Mercury Testing of Sport/Food Fishes from Nearshore Ocean Waters of Humboldt County, California

Final Report
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Mercury and Selenium Testing of Sport/Food Fishes from Nearshore Ocean Waters of Humboldt County, California

Project Purpose and Need

Mercury advisories have been issued for many major waterbodies in California, including coastal areas of Northern California. In 2012, the North Coast Regional Water Quality Control Board determined that Humboldt Bay did not warrant listing for mercury impairment under Clean Water Act Section 303(d) based on mussel testing done in the 1980s (NCRWQCB 2012). However, that same year, a report prepared for the Surface Water Ambient Monitoring Program (SWAMP) was released showing that Leopard Shark from Humboldt Bay had the highest mercury levels in a statewide assessment of contaminants in coastal fish (Davis et al. 2012), indicating a need for further sampling of commonly eaten fish caught in Humboldt Bay.

In 2018, Humboldt Baykeeper completed the first study of mercury levels of sport/food fishes from Humboldt Bay (Kalt and Taylor 2019). This study collected tissue samples from seven species of fish and several species of shellfish commonly caught, harvested or grown in the bay. The fish species were: California Halibut, Lingcod, Black Rockfish, Bat Ray, Leopard Shark, Jacksmelt and Walleyed Surfperch. An eighth fish species included in the results was ocean-caught Chinook Salmon from a 2005 testing effort. The shellfish tested for mercury included Horseneck, Littleneck, and Martha Washington clams from South Humboldt Bay, and non-native oysters cultured in North Humboldt Bay. The local response to Humboldt Baykeeper's 2018 study was large and positive, with results disseminated in report form, radio interviews and on a one-page handout that was printed in three languages: English, Spanish and Hmong. Soon after, numerous saltwater anglers who fish off the coast of Humboldt Bay and Trinidad were inquiring about the mercury levels in commonly caught fish from our nearshore waters, such as Cape Mendocino, Patrick's Point and Reading Rock.

The second California EPA grant awarded to Humboldt Baykeeper was for testing methylmercury levels in tissue samples collected from approximately 70 to 80 fish caught in nearshore ocean waters out of Eureka and Trinidad and also for testing a subset of these tissue samples for selenium levels. Selenium was tested because of published research suggesting that selenium in certain molar ratios may offset or buffer the harmful health effects of methylmercury from the consumption of fish.

Background

Fish consumption is the major route of methylmercury exposure in the United States (ATSDR 1999). For many years, mercury advisories focused primarily on which fish to avoid. A result of this approach was that many people simply eliminated fish from their diets, especially pregnant women.

There are many health benefits of eating fish that is low in mercury, PCBs, and other contaminants. Fish is high in protein and low in fat, and is an important source of omega-3 fatty acids, which support heart health and brain functions (Silbernagel et al. 2011). In recent years, concerns have been raised about generic fish advisories causing harm by encouraging people to limit their fish consumption, thereby limiting the beneficial effects of eating low-mercury fish (Verbrugge 2007).

Methylmercury (MeHg) is a powerful neurotoxin that can cause loss of coordination, blurred vision or blindness, and hearing and speech impairment. At lower levels of exposure, more subtle symptoms in adults are numbness or tingling in the hands, feet, and/or around the mouth. Groth (2008) documented 24 cases of methylmercury poisoning in the USA; 21 cases resulted from eating commercially caught and purchased ocean fish and three cases were people who ate freshwater fish they had caught. Each case was diagnosed by a doctor as methylmercury poisoning, based on symptoms and elevated levels of mercury detected in patients' blood and hair samples (Groth 2008). Developing fetuses are particularly sensitive, and can experience slight decreases in learning abilities, language skills, attention and/or memory function (Silbernagel et al. 2011).

Methylmercury accumulates in the body, and magnifies in larger, older animals that eat higher on the food chain (Davis et al. 2012). However, reducing mercury exposure from fish consumption can lower the mercury levels in blood and hair samples within a few months (Groth 2008; Bose-O'Reilly et al. 2010). This is especially important information for women of child-bearing age, because they can reduce their babies' mercury exposure by eliminating fish with high mercury levels from their diets.

