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Testing Potential Fish Fraud in Community-Supported Fisheries

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Abstract

The seafood industry has long been plagued by the substitution of a species under a false label. Seafood mislabeling is a major concern in the management of fish and marine species. Incorrect labels hamper the ability to estimate stock size effectively, reduce consumer choice, and represent potential health hazards. The rates of seafood fraudulence have been shown to differ across businesses and markets, and in recent years, community-supported fishery programs (CSFs) have sprung up as an alternative to fish markets and grocery stores. Using genetic analysis, I show that 17 out of 41 (41.5%) samples examined from multiple markets in New Hampshire and Maine were fraudulent. The rates of fraudulent labeling differed across species and across markets, with community-supported fishery programs having the lowest levels of fraud (3 out of 10 samples, 30%) followed by restaurants (33%), fish markets (44%), sushi restaurants (50%) and grocery stores (58%). While the different levels of fraudulence between CSFs and other markets were not found to be statistically significant (p=0.36), my findings should warrant future studies with a larger sample of CSFs to determine the extent to which CSFs can help reduce seafood fraudulence.

1.0 Introduction

1.1 Seafood Fraud

The seafood industry in the United States brings in roughly $90 billion annually and supports over 1.5 million jobs (Kearney *et al*. 2014). The net worth is dependent on a wide range of species advertised and chosen by consumers. While labels largely function to provide information on the species to the consumer, they also serve to standardize labelling through chains of production, enforce different safety standards per species, help facilitate conservation efforts, and avoid the illicit trade of species (Miller, 2010). The need for effective labels has become increasingly important considering a UN report by the Food and Agriculture Organization, which suggested that the sale of illegal, unreported and unregulated fisheries contributes to overfishing (FAO, 2007). Additionally, much literature has been written on the difficulty of managing fisheries, (Gaines and Costello, 2013, Roughgarden and Smith, 1996) but until recently the effect of IUU (illegal, unreported, and unregulated) fishing on the reduction of key species has been largely overlooked (Pauly, 2003, EFTEC, 2008). In 2008 alone IUU fishing was estimated at 11-26 million tons with a loss of $10-23.5 billion globally. This is a hefty global fraction of the $80 billion in total revenue of legal fishing in 2008 (Oliver, 2008).

Labels, however, are only effective in-so-far as they are accurate. Consumers rely on seafood labels so they can know the product they are buying. However, there are instances in which the species depicted by the label differs from the fish it is labeling, constituting seafood or fish fraudulence. There are many reasons why a fish can come to market with the wrong label. Less expensive and low quality products can replace higher quality and more expensive fish or a species that is illegal to catch may be relabeled under a similar species that is legal to catch. Within Ireland, estimated levels of seafood fraud for cod (*Gadus morhua*) at one large retailer showed that less popular species being sold as cod inflated profits by €400,000–550,000 in 2009 (Miller, 2010). However, because the retailer was not listed it is difficult to determine how much of an economic incentive mislabeling was in this instance.

Additionally, mislabeling can be done accidentally, or labels that are acceptable in one state or country may be unacceptable when brought to market in a different state or country (Logan *et al*. 2008). The more specific a label is, the less likely for the fish to be mislabeled. One study found that chum salmon (*Oncorhynchus keta)* was more often accurately labeled when compared to the generic label of salmon alone (Hold *et al*. 2001). Another study found that the broader or more generic a label was, the easier it was to confuse or use labels interchangeably (Gerson *et al*. 2008). In Canada, one study found that confusion of what species belonged to what label led to 30-50% of imported toothfish (*Dissostichus eleginoides)* to be mislabeled under the code for seabass. (Gerson *et al*. 2008)

Regardless of whether the intent to mislabel was profit driven or the result of confusing or relaxed labelling standards, the negative impacts extend to both human health and conservation efforts. Within Ireland, for example, 25% of cod samples were found to be mislabeled with 23.7% belonging to a different genus (Miller, 2010). Additionally, around 80% of smoked cod samples were mislabeled. Likely the rate is smoked samples is because it is harder to detect mislabeling in highly processed samples (Miller, 2010). In the United States, red snapper (*Lutjanidae*) appeared to be the most mislabeled, with studies finding instances of mislabeling occurring at rates of 63% (Logan, 2008), 77% (Marko, 2004), 78% (Wong, 2008) and 87% (Warner *et al*. 2013). Often, the redfish substitution was an Atlantic variety in place of a Pacific variety or vice versa (Marko, 2004), but one study found 56-58% of mislabeling to be attributed to a species which was declared overfished by the National Marine Fisheries Service (Logan, 2008). Another study noted red snapper was often priced at $2.93 per pound when compared to generic redfish which fetched a price of $0.72 per pound, suggesting economic motives (Wong, 2008). Nationwide levels of seafood fraud were found under one study to be 25% (Wong, 2008). By far, the most comprehensive study in the US was conducted through Oceana which sampled 1215 fish. The Oceana report found a slightly higher level of fraud at 33% (Warner *et al*. 2013). Additionally, the Oceana study looked at different markets and found that sushi restaurants were fraudulent 74% of the time, other restaurants 38% of the time, and grocery stores 18% of the time (Warner *et al*. 2013).

