AN ABSTRACT OF THE THESIS OF

Laura Ann Geise for the degree of Master of Science in Food Science and Technology presented on September 27, 2007

Title: Evaluation of the Off-Flavor in English Sole (*Parophrys vetulus*) using Descriptive Analysis Techniques and Consumer Testing

Abstract approved:

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Michael T. Morrissey

English sole (*Parophrys vetulus*) is a flatfish found in abundance in the Pacific Ocean and is part of the Pacific Northwest's and California's commercial trawl fishery. Stock levels of this fish are at all time highs but there are decreased landings due to low demand and acceptability. With new regulations in place to protect weak stocks of rockfish, trawl fishermen are looking for opportunities by developing new or underutilized fisheries. The low demand for English sole is due to its small size and an off-flavor that occurs in the fish at various times throughout the year. The purpose of this study was to identify geographical and seasonality effects for off-flavor intensity using a descriptive analysis (DA) panel. A consumer taste test was also run to investigate the potential of English sole to enter the fresh and frozen fillet market by comparing it to a more popular flatfish

Dover sole (*Microstomus pacificus*). The DA panel was used to identify intensity levels of overall aroma, iodine aroma, overall flavor, iodine flavor, and aftertaste from three fishing locations (Astoria, OR; Coos Bay, OR; and Eureka, CA) throughout the year. The DA panel identified seasonality changes in flavor intensities in fish caught off the coast of Eureka, CA with lower values in December and April. Flavor intensity levels were also consistently lower in fish caught off the Eureka, CA coast compared to Astoria and Coos Bay, OR. Samples from Astoria and Coos Bay, OR did not have significant variation of intensity levels in any of the five attributes evaluated. Consumer testing revealed consumers preferred a firmer fish that had a mild or natural fish flavor. Frozen Dover sole was preferred overall and fresh Dover sole was least preferred. There were significant differences in the texture of English sole and Dover sole as well as fresh and frozen fillets. There were no significant differences between the samples in flavor, aftertaste, or aftertaste acceptability. The detection or dislike of any off-flavor in English sole was not identified by the consumer panel. Results indicate the currently underutilized English sole could be a viable addition to fresh and frozen fillet markets.

Evaluation of the Off-flavor in English Sole (*Parophrys vetulus*) using Descriptive Analysis Techniques and Consumer Testing

by
Laura Ann Geise

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorized release of my thesis to any reader upon request.

Laura Ann Geise, Author

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DEDICATION

This thesis is dedicated to anyone who has ever helped me move

Evaluation of the off-flavor in English sole (*Parophrys vetulus*) using descriptive analysis techniques and consumer testing

CHAPTER 1

INTRODUCTION

The United States seafood industry is valued at $65.2 billion of which $32.9 billion comes solely from the marine fishing industry. Although there are general fluctuations in consumption levels for individuals, the U.S. population is increasing its seafood intake, with 16.2 pounds of fish and shellfish consumed per person in the United States in 2005 (NOAA 2007). The marine fishing industry has considerable economic and social implications for coastal communities. Economic contributions from onshore landings in Oregon in 2004 totaled over $254 million, with groundfish contributing $32.1 million (PSMFC 2006b). A change in the biological knowledge and stock assessments of many species of fish have lead to new management efforts limiting the fishing of certain species, and have created declining revenue streams for some communities that rely on ocean fisheries for their source of revenue. In order to compete with growing aquaculture and world fishery markets while at the same time maintaining sustainable fisheries, local fishermen and seafood processors are faced with the need to explore innovative ideas in the marketplace. One potential solution that could help the economic status in these communities is the development of new or under-utilized fisheries.

English sole (*Parophrys vetulus*) is a flatfish that currently has low demand and brings in very little revenue to the Northwest trawl fishermen despite high stock assessments. The

English sole fishery started to decline in the 1960s due to low demand and increased fishing of Dover sole (Lassuy 1989). Low demand for the fish is due to two main factors: small fillets and a metallic off-flavor found in different intensities throughout the year. The research project described in Chapter 3 is based out of the Oregon State University Seafood Laboratory and focuses on identification of intensity levels of this off-flavor throughout the year using a descriptive analysis panel. English sole samples were evaluated from three different landing locations in Oregon and California to determine seasonal and geographical differences in off-flavor. The project outlined in Chapter 4 utilized consumer testing at the Oregon State University Food Innovation Center to identify the ability of English sole to compete in U.S fresh and frozen fillet markets by comparing it with a more popular flatfish Dover sole (*Microstomus pacificus*). Consumer testing identified preferences by consumers for fresh and frozen English and Dover sole based on appearance, texture, flavor, and aftertaste. Results were presented to the Oregon Trawl Commission and the Fishermen's Marketing Association for use by the industry. Ideally, English sole can be developed into a large sustainable fishery for Northwest trawl fishermen and the communities that rely on ocean fisheries for revenue.

CHAPTER 2

LITERATURE REVIEW

2.1 Flatfish Management

Concern over the management and sustainability of our ocean's fisheries has been a topic of increasing interest and concern for the public, government agencies, fishing industry and scientific community. Despite worldwide management efforts, many fish stocks continue to experience major declines (Rice and Cooper 2003). An exception can be found with the Pacific flatfish stocks, where extensive management efforts have resulted in the creation of a sustainable fishery for trawl fishermen (Rice and Cooper 2003) and produced a near record-high abundance of many flatfish species (Trumble 1998). However, while many Pacific flatfish species are found in abundance, other more popular commercial species are fully exploited, particularly Pacific halibut and petrale sole (Trumble 1998). Although Pacific halibut is a flatfish, it is not included in the trawl fishery. Due to the larger size of halibut and the long history of the fishery, longlining is the main commercial gear used and management of the species is overseen by the International Pacific Halibut Commission (IPHC) supervised by both the United States and Canada (Trumble 1998). Other flatfish stock levels, i.e. Dover sole, and management efforts directly influence trawl fishermen whom rely on flatfish and other groundfish for a majority of their income. Trawl fishermen will abstain from fishing the lesser-valued flatfish, such as English sole, to target species of higher value, despite the lower allowable quotas of these fish species (Trumble 1998). Another factor influencing trawl fishermen is a series of recent regulations created to protect weak stocks of rockfish off the shores of Washington, Oregon, and California. These fishery restrictions have forced the industry to look for new fishery resources to supplement their income. In 2004 groundfish and Pacific whiting fisheries contributed over 15% of the total economic contributions for West Coast fisheries (PSMFC 2006b). Although many suggestions have been made to change the management policies currently used all over the world (Pauly and others 2002; Babcock and others 2005; Marasco and others 2005; Branch and others 2006; Rijnsdorp and others 2006; Rijnsdorp and others 2007), the Pacific trawl fisheries are still based on the most common scientifically determined acceptable biological catch (ABC) for commercially important species. Each year the Pacific Fisheries Management Council (PFMC) bases their total allowable catch (TAC) or optimal yield (OY) on the ABC's enforcing the limits bi-monthly. Higher priced, higher demand flatfish are already landed in amounts that equal the set OY (PFMC 2006; PSMFC 2006a), so one option to fill the gap left by restricted stocks of these more popular fish is to make efforts to increase the landings and price of flatfish with higher stock levels and fishing quotas.

In the 1990's, limits placed on rockfish, specifically *Sebastes spp.*, created particular economic strain on trawl fishermen along the U.S. West Coast. Rockfish stock declines were determined to be a result of poor long-term juvenile recruitment caused by adverse oceanographic conditions, as well as from essentially unregulated overfishing of adult fish (Love and others 1998). This created increasingly restrictive management of rockfish resources despite the fact that many species show, with few exceptions, little evidence of long-term declines (Stephens and others 2006). The American Fisheries

Society (AFS) acknowledged the need for conservative and strict management of these species because of naturally slow growth, the overfished state of some of the stocks, and the complex nature of the mixed-stock fisheries (Parker and others 2000). Along with these fishing restrictions, researchers are looking into new habitats for rebuilding the species and new trawl-gear that will lower the by-catch (Perez-Comas and others 1997; Love and others 2006). Despite these efforts, trawl fishermen still need to replace the revenue loss caused by the new fishing restrictions and they are turning to the underutilized flatfish fisheries to do this.

Petrale sole (*Eopsetta jordani*) and Dover sole are two flatfish species that are fully utilized and in high demand. Petrale sole is a highly valued species because of its larger size and delicate flavor and texture. It is the highest priced flatfish caught off the West Coast, ranging from $0.88-1.04 per pound over the past decade (PSMFC 2006a). The average landings for petrale sole are approximately 2,000 metric tons (mt) per year. The economic gain from petrale sole is comparable to that of Dover sole, which lands approximately 7,800 mt per year and has a price range from $0.29-0.38 per pound (PSMFC 2006a). PFMC set the 2006 OY for petrale sole equal to the ABC of that year at 2,762 mt; of which 94% was captured. Dover sole's 2006 ABC was determined to be 8,522 mt with the OY set at 7,564 mt, of which approximately 80% was landed (PFMC 2006; PSMFC 2006a).

English sole (*Parophrys vetulus*) is a flatfish that has potential to be a large sustainable fishery for Northwest trawl fishermen due to the large estimated biomass and essentially unharvested populations. When trawl fishing increased off the West Coast in the 1940s, English sole and petrale sole together consisted of approximately 50% of the flatfish landed (Trumble 1998). However, landings of English sole began to decrease in the 1960s due to the increase in demand and fishing of Dover sole (Lassuy 1989). Today the fishery continues to decline due to low acceptability for the fish, leaving the majority of the species unharvested. Two main factors contributed to the decrease in consumer demand for English sole: the smaller size of the fish, yielding smaller fillets, and a metallic or iodine-like off-flavor found in the fish at various times throughout the year. Currently the ABC and OY for English sole are set at 3,100 mt, and fishermen are landing approximately 34% of that limit (PFMC 2006; PSMFC 2006). The price range for English sole ranges from $0.32-0.34 per pound (PSMFC 2006). The economic impact of English sole is low due to decreased landings and price per pound. The most recent stock assessment from 2006 and early 2007 estimates a large population of English sole that can sustain higher levels of harvesting (Stewart 2007).

2.1.1 English Sole Biological Information

English sole can be found from Baja California to the Bering Sea in both near-shore and off-shore areas. It is smaller than petrale sole and Dover sole, ranging from 47 to 57 cm in length and weighing less than 1 kg (Lassuy 1989). English sole, like other flatfish, is classified as a demersal fish, living on the ocean floor and is often used as an indicator species for the presence and changes in fish food invertebrates (Levings and Ong 2003). English sole is one of few commercial species that relies a great deal on estuarine habitats as nurseries for juvenile growth stages (Rooper and others 2003; Rooper and others 2004;

Brown 2006). Spawning occurs primarily in winter but continues throughout the year. During the late summer and fall the majority of migration occurs when adult English sole leave the estuaries and move onto the continental shelf, where trawl fishermen can capture them and other flatfish on the sandy bottom (Lassuy 1989). Rooper and others (2004) determined that the whole adult population of English sole on the Washington-Oregon shelf could in fact be supported by estuarine production and based on the size of the available nursery area the population appears to be stabilized. This, coupled with evidence of a large and steady increase in the abundance, biomass, and annual recruitment of females (Sampson 1995), makes English sole a fishery that trawl fishermen should consider for a commercially sustainable fishery.

2.2 Seafood Flavor

Flavor is an important attribute of all foods, and is especially important in the seafood industry due to the quick rate of spoilage and development of off-flavors. The flavor of seafood products can have a negative or positive influence on consumer purchasing. The sensory characteristics, including flavor, aroma, and texture, of seafood are often the result of chemical and physical attributes of the muscle. Although the eating quality of fish has been extensively researched, it is often described in terms of nutritional, microbiological, biochemical, and/or physiochemical characteristics alone. Few studies have investigated the relationship of these parameters with quality-sensory perceptions or consumer acceptability information (Nielsen and others 2002). Work done in the late 1980's by Prell and Sawyer (1988) identified the flavor profiles of 17 species of North Atlantic fish. For each fish, aroma and flavor intensity, as well as intensity of character notes and aftertaste were evaluated. A cluster analysis of the results grouped fish into similar and dissimilar species providing a starting base for development of a comprehensive data base of similar species. Such a database could have applications in the seafood industry allowing marketing plans to be based on sensory characteristics of select species. Sawyer and others (1988) continued this research with consumer testing of 18 North Atlantic species. Results showed high correlation between previous trained panel work and the consumer testing especially in prominent attributes. These results indicate the importance of trained and consumer panel testing for principal flavors of seafoods. A consumer taste test administered by Sylvia and others (1995) of 189 participants indicated the preference of "wild-caught" chinook salmon over both farmed chinook and farmed Atlantic salmon. Of the five attributes shown to have significant positive effects on the overall enjoyment of the samples three of them were related to flavor; including "delicate/fresh fish flavor" "flavor intensity" and "sweet flavor". When focusing on the flavor and off-flavors in seafood, an important factor to consider is the sensory impact of intrinsic chemical properties of flavors and off-flavors.

