdowson, M.-A., Roy, S.L., Jones, J.L., Griffin, P.M., 2011. Foodborne illness acquired in the United States—major pathogens. Emerg. Infect. Dis. 17 (1), 7.

Shamshak, G.L., Anderson, J.L., Asche, F., Garlock, T., Love, D.C., 2019. US seafood consumption. J. World Aquacult. Soc. 50 (4), 715–727.

Shimshack, J.P., Ward, M.B., 2010. Mercury advisories and household health trade-offs. J. Health Econ. 29 (5), 674–685.

Ubaldi, B., 2013. Open government data.

Uchida, H., Roheim, C.A., Johnston, R.J., 2017. Balancing the health risks and benefits of seafood: how does available guidance affect consumer choices? Am. J. Agric. Econ. 99 (4), 1056–1077.

US Census Bureau, 2018. American community survey. " from. https://www.census.gov/programs-surveys/acs.

US Census Bureau, 2020. Harmonized system district level data. from. http://www.usatrade.census.gov.

USDA, 2020a. Food Patterns Equivalents database. from. https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/fped-overview/.

USDA, 2020b. FSIS datasets. from. https://www.fsis.usda.gov/wps/portal/fsis/topics/data-collection-and-reports/data.

USDA, 2020c. What we eat in America. from. https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/wweianhanes-overview/.

Vezzulli, L., Grande, C., Reid, P.C., Hélaouët, P., Edwards, M., Höfle, M.G., Brettar, I., Colwell, R.R., Pruzzo, C., 2016. In: Climate Influence on Vibrio and Associated Human Diseases during the Past Half-Century in the Coastal North Atlantic. Proceedings of the National Academy of Sciences: 201609157.

Wang, H.H., Zhang, X., Ortega, D.L., Widmar, N.J.O., 2013. Information on food safety, consumer preference and behavior: the case of seafood in the US. Food Contr. 33 (1), 293–300.

Willette, D.A., Cheng, S.H., 2018. Delivering on seafood traceability under the new US import monitoring program. Ambio 47 (1), 25–30.