Consumers often want to make the most sustainable choice. One survey found 72% of respondents would be more likely to buy a product if the product had an environmentally responsible label (Seafood Alliance, 2003). For example, since coming to market, tuna (*Thunnus alalunga)* labeled as “dolphin safe” has increased in sales when compared to tuna without the label (Kaiser, 2006). So when less desirable species are relabeled as more desirable species, they inflate the catch size of the most desirable species and decrease reporting on species that are not regulated (Marko, 2004). Sold fish are often used to estimate the stock size of a species. Mislabeled fish also lead consumers to believe that a species is widely available, making the stocks seem healthier than it may be (Miller, 2010). Unfortunately, consumer interest in sustainable choices may have increased instances of mislabeling. In the UK, supermarkets have competed to get the top spot in the Greenpeace league tables for sustainably caught seafood (Seafood Choice Alliance, 2003). This competition is only effective if what supermarkets are selling is accurately labeled. One super-market had 4 of 23 samples labelled as sustainable that were mislabeled, unsustainable species (Miller *et al*. 2011). In toothfish stocks, IUU catches have led to a massive decline in the species (CCAMLR, 2007). Additional harms may be passed on to consumers as different fish have different levels of mercury, and two individuals were poisoned by puffer fish (*Takifugu pardalis)* which was prepared poorly due to it being labeled as monk fish (*Lophius americanus*) (Miller, 2010). The evidence of health risks is further supported by one report which found that 58% of substitutions carried species-specific health risks (Warner *et al*. 2015).

Solutions at the policy level have been proposed to try to stop instances of mislabeling. Most notably, more specific labeling can be done, removing general labels that capture multiple species (Logan *et al*. 2008). In the European Union, products are required to have a standardized name, method of catch, and location of catch. Whereas in the US, only the name is required to be on a label (Miller, 2011). Often, generic labels include both sustainably and unsustainably caught fish, making it impossible for the consumer to make responsible choices (Jacquet and Pauly, 2007). Additionally, when multiple species with different ecological needs are marketed under one name, it becomes harder to pass regulation that can benefit all of the species grouped under that label (Logan, 2008). This difficulty is due to differential life history traits such as different growth rates and maturity rates (Parker *et al*. 2000). More accurate labels can reflect standard names or scientific names, but changes to labels can take up to 5 years to implement (Gerson *et al*. 2008). Other solutions proposed for the US include establishing a single agency to standardize labels across state lines, providing more transparent chains of custody, and developing more cost effective and available tools to test the species of samples that come to docks (Miller *et al*. 2010). However, the time and difficulty with implementing fraud solutions leaves the consumer with few options to know the product they are buying. My study seeks to examine the difference in markets and see whether community-supported fishery programs allow for the consumer to receive the most accurately labeled product.

1.2 Community-Supported Fisheries

Following the rise of community-supported agriculture (CSA), many fishermen have attempted to combine the direct marketing advantages of CSAs with fishing. CSAs have grown to over 2500 operating businesses in the US (Henderson and Van, 2007), causing the widespread application of their model into other fields. Community-supported fisheries (CSF) share the upfront payment and scheduled deliveries that have become a staple of CSAs and apply them to marine caught fresh fish. In the US, the CSA movement started in 1986 (Tegtmeier and Duffy, 2005), but CSFs started much more recently in 2007 within Maine (Libby, 2011). Because of their short history, not much is written on what makes a CSF successful or even whether or not the model is adaptable to fishing. Many risks apply to fisheries that CSA agricultural systems do not have to worry about, such as mechanical difficulties, regulatory closures, and weather events which make fishing unsafe (Brinson *et al*. 2011). Despite the challenges CSFs face, since 2010 the number of CSFs has grown from 14 to 30 following an initial decline (Christoferson, 2015).

The direct marketing model of CSFs has several benefits over traditional markets. When considering the overall benefits of the CSF model, one should pay attention to the benefits afforded to fishermen. Often, business owners are largely motivated by profit incentives, and the CSF model allows for fishermen to receive more money. A study done in North Carolina found that fish sold through a CSF model could get 33% more revenue for their catch (Stoll *et al*. 2015). The NC study also found that fishermen who work cooperatively to supply a single CSF saw 14-18% more revenue for their catch by year- end profit sharing when the profits are divided out. The profit boost makes CSFs particularly attractive for small scale fishery operations who currently struggle to get by due to their lack of political power, small market impact and fewer subsidies when compared to large-scale operations (Ponte *et al*. 2007). They bring in additional revenue by providing a market for some fish that does not exist, increasing the variety of species which can be sold. The catch and release of species that are not marketable presents a time sink for small scale fisheries. CSFs often receive money upfront when consumers buy shares of the total catch. Having the money up front allows them to work more collaboratively, share trade secrets and increase their overall catch (Rountree *et al.* 2008). Lastly, shares protect fishermen from price volatility, increasing the value of an upfront payment (Brinson *et al.* 2011).

Many consumers enjoy how CSFs bring local food to them. CSFs connect with the consumer through websites, letters, announcements, events, recipes and numerous other methods. Consumers have become increasingly concerned with where their food comes from (Brinson *et al.* 2011). Concern with the origin of food may be in part due to the rise of the locavore movement. Consumers have begun to believe that local food tends to taste better, be healthier, and help consumers build relationships with suppliers they can trust (Thomas and Mcintosh, 2013). Additionally, there is a growing movement of consumers who care about the social, economic and environmental impact of their food (O'Hara and Stagl, 2001). Thus, it is likely that consumers enjoy CSFs because of the benefits they are perceived to have and consumer's increased awareness of their food's effect on political issues. Finally, many people also enjoy the connection formed with fishermen (Brinson *et al.* 2011). This connection has the added benefit for fishermen of creating potential political allies in the regulatory process. Individuals involved in CSFs may then be an important ally when pushing for more accurate labelling within government bodies.