The cause of off-flavors in seafood and fish is often due to compounds found in the water or food chain that can build up in the tissue if exposed to the compound for an extended amount of time. One example is the muddy off-flavor found in pond-raised catfish caused by the buildup of 2-methylisoborneol (MIB) and http://en.wikipedia.org/wiki/IUPAC_nomenclaturegeosmin in fish tissue. It has been shown that this off-flavor is not found in all pond-raised fish or all catfish (Chambers and Robel 1993). The MIB and geosmin compounds are both produced by various species of cyanophytes (blue-green algae) and actinomycetes (bacteria) (Grimm and others 2004). Off-flavors such as these have been a major problem in the aquaculture industry, costing the catfish industry millions of dollars in lost revenue due to decreased value when fish containing off-flavors reach the market. These persistent off-flavors also have potential for jeopardizing future consumer satisfaction and market demand (van der Ploeg 1991). The presence of MIB and geosmin are not exclusive to catfish, an analysis of aroma compounds in rainbow trout (*Oncorhynchus mykiss*) identified 28 volatile compounds. The most powerful off-flavors in the extracts were attributed mainly to MIB and geosmin (Selli and others 2006). Trained sensory panels have been established at channel catfish farms to prevent off-flavored fish from being harvested (van der Ploeg 1991; Dionigi and others 1998; Gautier and others 2002). Despite the increased research and knowledge of these off-flavor compounds problems persist. There is still enough natural variation in the fish that it is difficult to segregate out individuals that have high levels of off-flavors (Dionigi and others 1998).

2.2.1 Marine Flavor and Off-Flavor Compounds

It is well known that marine fish and other seafood have different flavor profiles and characteristics than do fresh water fish. Bromophenol concentration has been determined to be an important flavor compound in marine species, providing sea-, brine-, or iodine-like flavor characteristics that freshwater fish lack. For example, in an analysis of Pacific salmon (*Onchorynchus, spp*.), Boyle and others (1992a) reported that the high bromophenol levels typically present in saltwater salmon were virtually absent in spawning run ocean and prime condition Great Lakes freshwater salmon. Although bromophenols are positive flavor compounds at low concentrations, higher concentrations can produce iodoform- or iodine- like flavors that are generally considered to have negative attributes (Boyle and others 1992a). Landings of shrimp from the North Atlantic and prawns from Australia occasionally have an intense iodoform- or iodine-like flavor making them unacceptable to certain consumers (Whitfield and others 1988; Anthoni and others 1990). Samples from both locations showed high levels of bromophenols. Boyle and others (1992b) further evaluated the flavor properties of several volatile bromophenols at different concentrations in various mediums to uncover specific flavor characteristics of each compound. In fish muscle tissue 2,6-dibromophenol (2,6-DBP) and 2,4,6-tribromophenol (2,4,6-TBP) were associated with iodine-, shrimp-, crab-, and sea salt- like flavors; whereas monobromophenols enhanced sweet, overall seafood-like flavors. These samples contained only one isomer, but informal evaluations showed considerable flavor interactions when more than one isomer was present, which reflects a more natural marine environment (Boyle and others 1992b).

In the case of the Australian caught prawns, the off-flavor was the result of high levels of 2,6-DBP concentrated in the head of the prawn where the stomach is located. Some samples exceeded 200 µg/kg of 2,6-DBP in whole prawns. This compound is detectable by sensory evaluation in prawn meat at levels as low as 0.06 µg/kg and presented a negative iodoform-like flavor at concentrations greater than 32 µg/kg (Whitfield and others 1988). North Atlantic shrimp with a related off-flavor also contained 2,6-DBP in high concentrations (120-250 µg/kg), mostly found in the head. A 2,4-dibromophenol (2,4-DBP) was also identified at high levels (~40 µg/kg) (Anthoni and others 1990).

Similar off-flavors have been detected in the flesh of the saltwater fish luderick (*Girella tricuspidata*), which is fished commercially and recreationally along the east coast of Australia. Identification of 2,6-DBP at levels near the threshold (0.04 μg/kg) were discovered in fresh fish, and increased in concentration in the flesh during a 56-day storage of the whole fish at -20°C. This resulted in 2,6-DBP levels above the detectable threshold levels, at 0.3 μg/kg, but still below the level causing an off-flavor (Whitfield and others 1994). These results indicate the need for immediate processing of seafoods prone to accumulation of select bromophenols in the flesh. It has also been noted that autolytic and biochemical processes in seafood tissue can greatly diminish flavor quality, demonstrating the need for quick processing to reduce any other off-flavors that may develop (Lindsey 1991).

Bromated compounds are found abundantly in seafood and marine fish, but do not always result in negative off-flavors. Crustaceans (Dungeness crab, king crab, snow, crab, blue crab, shrimp), mollusks (squid, West Coast oysters and butter clams, East Coast blue point oysters and littleneck clams), marine fish (pickled herring, European brine-cured herring, Icelandic haddock), and unrefined sea salt all contained 2,4,6-TBP, with crab samples containing the highest levels of all tested bromophenols which may contribute to their briny flavors (Boyle and others 1992b). There are considerable flavor interactions when more than one bromophenol isomer is present, which is the case in most marine-derived seafoods (Boyle and others 1992b), so the magnitude of total bromophenol content (TBC) is often used in the literature to describe the total flavor impact of all present bromophenols (Chung and others 2003b). Chung and others (2003b) tested for seasonal variations of bromophenol content in seafood important in the Hong Kong seafood market including: rabbitfish, brown-spotted grouper, clams, oysters, shrimp, and crab. As with Boyle's results, crab in this study also contained the highest TBC, although all marine-based samples contain bromophenols throughout the year. Large seasonal variations were documented, indicating that environmental factors might influence the TBC in seafoods (Chung and others 2003b).

Since seasonal variations have an effect on TBC in marine seafoods, environmental and dietary factors were investigated as sources of bromophenols. Research suggests that the diet of marine species may be the source of bromophenols, and excess accumulations of the compounds are the result of slow metabolism or excretion causing higher concentrations (Anthoni and others 1990). In the case of the luderick fish (*Girella tricuspidata*), the diet consists mainly of green algae (Chlorophyta) and red algae (Rhodophyta). These algae showed concentrations of 2-bromophenol, and 2,4-DBP, and 2,6-DBP that were similar to those found in samples of the fish gut (Whitfield and others 1994). Whitfield and others (1995) studied the bromophenol content of carcasses and guts of ten species of fish found on the east coast of Australia, discovering specific bromophenols were found in the carcass only when they were present in the gut. Most samples were found to contain specific bromophenol compounds in the carcass when they were detected in the gut at concentrations greater then 5 ng/g.

Chung and others (2003a) reported a direct correlation between bromophenols in the environment and in seafood, when seasonal differences in common seafoods from Hong

Kong were related to the seasonal growth of bromophenol-synthesizing seaweeds, i.e. brown algae, in the area. These samples of brown algae (*Padina arborescens*, *Sargassum siliquastrum*, and *Lobophora variegate*) from Hong Kong waters had higher TBC levels in winter and lower levels in the summer, mainly due to the large concentration of 2,4,6-TBP and its seasonal fluctuation. These results indicate that environmental factors, such as temperature, may influence the biosynthesis of bromophenols by the marine algae (Chung 2003a; Chung 2003b). The presence of bromophenols is due to bromoperoxidases, which are responsible for brominating organic substrates in the presence of bromide ion and hydrogen peroxide (Flodin and Whitfield 1999b). The type of bromophenol produced by plants has been reported to vary with geographic location. One example of a bromophenol-producing plant is the green marine alga *Ulva lactuca*, which is found in Australian waters. Bromoperoxidases in *Ulva lactuca* can convert phenol, 4-hydroxybenzoic acid, and 4-hydroxybenzyl alcohol to bromophenols (Flodin and Whitfield 1999a). As identified in the algae from waters around Hong Kong, *Ulva lactuca* also exhibits seasonal variations of TBC, with higher concentrations in January through the end of May (as measured over the period of Jan-Aug 1997), after which point concentrations drastically decreased (Flodin and others 1999). Flodin and Whitfield (1999b) continued this study through May of 1998 in monthly intervals, identifying the levels of 2-, 4-bromophenols, 2,4-DBP, 2,6-DBP, and 2,4,6-TBP over a period of 18 months. 2,4,6-TBP was the most abundant compound throughout the year, showing extreme seasonal variations with the highest concentrations in the late Australian summer of 1997 and lower concentrations the rest of the year. There was a difference of 2,4,6-TBP content between the summer of 1997 and 1998, in 1998 high concentrations of

2,4,6-TBP were only observed in February for a short period. Other bromophenols were always low, with no seasonal trend (Flodin and Whitfield 1999b). The high bromophenol levels reported during the Hong Kong winter and the Australian late summer indicate that temperature levels between ~17-23°C may be optimal for the biosynthesis of bromophenols in the species of algae studied (Chung and others 2003a).

Species of marine polychaetes and bryozoans found in Eastern Australian waters have also been shown to be a major source of bromophenols in the diets of the Australian prawns containing iodoform- and iodine-like off-flavors (Whitfield and others 1997). Testing of 16 species of polychaetes and 10 species of bryozoans from those locations showed a variation in bromophenol content. Analysis of the samples revealed higher levels of bromophenols in the polychaetes from locations with significant mud content compared to those animals from beach sand or shell grit (Whitfield and others 1999). Whitfield and others (1999) concluded that outbreaks of iodine-like off-flavors in these species of prawns or fish may be the result of the animal primarily feeding on polychaetes of high bromophenol content.

Knowing the impact that bromophenols have on the flavor of wild-caught seafoods, the addition of bromophenols to aquacultured feed has been investigated. Analytical and sensory data showed there is a major difference in the concentration and perceived flavor of wild-harvested and cultivated prawns from Australia (Whitfield and others 1997). However, attempts to increase the TBC of cultivated shrimp using feed with either freeze-dried polychaete or freeze-dried algae were ineffective for unknown reasons. The use of shrimp head meal (TBC >800ng/g) increased cultivated prawn's TBC when given the feed for 8-weeks at an addition rate of 15% (Whitfield and others 2002). The same TBC increase was found when aquacultured seabream (*Sparus sarba*) was fed marine algae-enhanced fish feed (30% *Saragassum siliquastrum*, 70% traditional feed powder) for 8-weeks. Sensory evaluations also showed a significant difference between the seabream fed the enriched feed (TBC= 340 ng/g) as opposed to the traditional feed (TBC= 8.9 ng/g) (Ma and others 2005). This type of feed could be beneficial to the aquaculture industry by providing the desirable sea salt-, seafood-, fish-like flavor in cultured fish and prawns while using a by-product of prawns containing off-flavors from high concentrations of bromophenols.

2.3 Sensory Evaluation of Seafood

Sensory evaluation of seafood began as a simple way to grade the quality of a product and has evolved scientifically to be used as a research tool to evaluate off-flavors, quality, consumer acceptability of specific attributes and other themes. The primary function of sensory testing is to perform valid and reliable tests which will provide sound decision-making data for the industry (Meilgaard and others 1999). Sensory evaluation is used for more than just food products, indicating the value of using human subjects as instruments in many fields. There are two main types of sensory evaluation: consumer and descriptive analysis. Consumer testing involves large groups of individuals (>50) that may or may not be familiar with the product. Large consumer groups will give valuable information for product preference, purchase intent, and in some cases how much they liked/disliked a specific attribute. Descriptive analysis (DA) panels involve a smaller number of individuals (8-12), and involve the detection and description of both the qualitative and quantitative sensory aspects of a product. The qualitative aspect includes the identification of the characteristics found in a specific product; whereas the quantitative aspect involves the intensity of which these characteristics are present in the product.

Forming a DA panel usually begins with several training sessions. Training of a DA panel has been shown to have a significant impact on performance, and panel training time can be reduced by monitoring panel performance during training and discontinuing when performance is acceptable (Labbe and others 2004). Panelists can be evaluated individually or as a whole group on the acceptability of their performance. The individual assessor may experience three main types of errors that can be identified with statistical analysis of the responses of panelists during training and evaluations. These errors are: location error, in which the panelist uses a different scale location; sensitivity error, meaning that a panelist cannot discriminate between products; and reproducibility error, in which a panelist's answers are not consistent over time. A sensory panel group error is usually defined by one assessor differing from the rest of the panel on one of four areas. Using a broader or narrower range on the scale is a magnitude error; rating products in the opposite direction of the other panelists is a crossover error; rating all samples as the same is the non-discriminator error; and scoring the attribute as "0" over all the products is a non-perceiver error (Kermit and Lengard 2006). These types of errors can be avoided by close attention to panel performance statistics and a readiness to dispense additional training, individual or group, as needed. A new method involving immediate computerized feedback known as the feedback calibration method (FCM) might reduce panelist errors and training time (Findlay and others 2007). The selection and implementation of a quantitative frame of reference can also reduce panel variability, since all panelists will have a common scale and reference point to use in evaluations (Munoz and Civille 1998). The product and attribute evaluated will have an influence on the type quantitative reference selected, but the more common references used are universal, product/attribute specific, or non-product/attribute specific.

Because of the small number of people required for a DA panel, implementation can be done in a research facility or in-house at a processing plant. To this effect, DA panels play an important onsite role in the catfish aquaculture industry. Many processors rely solely on a DA panel for the detection off-flavors caused by MIB and geosmin before harvesting the catfish. Sampling of the catfish differs between processing plants but generally starts 1-2 weeks before harvesting and each panelist will eventually sample between 3-12 fish from each pond depending on the size of the ponds and the processors (Gautier and others 2002). A gas chromatography/mass spectrometry instrumental evaluation of the off-flavors was compared to sensory evaluation to identify similarities between the two methods. Only recently have instrumental techniques provided the increased sensitivity needed to detect these compounds in the small quantities that are present in off-flavored fish samples. The correlation for sensory and instrumental evaluation in this study was high (R^2=0.9) indicating the accuracy of the trained sensory panels in this application (Grimm and others 2004). DA panel evaluation in this case is more cost effective since the instrumentation required for this off-flavor detection is expensive and requires technically trained operators. A similar study was performed by Olafsdottir and others (2004), in which the results of sensory tests were related to the results of physico-chemical analysis of fish quality. The study used the quality index method (QIM) for sensory evaluation, which is commonly used in Europe as a sensory-based objective tool for determination of quality (Hyldig and Green-Petersen 2004). The sensory and instrumental techniques used in this study were all essentially non-destructive. The instrumental multisensor approach used visible light spectroscopy, electrical properties, image analysis, color, electronic noses, and texture. By combining sensory scores to instrumental output the authors developed an Artificial Quality Index (AQI) that can be as accurate and precise as the QIM scores. The same limitations with costly equipment and technician training were encountered in this study as with the catfish study: making implementation into the industry impractical (Olafsdottir and others 2004).

Although sensory panels can be very accurate, limitations of sensory evaluation need to be seriously considered before a panel is put into operation, especially in large companies such as the channel catfish aquaculture processing plants. Some limitations that have been evaluated by Bett and Dionigi (1997) are: the type of sensory method chosen, variations or lack of descriptive terminology, sample preparation techniques, sensory test environments, human challenges and fatigue, and amount and time of sampling. These are all important details that need to be investigated before an in-house DA panel operation can be incorporated as a working system.

Training a DA panel can be expensive and time consuming; however, once the panel is trained it can produce a large amount of data. Chambers and Robel (1993) used a DA panel to determine the flavor and texture profiles of freshwater fish found in retail distribution, ultimately showing their flavor distinction from marine animals with distinguishing character notes such as a white meat character and less saltiness. This technique can be used for the same species from different locations and seasons. For example, a study was completed for evaluating changes in sensory properties of marinated herring (*Clupea harengus*) from different fishing grounds and seasons. The first training sessions were used to develop the lexicon of the fish and the rest of the training and retraining throughout the year focused on the qualitative analysis of these attributes (Nielsen and others 2004). Using a trained panel for the quantitative and qualitative analysis of seafood can also be helpful in the determination of specific compounds that are causing flavors or off-flavors. A DA panel evaluation of jumbo squid (*Dosidicus gigas*) was used to define the off-flavor and the intensity levels found in the squid. Compounds were then extracted with HPLC, allowing the sensory panel to evaluate actual chromatography peaks to determine specific compounds causing sour and bitter off-flavors in the squid (Sanchez-Brambila and others 2004).

Consumer testing is a useful tool in many different fields for development of new ideas and to refine existing ones. The input from actual consumers or targeted consumers is a valuable tool when developing or changing a product. One use of consumer testing in the seafood industry is to compare the consumer acceptance of different species to other more popular species for use as an alternative source. Problems with the ability of rainbow trout (*Salmo gairdneri*) to survive in adverse environmental conditions limited the industry from fully utilizing aquaculture for this species. Research indicated brown trout (*Salmo trutta*) might be a viable alternative due to survival and growth rates despite harsh conditions. Consumer testing was performed to determine if brown trout could serve as an alternative to rainbow trout in the seafood marketplace. One hundred and four families completed in-home consumer taste tests of three sets of both species of fish to be prepared each in three types of cooking instructions: pan-frying, oven-baking or barbequing, or microwave cooking. A home use test is considered the ultimate in consumer testing because the product is tested as it is intended to be used instead of in a sensory booth at the research facility. Results indicated brown trout would be acceptable to consumers and preference related back to pond of origin rather than species of fish (Rounds and others 1992). This type of consumer testing can help the industry in determining good alternatives for products that are not able to reach their full potential because of various circumstances.

Combining DA and consumer panel data can be helpful in determining what sensory attributes are important for consumption and non-consumption of different species of fish, not just how much consumers liked new fish products (Sawyer and others 1988). Research by Wesson and others (1979) used combined DA panel and consumer testing to determine the ability of people to recognize moderate and extreme quality differences. This was done using many different types and styles of seafood, including battered and breaded fish portions. The results from this study gave the industry an understanding of consumer quality discrimination abilities for future reference in fish product development and marketing.

Since aquaculture fish have become an important industry, many researchers are using sensory evaluations to determine differences in wild versus farm-raised fish. A study evaluating the quality characteristics and consumer acceptability of farmed and wild Atlantic salmon from locations around Northern Ireland also used the combined sensory methods to determine sensory differences in these fish. The DA panel (n=10) used quantitative analysis to compare specific attributes of farmed and wild salmon, while an untrained consumer panel (n=40) evaluated the acceptability of the fish in terms of appearance, odor, flavor, and texture. The DA panel results showed that sea-caught and farmed Atlantic salmon varied little in odor and flavor attributes, and most of the differences were due to texture variations. Despite these slight variations, the consumer panel found farmed salmon was at least as acceptable as sea-caught in every attribute evaluated (Farmer and others 2000). Slight variations detected by the DA panel were still acceptable to the consumers, thus providing valuable information to the industry for comparable products. A study by Sylvia et al showed consumers could differentiate between wild Chinook salmon, farmed Chinook salmon, and farmed Atlantic salmon from the West Coast of the United States in a consumer test (n=189) comparing eleven sensory attributes to overall enjoyment of salmon (Sylvia and others 1995). These results were positive for the Pacific ocean-caught salmon fisheries for distinction in the marketplace. The contradicting results of these two studies indicate there may be detectable sensory differences in fish from different areas.

Another study evaluated performance of aquacultured yellow perch against wild-caught market competitors, which included several different species (wild-caught walleye, ocean perch, and zander) (Delwiche and others 2006). The results showed the ability of an aquacultured fish to compete in the market with many types of fish, not just the wild-caught version already available on the market.

When choosing participants for a consumer test an important factor to consider is the level of consumer knowledge regarding the product. A study separating expert chefs and consumers was performed for U.S domestic shrimp vs. imported shrimp to differentiate quality attributes between the two sample sets. This test was set up with four panels representing two groups and two cooking methods. Results from the consumer panels rated imported shrimp higher than domestic shrimp whereas chef panels rated the domestic shrimp higher with strong correlations between overall ratings of shrimp and flavor ratings (Condrasky and others 2005). This data can be used to reintroduce domestic shrimp to consumers as a high quality, chef-praised product possibly increasing value over the imported shrimp with which consumers are familiar with.

2.4 Conclusions

English sole has been identified as an underutilized fish for West Coast fisheries. Stock assessments show there is potential for increased harvesting if new ideas for utilization and consumer acceptability of the off-flavor can be established. Off-flavors in English sole may be the result of accumulation of bromophenols in the tissue caused by environmental factors and diet. Research on several different species has shown seasonal variation of off-flavors that are caused by excess bromophenols. This study will identify seasonal and geographical effects on the off-flavor in English sole using a DA panel.

Consumer testing will determine consumer acceptability of English sole compared to Dover sole. The effects of freezing on acceptability of fillets will also be determined using consumer testing. Evaluation of an underutilized fish like English sole by a DA panel and consumer testing could help the industry to determine off-flavor intensities and enhance its ability to compete in domestic and foreign markets. Determination of English sole's viability in the marketplace using sensory evaluations will aid fishermen and processors alike in possible utilization of this essentially unharvested species.

CHAPTER 3

EVALUATION OF THE OFF-FLAVOR IN ENGLISH SOLE (*PAROPHRYS VETULUS*) USING DESCRIPTIVE ANALYSIS TECHNIQUES

3.1 Abstract

English sole (*Parophrys vetulus*) is an underutilized flatfish found in the Pacific Ocean from Baja California to the Bering Sea and inhabits both near-shore and off-shore areas. With new regulations in place that limit harvesting of traditional trawl fish such as rockfish, English sole has become more important to fishermen in the Pacific Northwest and California. A strong off-flavor, described as an iodine flavor is noted in the fish at various times throughout the year, which decreases its value and the demand for fillets. The purpose of this study was to investigate the relationship between this off-flavor and two factors: geographic catch location and seasonality. Knowledge of how these variables affect the off-flavor could help to improve the commercial importance and marketing of English sole. A descriptive analysis (DA) sensory panel was used to identify intensity levels of overall aroma, iodine aroma, overall flavor, iodine flavor, and aftertaste from three fishing locations (Astoria, OR; Coos Bay, OR; and Eureka, CA) throughout the year. Evaluations occurred during August, October, and December 2006, and February and April 2007. A statistical analysis of DA panel results showed English sole caught off the Eureka coast significantly changed in intensity scores within the area over time with lower values in Dec. and Apr. compared to Aug. and Feb. (ANOVA, Tukey's HSD $p \leq 0.05$). Intensity levels are consistently lower in Eureka-caught English sole than in English sole from other locations (ANOVA, Tukey's HSD $p \leq 0.05$).

Samples from Astoria and Coos Bay did not have significant variation in the intensity levels for any of the five attributes. Astoria-caught English sole had significantly higher percent lipids than the other locations. Moisture percentages did not vary between locations and fluctuated slightly over the sample period. Due to the presence of the off-flavor throughout the year, no recommendations for changes in fishing location or season were identified.

3.2 Introduction

New fishing regulations have been implemented for trawl fishermen to protect weak stocks of rockfish off the shores of Washington, Oregon, and California. This has forced the industry to look for new or underutilized fishery resources. Good management of Pacific flatfish stocks have created a sustainable fishery (Rice and Cooper 2003), and produced a near record-high abundance of many flatfish species (Trumble 1998). Despite large populations of some flatfish, others that are higher in price and demand, (i.e. petrale and Dover sole), are already landed in amounts that equal the scientifically determined acceptable biological catch (ABC) and optimum yield (OY) set by the Pacific Fisheries Management Council (PFMC 2006; PSMFC 2006). One way to improve income levels of trawl fishermen are to increase total landings and price of a fish that is currently underutilized. English sole (*Parophrys vetulus*) is a species of flatfish that is abundant along the Pacific coast, yet has landings well below the set OY. In 2006 the actual harvest of English sole was only 34% of the OY with just over 1,000 metric tons (mt) landed (PSMFC 2006). The most recent stock assessment from 2006 and early 2007 shows that English sole is abundant off the West Coast and can be harvested at higher levels (Stewart 2007). Two factors affecting demand and acceptability of English sole are off-flavors and small fillets. This study used a sensory science-based approach to evaluate intensities of these off-flavors throughout the year in fish from several geographical locations. If the cause of this off-flavor can be associated with a physical or temporal characteristic then a harvesting/marketing program could be created to focus fishing and sales efforts during a time or place at which the off-flavor is minimal.

English sole is a flatfish that can be found from Baja California to the Bering Sea in both near-shore and off-shore areas. It is slightly smaller than some more popular flatfish, like petrale and Dover sole, ranging from 47 to 57 cm in length and weighing less than 1 kg (Lassuy 1989). English sole is classified as a demersal fish, which is a bottom-dwelling species that is often in contact with the seafloor (Levings and Ong 2003). It is one of the few commercial species that relies on estuarine habitats as nurseries for juvenile growth stages (Rooper and others 2003; Rooper and others 2004; Brown 2006). Adult English sole migrate from the estuaries and onto the continental shelf, where they are harvested along with other flatfish on the sandy bottom by trawl fishermen. Landings of English sole began to decrease in the 1960s due to increase in demand and fishing of the more popular Dover sole (Lassuy 1989). Today the fishery continues to decline due to low acceptability and demand for the fish.