One of the most important aspects of CSFs is their impact on the environment. Many factors such as the distance food has travelled, fishing methods, and species taken operate differently under a CSF model. Many CSFs make sustainability one of their stated goals. In a meta-analysis of CSFs, the largest stated goal was shortening the supply chain, and environmental sustainability was a stated goal for 41% of CSFs (Bolton and Basurto, 2015). CSFs also had stated goals of promoting small-scale and low impact fisheries (27%) as well as promoting the use of underutilized species (14%). The interest in sustainability that some CSF owners have suggests that some CSF may take conservation and the long-term health of fish stocks into consideration.

In 2014 the US imported 94% of all fish consumed by Americans (Lowther and liddel, 2015). Distance travelled contributes to the amount of fossil fuels consumed, and local food should be preferred when possible (Pirog *et al.* 2001). A study found that the average distance travelled by seafood from CSFs in the US is 65 Km and 8,812 Km for more traditional markets (Mcclenachan *et al.* 2014). A study looked at produce specifically and found that transportation of food tends to be the most fossil fuel intensive portion of the process from harvest to consumer (Coley *et al.* 2009). Cutting down on the distance of food travelled allows for CSFs to have a much lower carbon impact than traditional markets. However, often CSFs are limited to only serving their local community and do not ship across states.

CSFs may also be able to aid in reducing the pressure of overfishing. Fishermen participating in CSFs have an incentive to pass sustainability measures which allow them to compete with large scale fisheries, making them often a political ally for conservation. Many hurdles exist to passing strong fishing regulation, and successfully enacted regulation often requires support from multiple private factions and public institutions (Acheson, 2013). The current incentive of fishermen is to maximize profit by increasing their overall market share. To achieve maximum profit, fishermen often try to fish at or near regulatory limits which can lead to overexploitation (Hilborn *et al.* 2003). Unfortunately, the response to decreased catches and an increase in the number of fishermen and industrial fishing has been to catch more (Kasperski and Holland 2013). However, the cooperative nature and profit sharing of the CSF model allow fishermen to worry less about their overall market share. This cooperation often results in fishermen agreeing on how to share fish, freeing up individuals to concentrate on reducing costs and improving market conditions (Hilborn *et al.* 2005). Additionally, because the shares are bought upfront, there is less pressure to take as many fish as possible. There has been a decrease in average trophic level in the last 50 years of fishing, (Pauly, 1998) and CSFs may contribute to the decrease in trophic level. One study found that the mean trophic level of sold CSF catches was 3.52 compared to 3.29 for more conventional systems (Mcclenachan *et al.* 2014). Despite this loss in trophic level, the study also found that CSFs tend to select fish from more highly abundant stocks (250% of target population size) more frequently than non-CSF fishermen. A study also created two focus groups—one where the price per fish was based on the number caught (i.e. fewer fish caught created higher prices) and one where there were no restrictions on price. Thus, fishermen who were able to get a higher price for less fish were more concerned about the future health of the fishery (Hopfensitz *et al.* 2015). If CSFs increase in popularity, they may have a positive effect on the number of fish that we remove from our oceans.

CSF fishermen tend to use more sustainable fishing gear as well. Some CSFs are incentivized to use lower impact gear (hook and line, trolling) due to the transparency the CSF has with its customers (Mcclenachan *et al.* 2014). This is further supported by research done by Witter (2012) which suggests that the CSF model may incentivize adopting lower impact gear. The switch in gear is important because the impact of bottom trawling and similar fishing methods is much greater than the impact of hook and line gear (Witter, 2012). Not only do they provide all the above environmental impacts directly, but their connection to the consumer means CSFs can pass on much of this information as a form of education (Mcclenachan *et al.* 2014). This exchange of knowledge means that CSFs may have an additional indirect and positive impact on the environment.

Hurdles exist in the creation of any community-supported program, but the adaptation of the CSA model without the consideration of the challenges related to fisheries specifically makes the creation of a CSF uniquely challenging. While fishermen and farmers have a unique set of skills that translate well to harvesting the product, many feel unprepared to run a business. Skills such as marketing and accounting can create barriers to starting a program, and some fishermen and farmers perceive their lack of skills to be preventative to success. When asked if lack of business skills was a challenge, 18% of fisherman responded with yes (Bolton and Basurto, 2015). Additionally, the cost to start up a CSA/F program creates additional burdens. Rather than selling fish or produce to a supplier, owners must store and supply themselves. In the same study, 14% believed that the cost of storage was a problem for them. CSFs likely have additional costs because of the transportation from the ocean to the dock and increased refrigeration that fish require. Many fishermen and farmers also fear that they may be alienated from traditional vendors and seen as a competitor. Being cut off from vendors may make it difficult to sell surplus, participate in events, or harm connections with restaurants.

Those roadblocks alone are challenging, but CSFs must contend with others. First, there have historically been stricter legal regulations in regards to seafood than produce. In Boston, a ban on the sale of seafood in a farmers' market made it difficult to connect to those who would likely be the largest customer base for CSFs. While farmers' markets were typically partnering with CSAs in the same communities, the lack of coverage for CSFs made it a challenging to gain traction (Tolley and Hall-Arber, 2015). The Boston ban was eventually lifted, but it highlights some of the fear surrounding seafood.