The prominent off-flavor, which is described as metallic or iodine-like, is found in English sole in varying intensities throughout the year. Off-flavors in seafood are often associated with deterioration in quality due to microbial growth and metabolism, resulting in formation of amines, sulfides, alcohols, aldehydes, ketones, and organic acids (Gram and Dalgaard 2002). However, in the case of English sole, the off-flavor is detected in the fresh fish as an aroma, flavor, and aftertaste, indicating that it is not associated with typical flavor problems related to seafood decomposition.

The iodine-like off-flavor found in the English sole has been noted in many different types of seafood and has been correlated to an excess of bromophenol compounds in the flesh. Boyle and others (1992b) determined that the distribution of bromophenols in marine fish was widespread, although not always at levels high enough to create negative iodine off-flavor such as the one noted in North Atlantic shrimp (Anthoni and others 1990) or Australian prawns (Whitfield and others 1992). Specifically, the presence of 2- and 4-bromophenol, 2,4- and 2,6-dibromophenol have been identified to cause the iodine-like off-flavor in these species. The more potent compounds 2,6-dibromophenol and 2,4,6-tribromophenol have been shown to have sensory threshold levels as low as 0.06 ng/g (Whitfield and others 1988).

The focus of this project is to evaluate the off-flavor that exists in English sole throughout the year using descriptive sensory analysis techniques. The project design was developed to determine if intensity level of this iodine characteristic could be correlated to fishing location, seasonality, or composition of fish. If correlations are found to exist, different fishing regimes could be established to improve marketability of English sole.

3.3 Materials and Methods

3.3.1 ENGLISH SOLE SAMPLING

English sole samples were harvested at three different locations off the coast of the Western United States from June 2006 to June 2007. The three sampling locations were Astoria (AST) and Coos Bay (CSB), Oregon, and Eureka (EUR), California. Samples were trawl-caught and stored in ice at sea for no more than two days. Once unloaded, the fish were immediately filleted and 5 pounds were shipped in ice to the Oregon State University Seafood Laboratory (OSU-SFL) in Astoria, OR. Upon arrival, samples were kept in ice at 4°C for no more than three days until further analysis could be completed. Fillets were separated into two groups, one for laboratory analysis and one for sensory evaluation. Samples from different locations were all caught within 10 days of each other for each time point in the study. A set of control samples was caught off the coast of Astoria on July 5, 2006. The fish were landed 1-day later, immediately filleted, and 25 lbs were transported on ice to the OSU-SFL where individual fillets were vacuum sealed and stored at -80°C.

3.3.2 Descriptive Analysis Panel Training

A descriptive analysis (DA) panel cutting was held in January 2006 to determine aroma, flavor, and aftertaste descriptors of English sole. This cutting session had 5 participants consisting of members of the community in Corvallis, OR and employees of Oregon State University Department of Food Science and Technology (OSU-FST). All participants were familiar with the descriptive analysis process, and had all participated in previous trained panels for OSU-FST. Petrale sole, which does not have an iodine off-flavor, was compared to English sole in order to identify and describe the off-flavor attribute found in English sole. The off-flavor attribute was described as an iodine aroma, iodine flavor, and an iodine flavor aftertaste. These descriptors were used throughout the remainder of the study. This cutting also determined that the fillets could not be ground together to eliminate variability in the samples because important volatile aromas were lost in the process.

A 10-member DA panel was selected from respondents at the OSU-SFL and surrounding community (Astoria, OR). Panelists were selected based on their ability to distinguish specific sensory characteristics found in English sole, and their ability to describe those characteristics verbally and use scaling methods for differences in intensities. DA panel training began in July 2006 and was completed as described by Meilgaard and others (1999). Panelists were introduced to a 16-point intensity scale with 0=none, 3=slight, 5=slight to moderate, 7=moderate, 9= moderate to large, 13= large to extreme, and 15=extreme. All samples, including control samples, were evaluated on this scale for 5 attributes: overall aroma (OA), iodine aroma (IA), overall flavor (OF), iodine flavor (IF), and aftertaste (AT) of the iodine flavor. Initial training was carried out over 3 one-hour sessions. Subsequent training took place as needed throughout the year.

A set of control samples was established for panelist reference and verification of panel performance though blind control testing. Intensity levels for this set of fish were established during the first training sessions on thawed fillets to mimic preparation of the control in later testing. The control was reanalyzed throughout the year at subsequent training sessions.

3.3.3 DESCRIPTIVE ANALYSIS PANEL EVALUATION

Do to the small size of the English sole fillets; all panelists could not evaluate the same fish, so each set of samples represents a specific population of fish harvested from one of three locations (AST, CSB, or EUR) at specific time periods during 2006-07. Samples were evaluated fresh and the frozen control samples were defrosted in cold water prior to preparation. Fillets were placed on a tray, covered with foil and baked at 175°C for 20 minutes in a conventional oven. During testing each panelist was presented with ~25 grams of each of the following: 3 replicate samples of the same fillet, a blind control, and a labeled control. The samples were presented in 8-ounce wine glasses with lids and labeled with a random 3-digit code. Order of presentation was balanced over all panelists. All samples were served at room temperature. Panelists were compensated $10 at the completion of each evaluation.

3.3.4 Laboratory Analysis

All laboratory analyses were carried out in triplicate. Sample fillets were prepared by blending for 1-minute on high. Lipids were determined using the AOAC Official Method 948.15 (Crude Fat in Seafood Acid Hydrolysis method, 1995). Moisture content was carried out according to the AOAC Official Method 950.46 B (Convection, Gravity method, 1995) by measuring the mass of a sample before and after drying overnight in an oven.

3.3.5 Statistical Analysis:

Statistical analysis of DA panel results was completed using SPSS 14.0 for Windows software, with a predetermined significance level set at $p<0.05$. A general linear model univariate analysis using a Type III sum of squares (error) was completed for each attribute as dependant variables and location*month, month, and location as fixed factors. Tukey's HSD post hoc test was performed on all significant data. Principle component analysis was completed using Kaiser Normalization rotation method.

3.4 Results and Discussion

3.4.1 DESCRIPTIVE ANALYSIS PANEL

Table 3.1 shows results from an overall analysis of all samples representing a separate variable. The only significant differences were found in OF with EUR APR (5.75) and EUR DEC (5.88) having the lowest values, and AST APR (7.48) and AST FEB (8.00) having the highest values. IF and AT also had variation in the samples, but due to panelist variabitlity results cannot be reported as significant. IF had lower values in EUR DEC (4.58) and higher values in CSB AUG (7.11). The same was true for AT values with the lowest levels in EUR DEC (2.75) and the highest levels in CSB AUG (5.50). This indicates there may be a relationship between the IF and AT of the samples. A principal component analysis (PCA) extracted two components that represent the variability in the model. PC1 consisted of OF, IF, and AT (r=0.49); and OA and IA were related (PC2, r=0.25). The separation between the three flavor attributes and the two aroma attributes in the PCA suggest the chemical compound causing the iodine-like off-flavor and aftertaste is different, or perceived differently than the compound causing any off-aromas in the samples.

Table 3.1. Intensity levels in all English sole samples as evaluated by DA panel

Sample[1,2]	OA[NS]	IA[NS]	OF[**]	IF[NS]	AT[NS]
AST AUG	8.13	4.13	6.38[ab]	4.94	3.69
CSB AUG	9.67	4.56	6.83[abc]	7.11	5.50
EUR AUG	9.11	4.33	6.89[abc]	6.28	4.83
AST OCT	9.37	5.13	7.47[bc]	6.83	3.20
CSB OCT	8.60	3.77	7.00[abc]	5.80	4.30
AST DEC	8.58	3.83	7.33[bc]	6.46	4.42
CSB DEC	8.33	4.33	7.25[bc]	6.04	4.13
EUR DEC	9.21	3.33	5.88[a]	4.58	2.75
AST FEB	9.63	4.56	8.00[c]	6.74	5.15
CSB FEB	9.30	4.67	7.00[abc]	6.04	4.33
EUR FEB	9.04	4.23	7.38[bc]	6.38	4.46
AST APR	8.48	4.26	7.48[bc]	6.89	4.81
CSB APR	9.10	4.19	6.38[ab]	5.19	3.62
EUR APR	8.08	3.17	5.75[a]	5.04	3.42

[1] NS= not significant
[2] *, **, *** treatment is significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively
[abc]Means in the same column with different superscript letters are significantly different from one another at TUKEY'S HSD 5%

An analysis of seasonality differences within separate geographical locations showed that there was no significant difference in any of the five attributes for samples from AST or CSB. EUR samples showed a significant difference in OF and AT. OF was significantly lower in the samples during APR (5.57) and DEC (5.88) than in AUG (6.89) or FEB (7.38). AT was significantly lower in APR (3.42) than in AUG (4.83), and it was also significantly lower in intensity in DEC (2.75) than in AUG or FEB (4.46) (Table 3.2). Intensity levels of IA and IF were also lower in DEC and APR, but results were not significant.

Table 3.2. Seasonality differences in English sole intensity levels within Eureka, CA caught English sole as evaluated by DA panel

Month[1,2]	OA[NS]	IA[NS]	OF[**]	IF[NS]	AT[*]
AUG	9.11	4.33	6.89[b]	6.28	4.83[c]
DEC	9.21	3.33	5.88[a]	4.58	2.75[a]
FEB	9.04	4.23	7.38[b]	6.38	4.46[bc]
APR	8.08	3.17	5.75[a]	5.04	3.42[ab]

[1] NS= not significant
[2] *, **, *** treatment is significant at p≤0.05, p≤0.01, and p≤0.001, respectively
[abc]Means in the same column with different superscript letters are significantly different from one another at TUKEY'S HSD 5%

Table 3.3 shows seasonality differences by month for all locations. An ANOVA revealed no significant differences for OA, IA, IF, and AT, but OF values were significantly lower in APR (6.58) samples than in FEB (7.46).

Table 3.3. Seasonality differences in English sole intensity levels for all geographical locations as evaluated by DA panel

Month[1,2]	OA[NS]	IA[NS]	OF[*]	IF[NS]	AT[NS]
AUG	9.00	4.35	6.71[ab]	6.15	4.71
OCT[*]	8.98	4.45	7.23[ab]	6.32	3.75
DEC	9.04	3.83	6.82[ab]	5.69	3.76
FEB	9.33	4.49	7.46[b]	6.39	4.65
APR	8.53	3.88	6.58[a]	5.78	4.00

[1] NS= not significant
[2] *, **, *** treatment is significant at p≤0.05, p≤0.01, and p≤0.001, respectively
[abc]Means in the same column with different superscript letters are significantly different from one another at TUKEY'S HSD 5%

An ANOVA comparing differences in attributes based on geographical location for all months combined showed considerable variation (Table 3.4). Although OA and AT showed no significant changes between locations, EUR caught English sole had significantly lower intensity levels for IA with a mean value of 3.74 compared to AST (4.44) and CSB (4.28). OF values of fish caught in EUR (6.47) were significantly lower than fish caught in AST (7.42). IF intensity levels in EUR (5.54) were also significantly lower than values from AST (6.51).

Table 3.4. Geographical differences in English sole intensity levels over all seasons as evaluated by DA panel

Location[1,2]	OA[NS]	IA[*]	OF[***]	IF[**]	AT[NS]
AST	8.92	4.44[b]	7.42[b]	6.51[b]	4.27
CSB	9.15	4.28[b]	6.92[ab]	5.99[ab]	4.33
EUR	8.85	3.74[a]	6.47[a]	5.54[a]	3.82

[1] NS= not significant
[2] *, **, *** treatment is significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively
[abc]Means in the same column with different superscript letters are significantly different from one another at TUKEY'S HSD 5%

Conclusions from DA panel results showed EUR English sole samples were the only samples that changed in intensity within a geographical location over time with lower OF and AT values in DEC and APR. EUR samples were also consistently lower in intensity overall and significantly lower in IA, OF, and IF. Since flavor has been shown to be one of the most important factors determining consumer acceptance of fish (Sawyer and others 1988), the lower intensity levels in EUR samples could indicate a higher acceptability of English sole caught in the Eureka area as opposed to farther north.

For all geographical locations, APR and DEC samples were lower in most attributes and APR samples showed significantly lower OF values. Seasonality differences have been identified in other marine species that have iodine-like off-flavors caused by intake of bromophenol-producing algae. Total bromophenol content (TBC) can fluctuate in bromophenol-producing plants. For example brown algae found in waters around Hong Kong tend to have higher TBC in winter months and lower levels in the summer, indicating that environmental factors such as temperature may influence biosynthesis of bromophenols (Chung and others 2003a). Similar fluctuations have been noted in green marine algae species found off the coast of Australia, although the seasonal variations changed from year to year (Flodin and others 1999; Flodin and Whitfield 1999b). This could explain the changes in the intensity levels of off-flavors found in English sole. The diet of English sole consists primarily of polychaetes and amphipods (Kravitz and others 1975), which could be the source of TBC in English sole. Whitfield and others (1999) concluded that outbreaks of iodine-like off-flavors in species of prawns or fish may be the result of the animal primarily feeding on polychaetes of high bromophenol content. There have been no studies as to the seasonal growth and production of bromophenol-producing plants off the U.S. West Coast and further investigation would have to be carried out to determine the relationship between diet and TBC of English sole.

3.4.2 Laboratory Analysis

Fish landed in AST had higher lipid content than fish landed in CSB or EUR, with an average percent lipid of 0.91±0.30% (range 0.37-1.29%) and a mean percent moisture of 82.84±1.24% (range 81.59-84.33%). English sole landed in CSB had a mean percent lipid of 0.55±0.22% (range 0.18-0.78%) and mean percent moisture of 83.04±0.81% (range 81.97-84.20). EUR samples had a mean percent lipid of 0.50±0.13% (range 0.33-0.75%) and mean percent moisture of 83.51±1.23 (range 81.97-85.02%) (Table 3.5).

Table 3.5: Lipid and moisture content of English sole fillets used in present study from June 2006-April 2007 (including samples used for DA panel training purposes)

	%Lipids[1,2]		%Moisture[1,2]	
	Range	**Mean*** ±Stdev**	**Range**	**Mean[NS] ±Stdev**
AST	0.37-1.29	0.83[b]±0.30	81.59-84.33	83.00±1.24
CSB	0.18-0.78	0.59[a]±0.22	81.97-84.20	83.04±0.81
EUR	0.33-0.75	0.53[a]±0.13	81.97-85.02	83.54±1.23

[1] NS= not significant

[2] *, **, *** treatment is significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively

[abc]Means in the same column with different superscript letters are significantly different from one another at TUKEY'S HSD 5%

Figure 3.1 shows seasonality changes in percent lipids for English sole fillets from June 2006-April 2007. There were no significant seasonality difference in lipid content (R^2=0.09). Figure 3.2 shows seasonality changes in percent moisture for English sole fillets from June 2006-April 2007. There was a slight positive correlation (R^2=0.52) between seasonality and moisture content. The percent moisture in the samples increased from June 2006 to April 2007.

It is well know that lipid content plays a major role in sensory characteristics of any food (Ho and others 1994), and fish can vary in lipid content depending on species and season. Fattier catfish (>2.5% muscle fat) have been shown to have increased levels of 2-methylisoborneol (MIB), an important off-flavor component, then leaner fish tissue (<2% muscle fat) (Johnson and Lloyd 1992). This could account for significantly higher off-flavors found in fattier AST-caught English sole. Further investigation between muscle lipid content and increased levels of bromophenols or other off-flavor causing compounds should be considered.

Figure 3.1. Seasonality changes in percent lipids of Pacific-caught English sole fillets from June 2006-April 2007 (including samples used for DA panel training purposes).

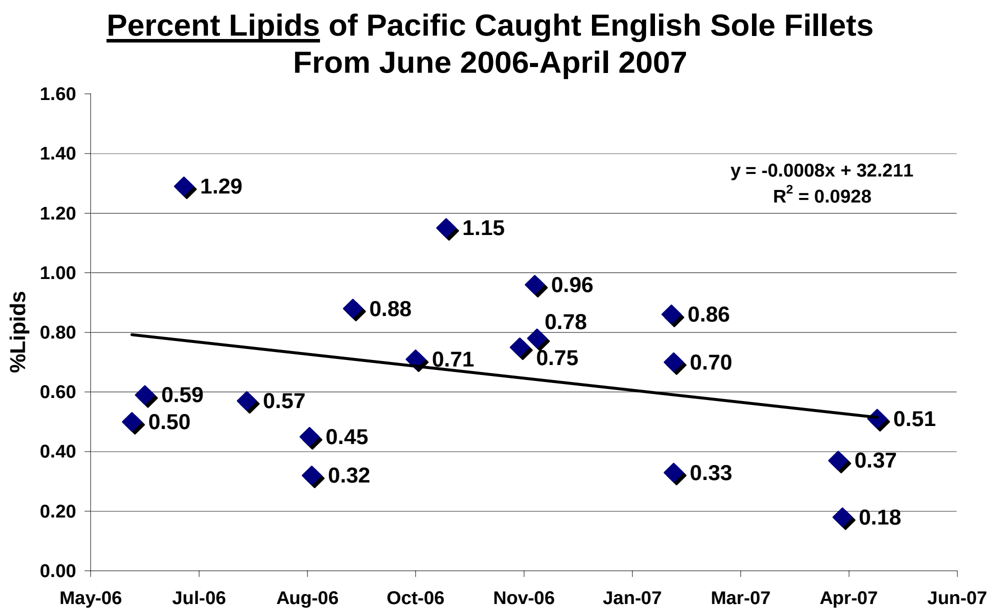
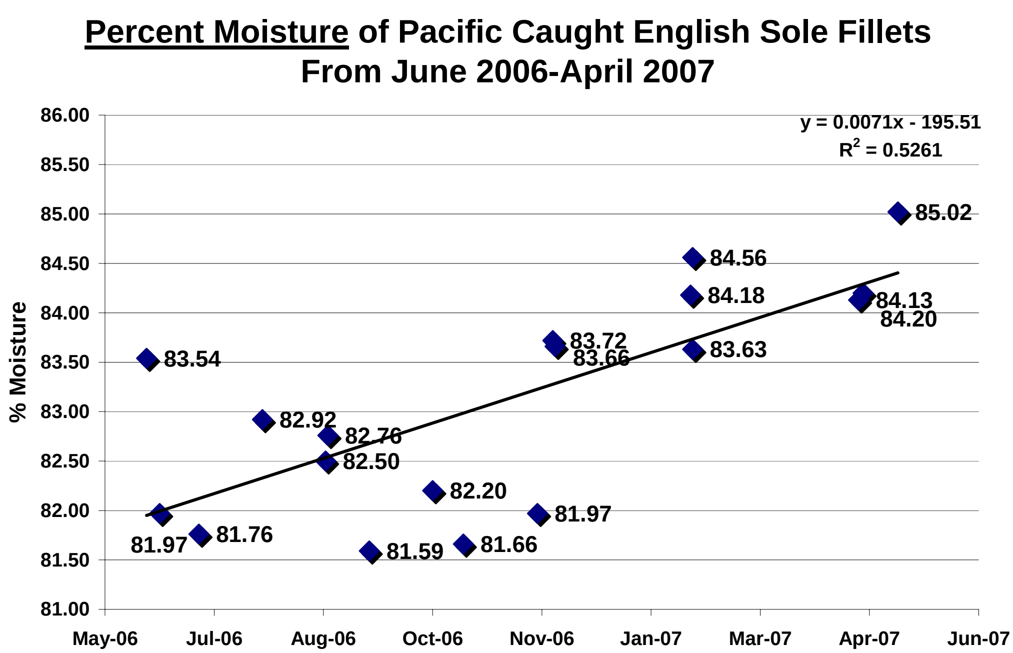


Figure 3.2. Seasonality changes in percent moisture of Pacific-caught English sole fillets from June 2006-April 2007 (including samples used for DA panel training purposes).



3.5 Conclusions

The iodine off-flavor and aroma were detectable by the DA panel in all geographic locations and seasons, indicating the presence of an underlying flavor compound present in English sole at all times. This finding and the small amount of variation over locations and seasons limits the ability of trawl fishermen to avoid the negative off-flavor during the fishing season. However, English sole from Eureka did show lower OF and AT values in DEC and APR. Fish landed in Astoria had higher lipid content and higher intensity levels of off-flavors. Specific flavor compounds were not identified during this study, but similar iodine-like off-flavors noted in other marine species have been caused by high concentrations of bromophenols. Further research is suggested to identify specific off-flavor compounds present in English sole.

CHAPTER 4

CONSUMER TESTING OF FRESH AND FROZEN ENGLISH SOLE (*PAROPHRYS VETULUS*) AND DOVER SOLE (*MICROSTOMUS PACIFICUS*)

4.1 Abstract

A consumer test undertaken to determine the ability of underutilized English sole (*Parophrys vetulus*) to compete in a fresh and frozen fillet market with the more popular flatfish Dover sole (*Microstomus pacificus*). The effect of freezing was also investigated to determine consumer preferences on fresh and frozen fish fillets. The consumer test involved 108 participants that were screened for frequency of seafood consumption. Consumers evaluated four samples (fresh English sole, frozen English sole, fresh Dover sole and frozen Dover sole) for five attributes (appearance, texture, flavor, aftertaste and aftertaste acceptability). Participants also determined preferences based on these attributes and on the overall samples. Consumers preferred a firmer fish that had a mild or natural fish flavor. Frozen Dover sole was preferred overall and fresh Dover sole was least preferred. There were significant differences in the texture of English sole and Dover sole as well as fresh versus frozen fillets. There were no significant differences between the samples in flavor, aftertaste, or aftertaste acceptability. Results indicated consumers liked the flavor of all the samples moderately, and there was a slight aftertaste that was evaluated between somewhat and extremely acceptable. The detection or dislike of any off-flavor or aftertaste that can sometimes be found in English sole was not identified. Results indicate that English sole could compete favorably against Dover sole in the marketplace. The evaluation of fresh and frozen fillets revealed that frozen storage

of these types of flatfish may produce positive effects on the texture, creating a firmer fish fillet.

4.2 Introduction

With the recent food trend to buy fresh and local products, the fishing industry is struggling with delivering fresh high quality seafood to consumers without freezing during shipping. The demand for fresh fish is increasing and processors are concerned about the increased costs of shipping fresh, the rapid decrease in quality, and the loss of products not purchased. Many of the flatfish caught off the coast of Washington, Oregon, and California are filleted, frozen and shipped overseas. Processors and trawl fishermen alike are interested in establishing a larger domestic market for frozen flatfish fillets. The first step is to investigate if there is a perceived difference or preference by consumers for fresh fish over frozen fillets. Another problem facing the flatfish fishery is the limited ability to increase fishing of already popular fish, like Dover and petrale sole, due to management efforts to maintain sustainable fisheries. Investigation of consumer acceptability for different types of fresh and frozen flatfish will provide the industry with information it needs to compete in the domestic and world seafood market.

The flatfish Dover sole (*Microstomus pacificus*) is an important commercial fishery for trawl fishermen on the West Coast of the United States. There is high demand for the fish in the fresh and frozen fillet market and it is the most abundant catch of the trawl-caught flatfish (PSMFC 2006). Currently landings of Dover sole are equal to the optimal yield set by the Pacific Council every year (PFMC 2006; PSMFC 2006). Trawl fishermen are experiencing lower revenues due to low stock assessments and new regulations of several important commercial rockfish species. The ability to increase the landings of popular fish such as Dover sole is limited, causing the industry to look in new directions. English sole (*Parophrys vetulus*) is a flatfish found in abundance along the U.S. West Coast and could be a sustainable substitute for fish such as Dover sole. The most recent stock assessment of English sole showed the fish is plentiful and can be harvested at higher levels (Stewart 2007). Therefore, English sole may be a suitable alternative to already popular flatfish such as Dover and petrale sole which are already caught at maximum sustainable limits.

Consumer sensory testing is a well developed science which can establish the worth or acceptability of a commodity (Meilgaard and others 1999) and has been well established in the seafood industry as a tool for a wide range of products and uses. Consumer testing has been used to determine the acceptability of an alternative species to a more popular species in the marketplace, as with the in-home consumer testing of rainbow trout (*Salmo gairdner*) and brown trout (*Salmo trutta*) (Rounds and others 1992). Consumer testing has also been involved in the growing aquaculture industry for the evaluation of aquacultured fish acceptability compared to wild-caught fish. The comparison of farmed and wild-caught salmon has been evaluated by consumers for several species of salmon (Sylvia and others 1995; Farmer and others 2000). Another study compared aquacultured yellow perch to the wild-caught version as well as other competitors found in the marketplace (Delwiche and other 2006). A consumer study using separate groups of consumers and experts evaluated the quality differences of domestic shrimp and imported shrimp for uses in marketing and adding value (Condrasky and others 2005). A review of the literature by Olsen (2004) for seafood consumer tests indicated taste, distaste, nutritional value and freshness are suggested to be the most important attributes in forming consumer's attitudes toward seafood; although there was an underlying factor of health benefits and environmental factors not identified by consumers for other food products.

The objectives of this study were to determine the possibility of English sole entering the domestic fresh and frozen fillet market, and the effects of freezing on consumer's acceptability. A consumer test comparing fresh and frozen English and Dover sole was carried out to answer these questions.