Additionally, CSFs have a harder time prescribing variety than CSAs. While farmers can plant in a way that maximizes how variable their crops are, fishermen are at the mercy of whatever they happen to catch on a particular day (Campbell *et al.* 2014). The lack of control over what is caught can be problematic in-so-far as people expect certain familiar fish to be supplied to them on a weekly basis. Too many unknown or strange fish can turn a customer off from a CSF. Even worse, a farmer's output is often determined by how much they plant, while a fisherman's is determined by what they can catch. There is increased risk involved if a CSF is unable to catch enough fish to supply all their shareholders. Often CSFs try to make up the difference by compensating with more product in other deliveries, (Fensitz *et al.* 2016) but this increase in catch can be an additional cost which can hurt a CSF program. Lastly, less seafood is consumed than produce. Annual seafood consumption in the US in 2012 was roughly 14.5 lb. per capita in 2014 (Lowther and Liddel, 2015) while annual agricultural consumption was 675 lb. per capita (Produce for Better Health Foundation, 2015). Fish seem to be a less consistent dinner food than vegetables, but this differences in per capita consumption could also be due to a higher supply of agricultural products. Too much fish could lead to individuals cancelling subscriptions if consumers feel like they are getting more fish than they can eat. Less fish consumption could represent a potential limit to how much a CSF can increase their profit by when compared to a CSA.

CSFs' greater commitment to sustainability, decreased pressure to supply specific 'popular species', and the shortened distance that a fisherman's product travels may be factors that contribute to lower levels of seafood fraudulence. If consumers can receive a product with lower instances of fraud and CSFs are able to attract more consumers, CSFs and consumers could both benefit. My paper seeks to establish both a standardized method for selecting samples to test as well as establish the difference in instances of fraudulence between CSFs, restaurants, sushi restaurants, fish markets and grocery stores. I hypothesized that there is a statistical difference in fish fraud rates between CSFs and other markets.

2.0 Methods

2.1 Selection Methods

Three CSF programs were selected between Maine and New Hampshire—2 in Maine centered in Portland and the midcoast (Rockland, Rockport and Camden) and 1 in New Hampshire centered around Portsmouth. Unfortunately, the CSF program in Portland, Maine cancelled orders mid-May and chose to only supply restaurants. Within each location (Portland, midcoast and Portsmouth) two fish markets, grocery stores, restaurants and sushi restaurants each were chosen. To choose which businesses to select for each category, all businesses where put into a list (i.e. a list of all sushi restaurants in Portland Maine) and assigned a number. A number was then randomly selected and the corresponding business was selected. The only requirement for restaurants was that they serve two different types of fish, and menus were double checked online before attending. Grocery stores were defined as any national or multistate chain food store, and were distinct from fish markets which were limited to only one store or were only a statewide chain.

To determine what kinds of fish to buy, I first waited to see what the CSF gave to us. The two CSFs had different business models. The CSF in New Hampshire followed a similar model to CSAs. I bought into an 8-week program and received a weekly share of whatever happened to be caught that week. Each week was also accompanied by an email which explained the fish being caught and highlighted the fisherman who caught it. The CSF in the midcoast operated by consumer choice. Each week they would put up a list of what they had in stock and I could select what I wished to purchase, and the fish would be delivered to a set pick up point. I selected the first 5 samples from the CSF in New Hampshire to be our target species: dogfish (*Squalus acanthias*), haddock (*Melanogrammus aeglefinus*), monkfish, hake (*Merluccius bilinearis)* and acadian redfish (*Sebastes fasciatus*). However, frequently restaurants would have only one or a few of the CSF fish, leading to a wide range of samples selected (i.e., often sushi restaurants were limited to tuna and salmon).

2.2 Extraction Methods

Two samples were bought from each business. Roughly a 5-mm^2 piece of tissue was cut from the middle of each fish, and all samples were stored in 70% ethanol in a 1.5-mL test tube at 4°C. Two methods were used to extract DNA. The first method, the NaOH method, took a roughly .1mm^2 piece of each sample in a test tube with 100µl of 50mM NaOH. This mixture was heated at 95°C for 20 minutes and cooled at 4°C for 10 minutes. Then 10 microliters of 1 M pH 8 Trist HCl was added. The test tube was then centrifuged for 2 minutes to pellet the debris and the supernatant was pipetted into a clean 1.5 mL test tube. The extracted DNA samples were stored at -20°C. 648 base pairs from the 5' region of the CO1 gene were amplified through a PCR process. The total volumes for the NaOH extraction method PCR reactions were 10 microliters and contained 1 microliter of the extracted DNA, .8 microliters each of the F2 and R2 primers (Ward *et al.* 2005), 5 microliters of a PCR reaction buffer, and 2.4 microliters of Nuclease free water. PCR reactions were run in a BIORAD T100 Thermal cycler at 95°C for 30 seconds, 55°C for 30 seconds and 72°C for 30 seconds. This cycle was repeated 29 times. The PCR products were then run via electrophoresis on a 1% agarose gel for visualization.

The samples that did not successfully amplify via PCR were extracted using the DNeasy Blood & Tissue Kit created by Qiagen (www.qiagen.com). The extracted DNA was run through the same PCR process and electrophoresis procedure as outlined above. All samples that were successfully amplified were purified through the addition of exonuclease 1 shrimp alkaline phosphatase (Exosap). Samples were sequenced by the DNA Analysis Facility at the University of Vermont. The sequences were then edited in FinchTV, and the final sequences were entered into BLAST on GenBank. The BLAST results provided us with a percent match to a species in the data base and a score evaluating the confidence in the match. To determine whether a species was mislabeled, acceptable names for species were looked at under the FDA Seafood List (http://www.accessdata.fda.gov). From the fraud data, I used a one sample t-test comparing the levels of fraud in CSFs and all other markets to determine if there was a statistical difference between the two.