4.3 Materials and Methods

4.3.1 Consumer recruitment and demographics

A consumer taste test was completed in June 2007 at the Oregon State University Food Innovation Center (OSU-FIC) in Portland, OR. The OSU-FIC consumer database of over 3,000 people located in the greater Portland metropolitan area was used for recruitment of participants. Selection of participants was based on the frequency of seafood consumption, with a minimum consumption of two types of seafood per month or more. One hundred and eight consumers, 61 female and 47 male, completed the taste test. Age distribution was: 9 panelists age 18-24; 32 panelists age 25-34; 26 panelists age 35-44; 19 panelists age 45-54; 15 panelist age 55-64; and 7 panelists age 65+. Education level distribution was: 4 panelists with high school or less; 29 panelists with some college; 11 panelists with 2-year degree; 40 panelists with 4-year degree; and 24 panelists with graduate degrees. Sixty-one consumers had an annual household income $\leq$\$49,999; while the remaining 47 consumers had an annual household income $\geq$\$50,000.

Consumers ate fresh/frozen fish at home more often than in restaurants, with 93 people eating fish fillets at home at least 2-3 times per month, and 59 people eating fish fillets at restaurants at least 2-3 times per month. Consumers frequented casual dining restaurants more often (n=50) in the past month than any other kind. The majority of the consumers, (n=91), claimed they almost always review nutritional labels and ingredient lists before purchasing a new food item at the store.

4.3.2 SAMPLE PREPARATION

Four samples were evaluated during the consumer taste test: fresh English (FSH ENG) and Dover sole (FSH DOV), and frozen English (FRZ ENG) and Dover sole (FRZ DOV). Fresh samples were landed in Astoria, OR three days prior to testing. Frozen samples were landed at Bornstein Seafoods in Astoria, OR, individually quick frozen, and stored at -10°C for 2-3 months. Frozen samples were defrosted in cold water prior to cooking. All samples were placed on trays, covered with foil and baked at 300°F for 12 minutes in a convection oven. Samples approximately 10 cm in length and 6 cm wide were placed on 6-inch plates coded with 3-digit numbers. FSH ENG and FRZ ENG were evaluated by a descriptive analysis (DA) panel previously trained to evaluate iodine-like off-flavors in English sole. The panel evaluated 5-attributes: overall aroma (OA), iodine aroma (IA), overall flavor (OF), iodine flavor (IF), and iodine aftertaste (AT). All samples were evaluated on a 16-point intensity scale as described in section 3.3.3.

4.3.3 QUESTIONNAIRE

Panelists were seated ten at a time in individual sensory booths under white lighting. The questionnaire was presented on individual computers and data was entered in the Compusense® Data Acquisition System. Panelists were presented with all four samples at the beginning for an "overall appearance" likeability ranking question. Subsequent samples were presented individually in randomized order for evaluation of texture, flavor, aftertaste intensity, and aftertaste acceptability. After individual evaluations, all four samples were presented together for preference, purchase intent, and demographic questions. The Panelists were compensated $20 at the completion of the taste test for their time.

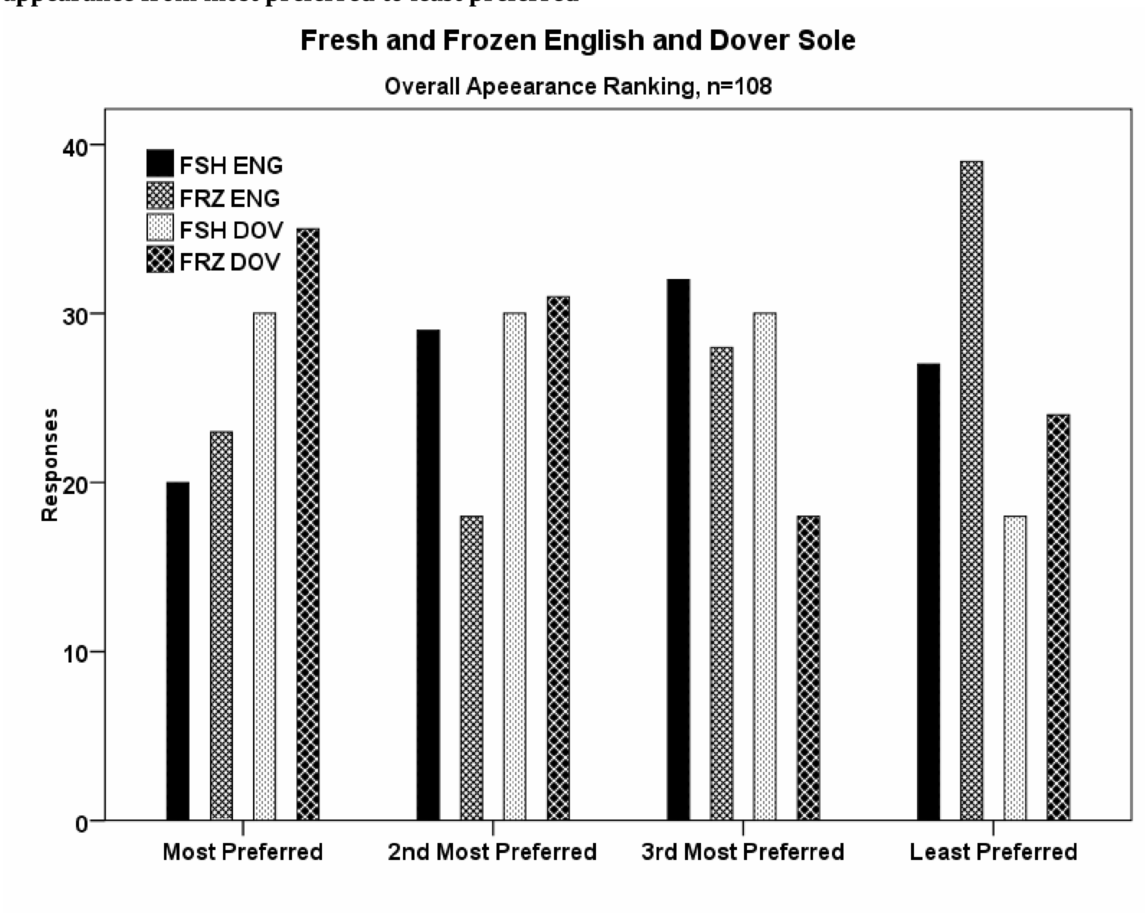
4.3.4 STATISTICAL ANALYSIS

Several statistical tests were used to analyze the data. Means, standard deviations, ANOVA, and Friedman Analysis of Rank were computed using Compusense®. Correlation analysis was calculated using SPSS 14.0 for Windows software. The level of significance for all tests was pre-set at $p<0.05$.

4.4 Results and Discussion

Figure 4.1 shows the distribution of the overall appearance likeability results from most preferred to least preferred. FRZ DOV was ranked first more often than the other samples (n=35); while FSH ENG sole was ranked first least often (n=20). An analysis of rank indicated the two samples significantly differed at the 5% level. Solely based on appearance consumers preferred Dover sole fresh or frozen over the appearance of English sole.

Figure 4.1. Consumer ranking of fresh and frozen English and Dover sole based on overall appearance from most preferred to least preferred



Each sample was evaluated separately for four attributes: texture, flavor, aftertaste, and aftertaste acceptability. Figure 4.2 shows the distribution of consumer responses for texture evaluated on a 9-point hedonic scale, with 1= “firm” and 9= “very soft.” Dover sole is known in the industry for its softer texture compared to other popular flatfish. This texture difference is shown in Fig. 4.2 where FSH DOV was evaluated as “softer” or “very soft” more often than all other samples and more often then FRZ DOV indicating there may be a textural change during frozen storage of the fillets. FRZ ENG sole was rated by consumers as the firmest texture. FSH ENG sole was also evaluated as firm with most of the responses from consumers landing in the four firmest categories. Texture differences are also shown in Fig. 4.3 where the texture mean scores on the 9-point hedonic scale are shown. FSH DOV was rated as significantly softer than the other samples with a mean of 6.25. FRZ ENG was rated significantly firmer than both Dover sole samples with a mean of 3.41. Consumers who ranked the preference of the samples based on texture showed a trend toward preference of FRZ ENG over FSH DOV at the 10% significance level. Consumers preferred a firm fish and frozen fillets tended to be firmer than fresh fillets.

Figure 4.2. Consumer responses of fresh and frozen English and Dover sole texture score distribution on a 9-point hedonic scale

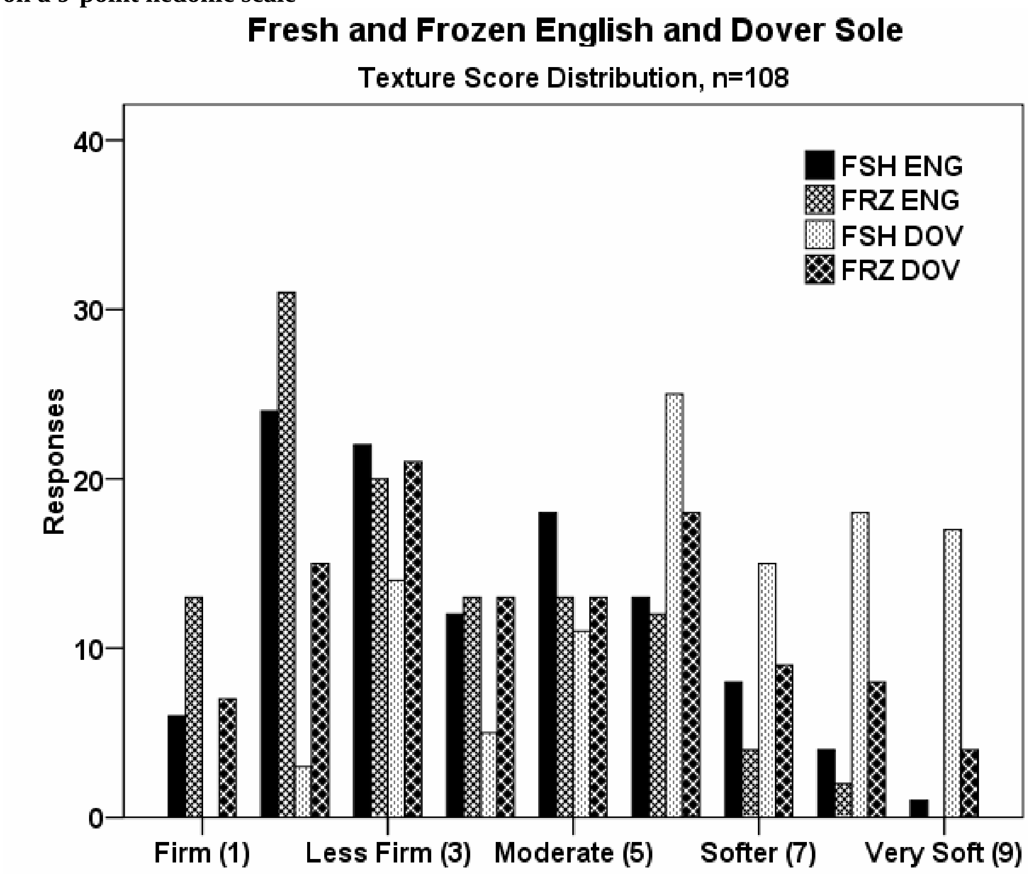
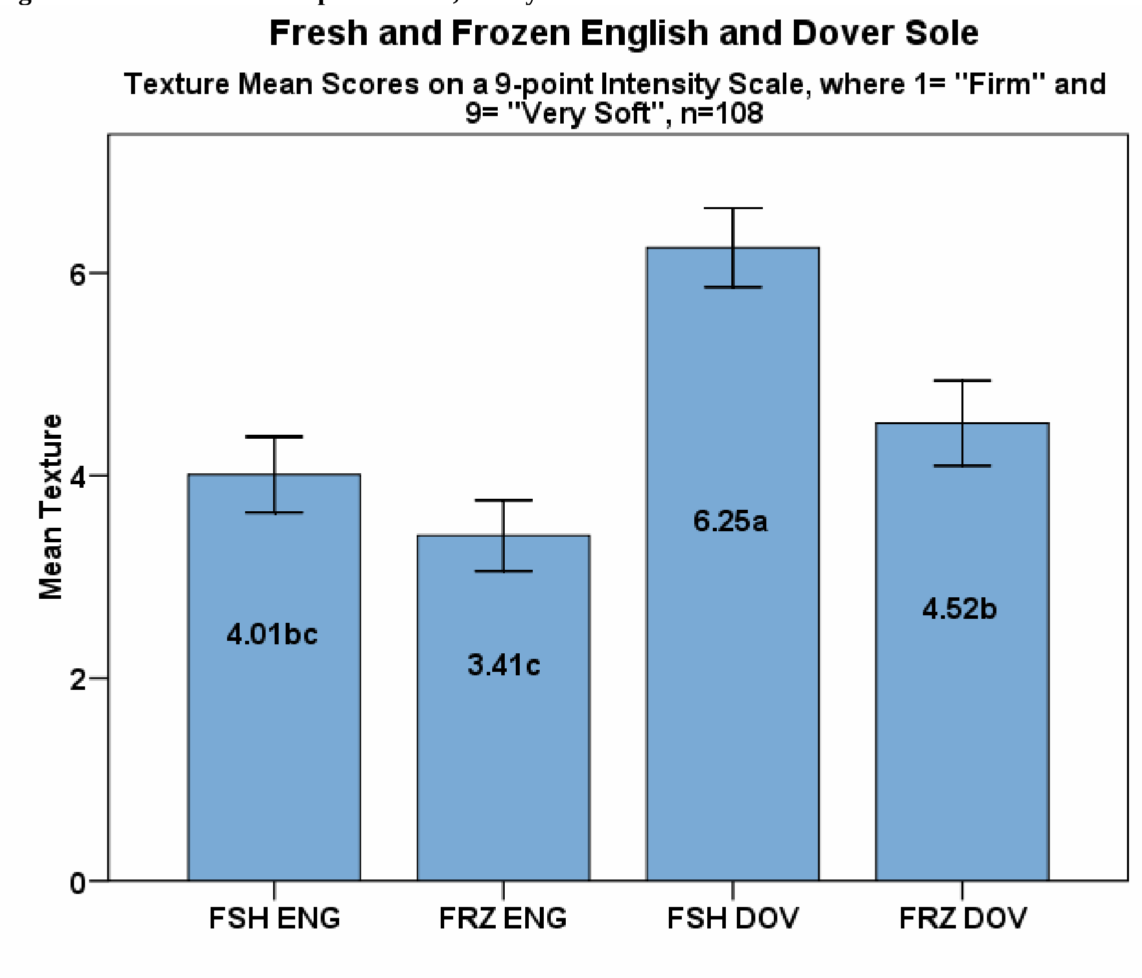


Figure 4.3. Consumer responses for fresh and frozen English and Dover sole texture mean scores on a 9-point intensity scale, where 1="Firm" and 9="Very Soft." Different superscripts represent a significant difference at the p<0.05 level, Tukey's HSD



Intensity levels of FSH ENG and FRZ ENG were determined on a 16-point intensity scale by a previously trained DA panel. Five attributes: overall aroma (OA), iodine-like off-aroma (IA), overall flavor (OF), iodine-like off-flavor (IF), and iodine-like aftertaste (AT) were evaluated by the DA panel. Evaluations were used to compare samples in the consumer test with English sole tested by the DA panel in a 9-month project identifying intensity levels of off-flavors. FRZ ENG had slightly lower intensity levels for OA, OF, IF, and AT, yet there were no significant differences between FSH ENG and FRZ ENG. Intensity levels are similar to results in section 3.4.1 indicating intensities of FSH ENG

and FRZ ENG in this study are a good representation of English sole found throughout the year. Identification and acceptability of the iodine-like off-flavor found in English sole is evaluated by the consumer panel though flavor, aftertaste, and aftertaste acceptability ratings. No specific question about off-flavor was presented for the purpose of not suggesting to consumers that they were looking for an off-flavor.
Flavor scores were evaluated on a 9-point likeability scale with 1="Dislike extremely" and 9="Like extremely." All samples were comparable across the scale with the majority of consumers choosing "Like Moderately" for every sample. There was no significant difference for mean scores of flavor. All mean scores ranged between "Neither Like nor Dislike" and "Like Moderately" categories. The consumers indicated flavor was the most important attribute when repeat purchasing any type of fish fillet, indicating English sole may be a possible addition to the fresh or frozen fillet market based solely on flavor results.

Aftertaste intensity was based on a 9-point hedonic scale with 1="Just Detectable" and 9="Extremely Detectable." The most common response for FSH ENG, FRZ ENG, and FRZ DOV was in the "Slight" category; whereas the most common response for FSH DOV was between "Just Detectable" and "Slight" categories (Fig. 4.4). The aftertaste intensity mean scores were not significant over all samples; and all means fell between the "Slight" and "Moderate" categories. Figure 4.5 shows aftertaste acceptability evaluated on a 9-point hedonic scale with 1="Extremely Unacceptable" and 9= "Extremely Acceptable. There was no significant difference between means of aftertaste acceptability. All means fell between "Neither Like nor Dislike" and "Somewhat

Acceptable." These results indicate that few people can detect any aftertaste in English sole compared to Dover sole.

Figure 4.4. Consumer responses of fresh and frozen English and Dover sole aftertaste intensity distribution on a 9-point hedonic scale.

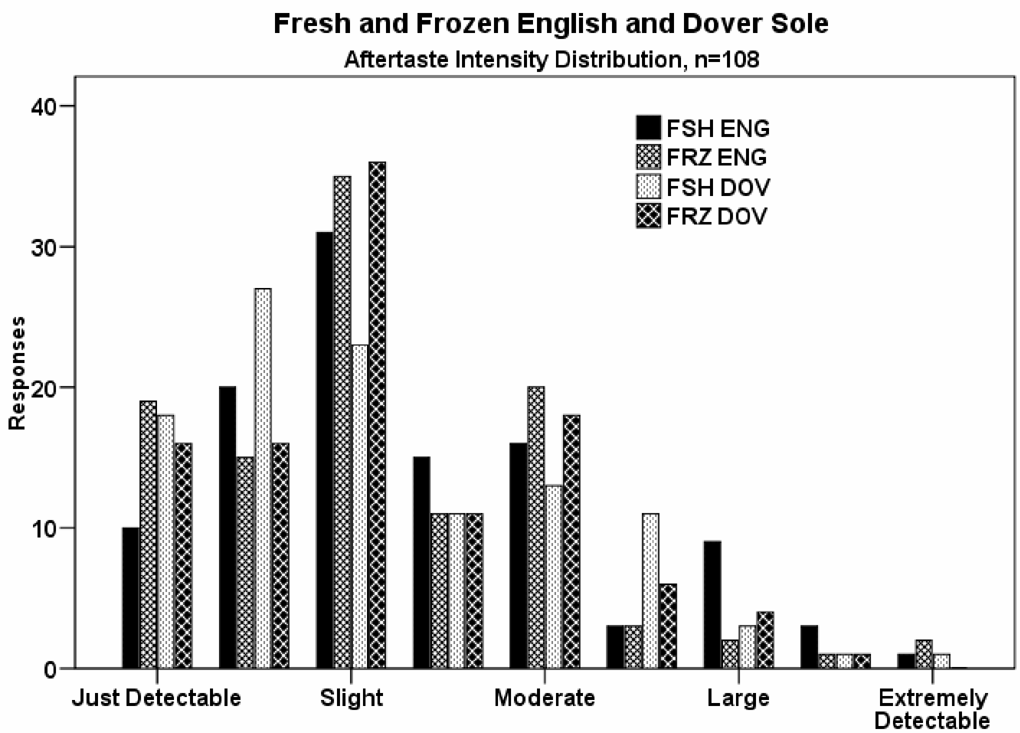
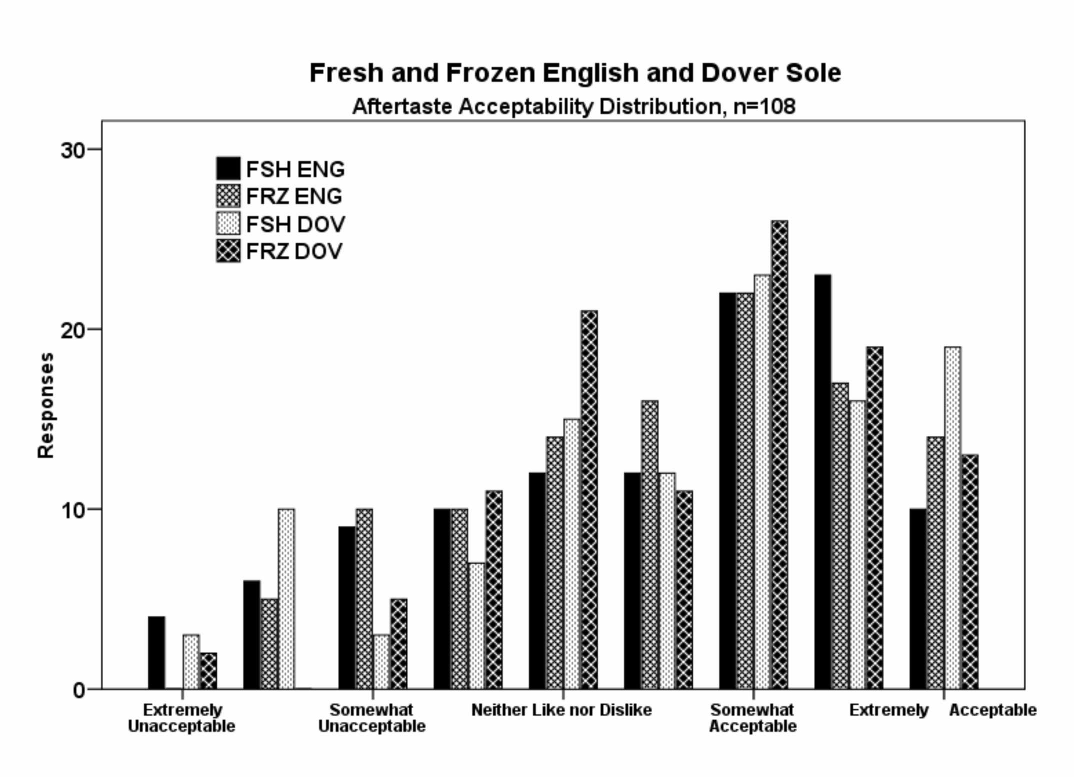


Figure 4.5. Consumer responses of fresh and frozen English and Dover sole aftertaste acceptability distribution on a 9-point hedonic scale.



Identification of the product attributes that are related to each other can be useful to the industry when developing new products or marketing raw fish. A relationship among sensory attributes and preference is shown in Table 4.1. Sensory attributes did not correlate with the samples consumers preferred most or least overall. There was a high positive correlation between flavor and aftertaste acceptability. This showed the more consumers liked the flavor the more acceptable the aftertaste was. There was a slight negative correlation between flavor and aftertaste intensity, indicating an increase in flavor likeability occurred with lower aftertaste intensity. This was also true with aftertaste intensity and aftertaste acceptability. The negative correlation between the two attributes shows lower aftertaste intensity corresponds with an increase in aftertaste acceptability. A slight positive correlation occurred between appearance and preference based on texture, flavor, and aftertaste. This correlation between preference and appearance indicate the importance of proper handling to produce a high quality fillet.

Table 4.1 Correlation coefficients among sensory attributes in fresh and frozen English and Dover sole.

	Appearance	Texture	Flavor	After-taste	Aftertaste Acceptability	Preference Texture	Preference Flavor
Texture	-.013						
Flavor	-.075	-.168**					
Aftertaste	.010	.100*	-.280**				
Aftertaste Acceptability	-.098*	-.142**	.682**	-.397**			
Preference Texture	.176**	.136**	-.180**	.025	-.142**		
Preference Flavor	.183**	.084	-.167**	.041	-.138**	.506**	
Preference Aftertaste	.156**	.075	-.207**	.048	-.174**	.476**	.631**

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

As shown in Fig. 4.6 and 4.7, consumers preferred FRZ DOV (n=32) most overall, and FSH DOV (n=41). Consumers were divided on preference of one species over the other. A slight majority (n=61) preferred the Dover sole sample over the English sole samples (n=47). Consumers were split on which species was preferred least; with 56 consumers preferring Dover sole least overall and 52 consumers preferring English sole least overall. This indicates English sole and Dover sole would be comparable products on the market. These results correspond with a consumer study of 18 common fish from the Atlantic where the less commonly known and eaten fish are liked as well as common species with flavor being the most important attribute for consumer acceptance (Sawyer 1988).