3.0 Results

Of the 58 samples, 43 were successfully amplified and sequenced bi-directionally (Table 1). I was not able to get the full length of the COI barcode for all the samples that were successfully amplified. Some, due to errors in the tail end of either the forward or reverse primer were sequenced for less than 680 base pairs. The samples with fewer base pairs could represent a flaw in extraction method as previous studies (Wong *et al.* 2008, Miller *et al.* 2011) could get much higher rates of extraction. A total of 8 samples had a less than 95% match on BLAST. Of those 8, 6 of them were sequenced with less than 680 base pairs. Additionally, 2 samples were successfully amplified but could not be sequenced with enough accuracy to match to a species.

The eight samples that had less than a 95% match with a species through BLAST were cross referenced with the BOLD identification engine (http://www.boldsystems.org/). BOLD could not return a match for four of the samples, one labeled as haddock from New Hampshire restaurant 1, one labeled as haddock from Midcoast grocery store 2, one labeled as haddock from midcoast restaurant 2, and one labeled as salmon from midcoast restaurant 1. In the other 4 instances, the BOLD and BLAST searches revealed the same species.

Of the 41 samples that were successfully amplified and sequenced, 17 of them were believed to be mislabeled (Table 2). This is a rate of 41.5% of all samples taken—higher than previous studies which estimate fraudulence rates between 28%-33% (Warner *et al.* 2013, Wong *et al.* 2008). However, the Oceana study notes that there are differences in levels of seafood fraud regionally in North America, and seafood fraud may be of concern in the Gulf of Maine. The higher rate of fraud is further supported by yearly reports done by the Boston Globe (Abelson and Daley, 2012) showing a rate in restaurants of 76%. However, many studies have relied on self-selection by researchers and volunteers. The self-selection of businesses has the potential to skew results because researchers may be looking for, or avoiding, businesses that they believe to be fraudulent. However, a report from the Baltimore Sun notes that instances of seafood fraud may be on the rise in the US as NOAA cuts investigators and brings fewer cases to trial (Rentz, 2014).

Of all the markets examined community-supported fishery programs had the lowest level of fraud. 30% of samples from CSFs were fraudulent compared to 33% of restaurants, 44% of fish markets, 50% of sushi restaurants, and 57% of grocery stores (Figure 1). When rates of fraud were compared between CSFs and all other markets, the results showed no statistical difference between the two (p=0.036). Previous studies that discerned the difference based on market (Warner *et al.* 2013) found cases of fraudulence to be 74% in sushi restaurants, 28% in restaurants and 18% in grocery stores. While our results for restaurants are somewhat consistent, our sushi results of 50% fraud is much lower. The Warner study did not discern between fish markets and grocery stores, but both types of businesses were higher than the 18% instances of fraud in the Warner study. Additionally, the high levels of fraud in both grocery stores and fish markets suggest that the relationship between vendor and fisherman, and distance the final product travels may not be influential factors that impact levels of fraud.

4.0 Discussion

4.1 CSF Business Models

Both CSFs had differing business models in terms of how they sold their product to consumers. The CSF in midcoast Maine sent weekly newsletters out explaining what was caught each week, and consumers could place an order from this list. The midcoast CSF offered the fish that it caught on a first come, first serve basis. Of the 5 samples that were bought, on the day of pick up 2 of the samples were replaced. The order of fresh cod was replaced by a second order of haddock, and an order of redfish was replaced by scallops (*Placopecten magellanicus)*. These substitutions were not made known ahead of time, but were clearly labeled on the fish at pick up. Of the substitutions that were made, one of them was mislabeled. The scallops were found to be goosefish, more commonly labeled as monkfish. Additionally, what was labeled as monkfish was found to be haddock, meaning a total of 2 out of 5 (40%) of midcoast CSFs samples were mislabeled.

The New Hampshire CSF operated similar to the typical CSA model. A share was bought at the beginning of the summer season, and I did not know in advance what I would be receiving. Before each week's pick up, the New Hampshire CSF would outline the species being caught each week, highlight the fisherman who caught it, and offer up tips on how to cook and prepare it. Only one of five (20%) samples from the New Hampshire CSF was mislabeled. Acadian redfish was an equal match with deepwater redfish (*Sebastes mentella*) and golden redfish (*Sebastes norvegicus*). All three species under the FDA Seafood List can be acceptable labeled as Ocean Perch, but the CSF chose the specific name, Acadian redfish, constituting a case of fraudulence.

It's important to note that with only five samples taken from each CSF, the difference between one and two instances of fraud cannot be claimed to be statistically significant. With that in mind, the differences between the two different CSFs could be influenced by a number of factors which warrant a more complete study. First, having an upfront order to dictate amount of fish to catch per week, may reduce pressure to mislabel. For example, the midcoast CSF may have different orders week to week, forcing the business to make predictions on demand that may not align with actual amount of fish ordered. If not enough variety was caught one week, it may be easier to mislabel samples than to provide multiple substitutions that could turn away customers from buying future fish. The New Hampshire CSF avoids the problem of self-selection. By receiving the money upfront, and choosing the product for the customer, the CSF may have less of an incentive to provide the wrong product. Additionally, the bio on the fisherman and fish being caught by the New Hampshire CSF provides both accountability and greater liability for mislabeling, creating a positive incentive to accurately label the product. Conversely, because the New Hampshire CSF had to supply a single species of fish for all customers each week, they may have more of an incentive to mislabel than the midcoast CSF. For example, having to supply 600 lbs. of haddock for 600 customers could lead to instances of mislabeling when one is only able to catch 500 lbs. of haddock a particular week.