Figure 4.6. Fillets preferred most overall by consumers between fresh and frozen English and Dover sole

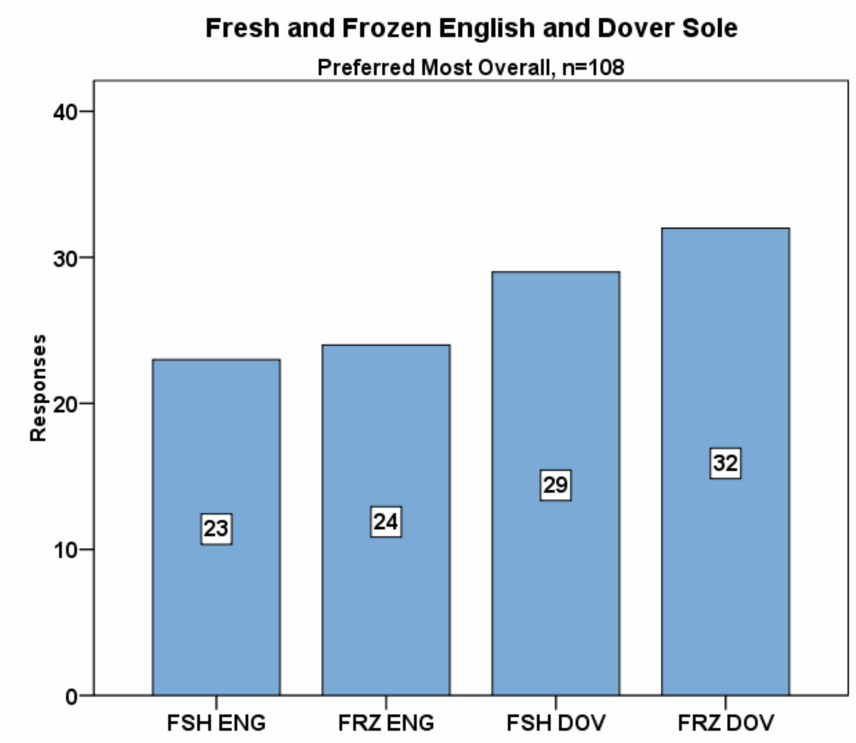
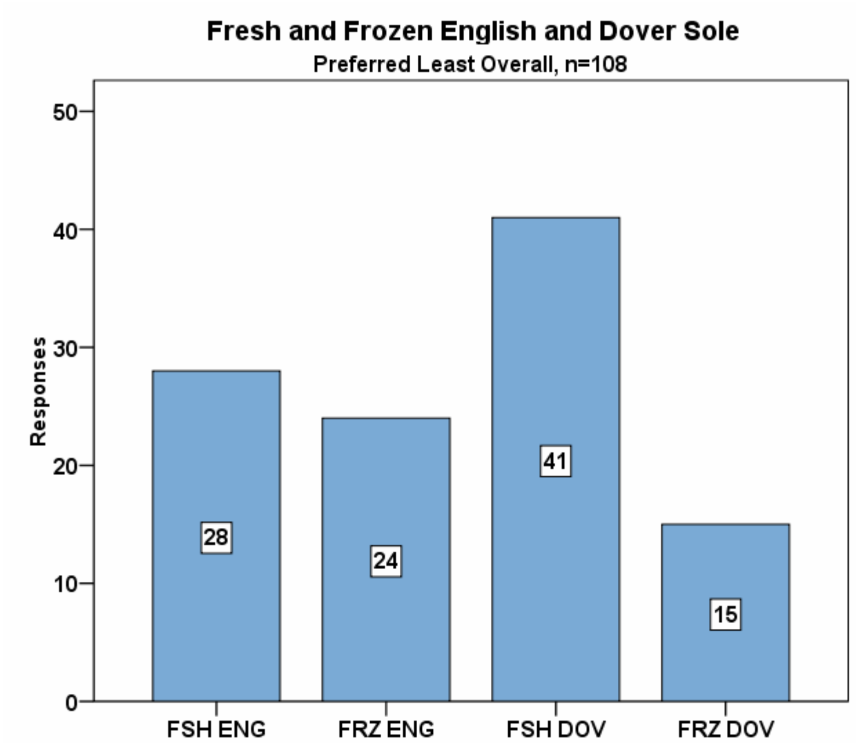
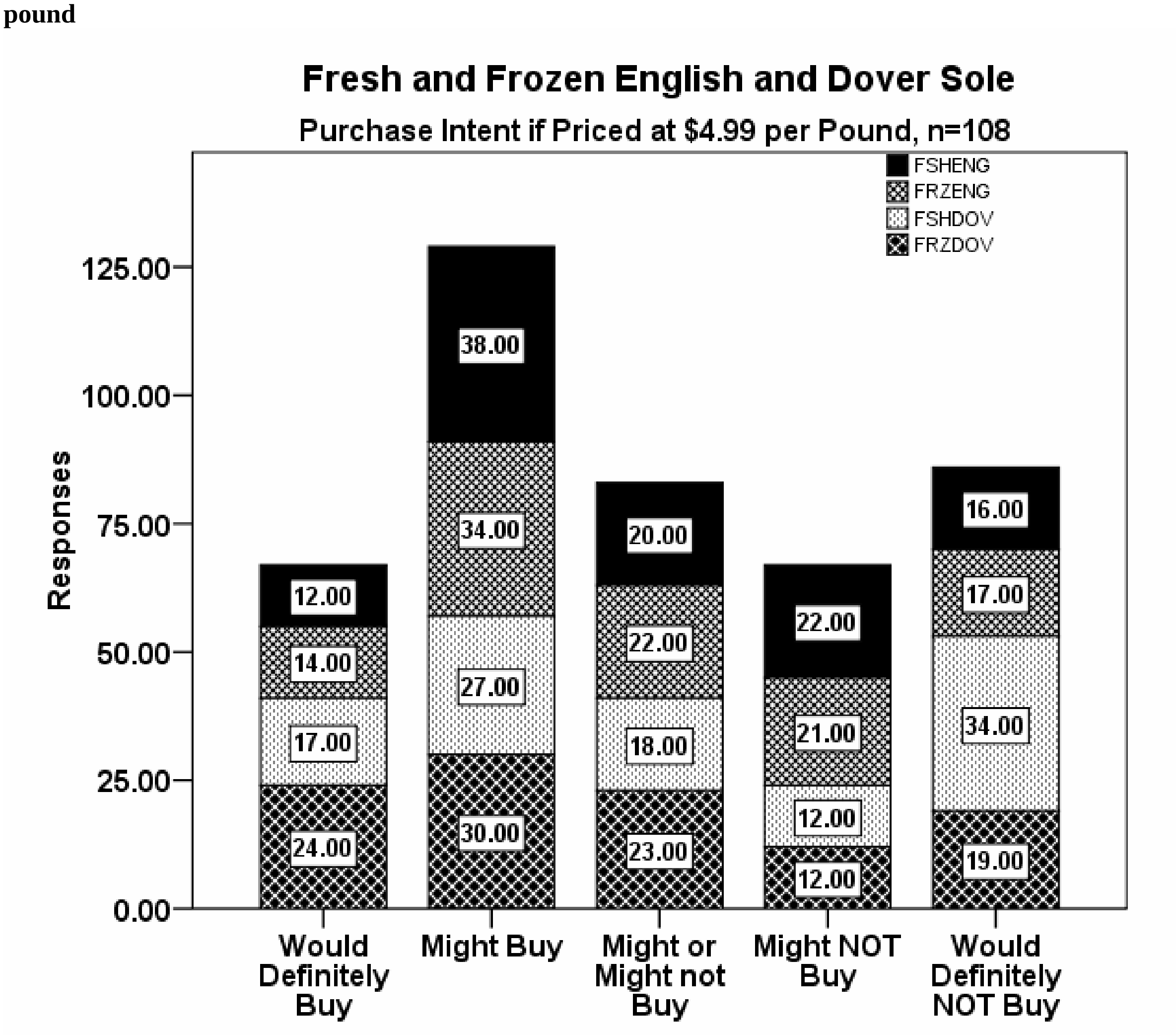


Figure 4.7. Fillets preferred least overall by consumers between fresh and frozen English and Dover sole



Consumers were asked purchase intent if the fillets were priced at $4.99 per pound. Responses were given on a 5-point scale with 1= "Would Definitely Buy" and 5= "Would Definitely NOT Buy." With all data combined most consumers selected "Might NOT Buy" (n=129) indicating $4.99 per pound may be too high of a price for this type of fish. Individually, 38 consumers claimed "Might Buy" FSH ENG fillets at that price. FRZ ENG had similar results for purchase intent claiming "Might Buy" (n=34) at $4.99 per pound (Fig. 4.8).

Figure 4.8. Purchase intent of fresh and frozen English and Dover sole fillets priced at $4.99 per pound



The majority of consumer selected they “Would Definitely NOT Buy” FSH DOV (n=34), and only 27 choose “Might Buy” if sold at $4.99 per pound. Whereas, with FRZ DOV consumers claimed they “Might Buy” (n=30) and only 19 consumers said they “Would Definitely NOT Buy”. Consumers were split with purchase intent of FSH DOV with 44 responding in the first two categories, indicating might purchase; and 46 responding in the last two categories, indicating might not purchase. With FRZ DOV fillets purchase intent at $4.99 per pound was more positive with many consumers responding in the first two categories (n=54), indicating might purchase; and only 31 responding in the last two categories, indicating might not purchase (Fig. 4.8).

Consumers were asked to indicate the most important attribute for their repeat purchasing of fish fillets. There were four choices: appearance, texture, flavor, and aftertaste. Once selected, panelists were asked to comment on what they like about that attribute. The most common answer for the repeat purchasing of fish was flavor (n=78). Nineteen individuals selected texture, 6 individuals selected appearance, and 5 individuals selected aftertaste. Forty-five out of 78 panelists commenting on flavor mentioned “mild fish” “delicate” or “subtle” in their answer. “Natural” or “fresh” was mentioned 17 times by the people commenting on flavor. Fifteen out of 19 consumers mentioned “firm” as an important texture attribute. Some comments included: “fresh fish depending on the type is always firm” and “I like firm fish… more likely to be thought of as wild caught.” Out of the six people that commented on appearance, four mentioned the color and good preparation as an important factor. The remaining 5 panelists chose aftertaste as their deciding factor for the repeat purchasing of fish and 3 commented as to either not wanting an aftertaste at all or for it to be minimal. Two of the 5 preferred a slight fishy aftertaste and one that was not metallic or artificial.

4.5 Conclusions

Consumers indicated they preferred firmer fish that had a mild or natural fish flavor. Appearance of the fillets was an underlying factor when it came to indicating preference of the fillets based on specific attributes. Although the consumers tended to rank Dover sole appearance likeability higher than English sole the opposite was true for texture ratings and preferences. English sole is a firmer fillet than Dover sole and there are texture changes during freezing and thawing. It is well documented that there is a loss of juiciness and an increase in toughness in fish that have been frozen due to changes in muscle proteins (Mackie 1993). The increase in toughness in these samples was positive for these flatfish providing a more desirable firmer fillet.

The consumers did not identify any strong off-flavor or aftertaste that can sometimes be found in English sole. There were no significant differences in flavor, aftertaste, or aftertaste acceptability for fish in the study. Results for all samples indicated consumers liked the flavor moderately, and there was a slight aftertaste that was between somewhat and extremely acceptable. Flavor was chosen by the majority of the participants as the main factor when buying fish fillets over appearance, texture and aftertaste. There was a correlation between flavor, aftertaste, and aftertaste acceptability suggesting fish with an off-aftertaste or flavor could impact the repeat purchasing of fish fillets.

Overall, frozen Dover sole was preferred; however, preference was spread fairly evenly over all samples. This contradicted the least preferred results where consumers chose fresh Dover sole almost twice as many times as the other samples for least preferred. This could be due to the softer texture of the fresh Dover sole and the consumer's preference of a firmer fish fillet. This dislike for the fresh Dover sole was also shown in purchase intent with consumers claiming they would definitely not buy the product if it was priced at $4.99 per pound but with other samples in the study the might buy option was selected most. Combining all purchase intent data showed the price of $4.99 per pound might be too high because consumers might not buy the product at that price.

The evaluation of fresh and frozen English and Dover sole by consumers revealed frozen storage of these types of flatfish may produce positive effects on the texture creating a firmer fish fillet. The detection or dislike of any off-flavor or aftertaste in English sole was not identified by the consumers, making this fish a potentially marketable and sustainable and viable addition to domestic fresh and frozen fillet markets.

CHAPTER 5

CONCLUSION

This study used sensory science-based research to evaluate the iodine-like off-flavor in English sole, and the consumer acceptability of the fish compared to another popular flatfish. Currently English sole is underutilized, though the stock levels are at an all time high. Identification of off-flavor intensity levels for seasonal and geographical changes, and determining consumer acceptability of English sole could lead to new uses and added value for the fish.

Results from the DA panel indicated there were no locations or time during the study where the off-flavor, aroma and aftertaste were not detectable. This indicates the presence of an underlying flavor compound present in English sole at all times. This finding and the small amount of variation over geographical location and seasons limits the ability of the trawl fishermen to avoid the negative off-flavor during the fishing season. Specific flavor compounds were not identified during this study but similar iodine-like off-flavors have been noted in other marine species caused by high concentrations of bromophenols. Further research should be done to identify specific off-flavor compounds present in English sole.

The evaluation of English sole by consumers showed promising results for this species to enter the fresh and frozen fillet market with similar species such as Dover sole. There were no significant differences in the flavor, aftertaste or aftertaste acceptability. Overall preference was split between English sole and Dover sole. Fresh English sole was evaluated as a firmer fish than fresh Dover sole, and freezing increased the firmness of the fillets. Consumers preferred a firmer fish so freezing may improve the acceptance of flatfish while helping the industry to deliver higher quality seafood to the market.

This study has identified the presence of the iodine-like off-flavor throughout the year and in several geographical locations; nevertheless, consumer data suggests the presence of this off-flavor is not a factor influencing the acceptability of the English sole. These findings are promising for flatfish trawl fishermen and processors alike because English sole has the potential to become a more marketable and profitable fishery.

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