4.2 Species Differences

Consistent with previous studies (Warner *et al*. 2013, Wong *et al*. 2008, Marko *et al*. 2004) red fish showed the highest level of fraudulence with two out of three samples (66%) being mislabeled. The sample of red snapper which was labeled correctly was identified as Pacific red snapper (*Lutjanus campechanus*). This Pacific red snapper sample was simply sold as red snapper with no mention of which ocean the fish came from, but the sales person noted that the snapper may have come from the Gulf of Mexico. The sales person's knowledge gap highlights that some instances of fraud may be due to a lack of knowledge of workers, rather than an effort to gain more money. Because he had been unsure at the time, I chose not to include the Pacific red snapper sample as an instance of mislabeling. The substitution of deepwater redfish (or golden redfish) for the Acadian redfish at the New Hampshire CSF has some startling ecological impacts. The IUCN redlist finds Acadian redfish to be endangered (Sobel, 1996) and deepwater redfish to be threatened (Acero *et al*. 2010). The substitution of an endangered species for a threatened species, may be seen as positive, but mislabeling under-estimates the stock of acadian redfish, and over-estimates the stock of deepwater redfish. This fraudulence is particularly problematic due to deepwater redfish having life history traits that may make it more vulnerable to overfishing than other species. Deepwater redfish mature between 18-23 years, while acadian redfish mature 8-18 years (COSEWIC, 2010). Unfortunately, slow growing and slow maturing fish are often the most vulnerable to overfishing (O'Connor, 2015). With the growth rate of deepwater redfish in mind, the North East Atlantic Fisheries Commission (https://www.neafc.org/) reduced the catch of deepwater redfish to 95,000 tons in 2001 between the contracting parties of Denmark, Iceland, Norway, Russia and the EU. Continued exploitation of deepwater redfish that isn't measured could be contributing to a future collapse of the species. Additionally, the lack of a genetic divide between North American populations and European populations (Roques *et al*. 2002) could mean that a collapse due to fraud in the US could impact all the Atlantic. Despite their different conservation needs, Acadian and deepwater redfish are particularly hard to distinguish (COSEWIC, 2010). Their morphological similarities could be a reason for the existence of their more generic label: ocean perch. Better tools to distinguish between the two species may help fishermen accurately label their product.

Tuna had comparatively low levels of fraudulence compared to previous studies (Warner *et al*. 2013). Tuna was mislabeled in 3 out of 10 samples. In two of the instances of mislabeling the tuna was replaced by *Seriola quinqueradiata* (Amberjack). This species has a common vernacular name of yellowtail. It is therefore possible that the amberjack was sold under its vernacular name despite the name not being an acceptable label under the FDA Seafood List. The confusion of vernacular and accepted names highlights the importance of strict labeling standards between state and international boundaries. In both instances when Amberjack was substituted, it came from Boston fish markets, which got the fish from Japanese shipments, and made its way up to New Hampshire and Midcoast sushi restaurants. Additionally, the more specific the label was for tuna, the higher levels of fraud. Of the three tuna samples listed as yellowfin tuna (*Thunnus albacares*), two were fraudulent. Whereas only one of the seven samples broadly listed as tuna was fraudulent. Four of the samples listed broadly as tuna were also the more highly sought after yellowfin tuna.

By far the most commonly available and purchased fish in all three locations was haddock. Of the 17 samples labeled haddock, six were a different species (35%). Haddock was also labeled a product other than haddock four out of the total 17 instances of mislabeling, tied with goosefish. Goosefish and haddock combined made up nearly half of all substitutions. Both species can easily replace other whitefish with similar textures and taste. Unfortunately, the haddock and goosefish substitutions may mean that current estimates set a low bar for how much haddock and goosefish are being removed annually. Much of the haddock was labeled as a product of Norway, but when the wrong label was attached to haddock, discerning the fish's origins became more difficult. The Marine Conservation Society's annual sustainability list rates Norwegian haddock as sustainable (https://www.mcsuk.org/), but more accurate catch size may better determine the health of the stock. Goosefish stocks are currently overfished (NMFS, 1997), and additional, unreported exploitation may be particularly harmful to goosefish due to their slow growth rate and maturity (NOAA, 1999). It is also important to note that the mislabeled Atlantic cod (*Gadus morhua*) may have been mislabeled due to catch restrictions placed on the species by the department of commerce. In 2016 the department of commerce set the total annual catch limit of Atlantic cod to 730 pounds (US Department of Commerce, 2016). Mislabeling this cod as haddock may have been a way to get around the catch limit and sell more fish.

Hake showed most consistently the lowest levels of fish fraud across the species sampled. Of the four samples that successfully amplified and were sequenced for hake, all of them were correctly labeled. The samples of hake included both white (*Urophycis tenuis)* and silver hake (*Merluccius bilinearis*), which do not share the same general label (FDA Seafood List). The IUCN red list notes that populations of silver hake in the US and Canada appear to have stabilized after previous declines and have increased in some areas (Carpenter, 2015). Similarly, a report done by NOAA notes that white hake does not appear to be overfished (Chang *et al*. 1999), but the report notes that there may be an overall decline in the stocks of hake that could become problematic in the future (Sosebee *et al*. 1998).

A couple of strange results should be noted here. First, three instances of mislabeling seem unlikely. Yellowfin tuna being mistakenly labeled as haddock (midcoast fish market #2) seems unlikely given that the product labeled haddock was sold as a fillet at a fish market. Yellowfin tuna and haddock differ greatly in texture and color. Haddock was also mistakenly labeled as salmon (midcoast restaurant #1). This substitution seems even more dubious than the yellowfin replacement, as even the average intelligent seafood consumer could likely tell the two species apart on the plate visually. The salmon replacement can likely be explained by the sequence data. This salmon, restaurant sample had an 84% match and was sequenced for 445 base pairs (Table 1). Finally, monkfish was mistakenly labeled yellowfin tuna. Additionally, there were a total of eight samples of labeled salmon, and only one was successfully amplified, and this salmon sample appeared to be fraudulent. The lack of salmon amplification could be due to the primers used. The primers identified by the Ward study (Ward *et al*. 2005) were used on Australian fish species with great success, but may be less applicable to the salmon samples that were gathered.

A few possible factors could explain why the levels of seafood fraud found were so high and why some substitutions appear to be false. First, the sample size was limited in my study. With only two CSFs operating in the Gulf of Maine, there was not much variety. With only five samples taken from either CSF, it is difficult to determine whether their difference in fraudulence is significant or random. Because there were several species that had unusual matches, I would suggest that fraudulent samples should be re-extracted and sequenced to check species identification.

My initial study shows higher levels of seafood fraud than expected. Future studies should strive to randomize sampling. People who are particularly connected to a region may avoid places that are more likely to be fraudulent, or individuals seeking fraud may target businesses that they believe to be mislabeling. Either scenario may skew rates of seafood fraud. Furthermore, because there were no instances of fraud, future studies looking at the Gulf of Maine should examine more samples of white fish to determine if hake is consistently more accurate than other species. Despite the high rate of mislabeling, CSFs showed lower levels of fraudulence than all other types of markets. However, the results show that, while CSFs had lower levels of fraud, there was no statistical difference between CSFs and other markets. It is difficult to evaluate whether the two different CSFs business models caused their levels of seafood fraudulence to differ, or whether sampling error resulted in different levels of fraud. Additionally, it is difficult to determine whether the two CSFs sampled are representative of CSFs as a whole. My report warrants a broader study into levels of fraud across multiple types of CSFs as well as potential regional differences between CSFs.

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Table 1: Seafood samples that were successfully amplified and sequenced, sorted by the type of market and the location where purchased. The table also includes the percent match on BLAST and the number of nucleotides recovered when sequencing.

Market	Location	Sold as	Identified as	Fraudulent?	Percent Match on BLAST	Length of gene recovered
CSF	NH	Acadian redfish	*Sebastes mentella* (deepwater redfish)	Yes	98%	680
	NH	king whiting	*Merluccius bilinearis* (silver hake)	No	87%	680
	NH	monk fish	*Lophius americanus* (goose or monkfish)	No	100%	677
	NH	haddock	*Melanogrammus aeglefinus* (haddock)	No	100%	679
	NH	dog fish	*Squalus acanthia* (spiny dogfish)	No	98%	680
	Midcoast	haddock	*Melanogrammus aeglefinus* (haddock)	No	98%	635
	Midcoast	hake	*Urophycis tenuis* (white hake)	No	92%	680
	Midcoast	haddock2	*Melanogrammus aeglefinus* (haddock)	No	96%	680
	Midcoast	monkfish	*Melanogrammus aeglefinus* (haddock)	Yes	100%	680
	Midcoast	scallops	*Lophius americanus* (goose or monkfish)	Yes	97%	393
Fish Market	NH	haddock	*Melanogrammus aeglefinus* (haddock)	No	100%	680
	NH	haddock	*Melanogrammus aeglefinus* (haddock)	No	100%	533
	NH	redsnapper	*Melanogrammus aeglefinus* (haddock)	Yes	96%	680
	Portland	haddock	*Lophius americanus* (goose or monkfish)	Yes	98%	669
	Portland	hake	*Urophycis tenuis* (white hake)	No	97%	680
	Portland	redsnapper	*Lutjanus peru* (Pacific red snapper)	No	99%	680
	Midcoast	haddock	*Hippoglossoides platessoides* (American plaice or sole)	Yes	94%	680
	Midcoast	hake	*Urophycis tenuis* (white hake)	No	94%	680
	Midcoast	haddock	*Thunnus albacares* (yellowfin tuna)	Yes	100%	676
Grocery Store	NH	scrod haddock	*Melanogrammus aeglefinus* (haddock)	No	99%	676
	NH	cod	*Lutjanus guttatus* (spotted rose snapper)	Yes	99%	673
	NH	haddock	*Melanogrammus aeglefinus* (haddock)	No	95%	634
	Portland	Monk fish	*Melanogrammus aeglefinus* (haddock)	Yes	100%	680
	Portland	haddock	*Gadus morhua* (Atlantic cod)	Yes	100%	680
	Midcoast	haddock	*Lophius americanus* (goose or monkfish)	Yes	95%	680
	Midcoast	haddock	*Melanogrammus aeglefinus* (haddock)	No	92%	455
Restaurant	NH	tuna	*Thunnus albacares* (yellowfin tuna)	No	100%	675
	NH	haddock	*Gadus macrocephalus* (Pacific cod)	Yes	84%	622
	NH	tuna	*Thunnus obesus* (big eye tuna)	No	95%	680
	Portland	yellowfin tuna	*Thunnus albacares* (yellowfin tuna)	No	99%	680
	Portland	ahi tuna	*Thunnus albacares* (yellowfin tuna)	No	100%	675
	Midcoast	salmon	*Melanogrammus aeglefinus* (haddock)	Yes	84%	445
	Midcoast	haddock	*Melanogrammus aeglefinus* (haddock)	No	99%	436
	Midcoast	haddock	*Melanogrammus aeglefinus* (haddock)	No	92%	455
	Midcoast	yellowfin tuna	*Lophius americanus* (goose or monkfish)	Yes	99%	651
Sushi Restaurant	NH	yellowfin tuna	*Seriola quinqueradiata* (Japanese yellowtail)	Yes	99%	646
	NH	tuna	*Thunnus albacares* (yellowfin tuna)	No	99%	674
	Portland	flounder	*Lophius americanus* (goose or monkfish)	Yes	94%	680
	Portland	tuna	*Thunnus obesus* (big eye tuna)	No	99%	680
	Midcoast	yellowfin tuna	*Thunnus albacares* (yellowfin tuna)	No	100%	678
	Midcoast	tuna	*Seriola quinqueradiata* (Japanese yellowtail)	Yes	99%	680

Table 2: Species that were found to be fraudulently labeled and the actual species purchased.

Sample Code	Sold as	Location	Identified as
N1	Acadian redfish	NH CSF	Sebastes mentella or Sebastes norvegicus
NF4	Redsnapper	NH Fish Market #2	Melanogrammus aeglefinus (haddock)
NG3	Cod	NH Grocery store #2	Lutjanus guttatus (spotted rose snapper)
NR2	Haddock	NH Restaurant #1	Gadus macrocephalus (Pacific cod)
NSU1	Yellowfin tuna	NH Sushi #1	Seriola quinqueradiata (Japanese yellowtail)
PF1	Haddock	Portland Fish Market #1	Lophius americanus (goosefish or monkfish)
PG2	Monkfish	Portland Grocery Store #2	Melanogrammus aeglefinus (haddock)
PG3	Haddock	Portland Grocery Store #2	Gadus morhua (Atlantic cod)
PSU2	Flounder	Portland Sushi #1	Lophius americanus (goosefish or monkfish)
P4	Monkfish	Midcoast CSF	Melanogrammus aeglefinus (haddock)
P5	Scallops	Midcoast CSF	Lophius americanus (goosefish or monkfish)
MF1	Haddock	MidCoast Fish Market #1	Hippoglossoides platessoides (American plaice or sole)
MF3	Haddock	Midcoast Fish Market #2	Thunnus albacares (yellowfin tuna)
MG1	Haddock	Midcoast Grocery Store #1	Lophius americanus (goosefish or monkfish)
MR1	Salmon	Midcoast Restaurant #1	Melanogrammus aeglefinus (haddock)
MR4	Yellowfin tuna	Midcoast Restaurant #2	Lophius americanus (goosefish or monkfish)
MSU4	tuna	Midcoast Sushi #2	Seriola quinqueradiata (Japanese yellowtail)

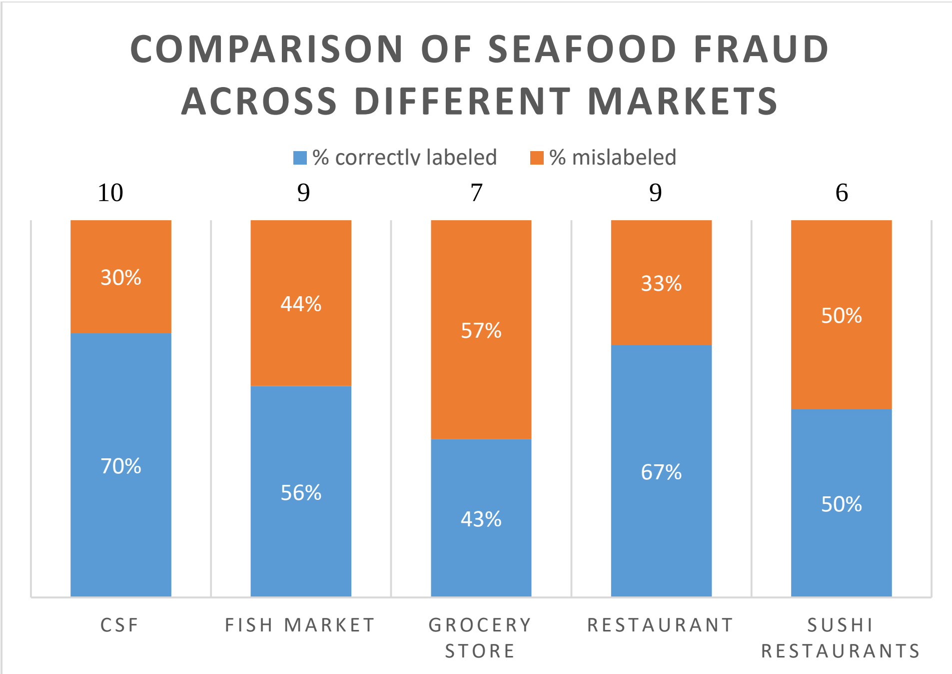

Figure 1: The proportion of fraudulence per market. The sample size is listed above each bar.