The most vulnerable populations are people who eat a lot of fish, including recreational and subsistence fishermen and their families. Some populations that consume large amounts of fish include: tribal members, Hmong and other Asian residents, Latino residents, and people with low incomes that fish to feed their families. Another group at risk includes people with high incomes who can afford to eat a lot of expensive fish such as tuna, swordfish, and sushi. There are increased concerns for people who may consume many meals from one large animal, such as recreational and subsistence users who freeze, smoke, or pressure cook/can fish they've caught to eat year-round. Also, people who eat fish they catch also tend to consume larger portions than amounts used in health advisories (Harris et al. 2009).

Mercury is a natural element found in some rock and soil. Human activities, such as burning coal and the use of mercury to mine gold, have added available mercury to the environment (Smith et al., 2016). At this time, there are no known local sources of mercury in the Humboldt Bay area. Mercury was used in historic gold mining in the Klamath, Trinity, and Russian Rivers, but is not known to have occurred near Humboldt Bay or in the adjacent Eel and Mad River watersheds. Most of the mercury in the Humboldt Bay and Northcoast region is thought to originate from coal-burning power plants in Asia and elsewhere, which is emitted into the atmosphere and deposited across western North America. Asian countries, primarily China and India, generate approximately 60% of the coal-fired mercury emissions in the world (CarbonBrief.org 2021). A recent study found that coastal fog deposits mercury at higher levels than rainwater in Central California (Weiss-Penzias et al. 2012). Globally, around 80% of the inorganic mercury (Hg) that is emitted to the atmosphere from natural and human sources is deposited in the oceans, where some is converted by microorganisms to the neurotoxin MeHg (Schartup et al. 2019). Some studies have found that methylation of elemental Hg to MeHg can be accelerated within sediments in estuaries (Brown et al. 2015), while others have found that methylation occurs primarily within the water column in both estuaries (Prentiss et al. 2015) and upstream freshwater tributaries (Tsui et al. 2010). In higher-trophic predatory fish, environmental MeHg concentrations are amplified by a million times or more (Schartup et al. 2019).

Studies dating back to the 1970s suggest that selenium intake can protect against mercury exposure due in part to its binding affinity for both mercury and methylmercury (Cusack et al., 2017). This binding affinity leads to the formation of a biologically-unavailable mercury-selenide precipitate (Zhang et al., 2014). Ralston (2008) and others (Peterson et al. 2009) have suggested that selenium:mercury molar ratios greater than 1.0 may reduce the harmful effects of mercury exposure from fish consumption.

Selenium deficiency is a documented problem for cattle raised in Northern California due to low levels in soils and forage plants (Davy et al., 2019). Because low selenium levels in one’s diet may exacerbate the impacts of mercury exposure, documenting selenium concentrations in northern California nearshore ocean fish species was identified as a priority for this study. In addition, researchers have pointed to the importance of reporting both mercury and selenium levels in fish due to geographic variation (Burger et al. 2011) and intraspecific variation (Burger and Gochfeld 2012; Cusack et al. 2017).

Previous Studies in the Region

As previously mentioned, the SWAMP report found the highest levels of mercury in California coastal waters in Leopard Shark captured from Humboldt Bay (Davis et al. 2012). The average mercury levels in these Leopard Shark from Humboldt Bay was 1.66 parts per million (ppm) – more than three times Office of Environmental Health Hazard Assessment's (OEHHA) "do not consume" level of 0.44 ppm for women under 45 and children (Klasing and Brodberg 2018) and more than twenty times the advisory level used to define subsistence fishing in which fish consumption is a primary protein source (Gassel and Broberg 2005; Klasing and Brodberg 2018). For the Northcoast region of California, the SWAMP study tested fish caught at Shelter Cove, Cape Mendocino, Trinidad and the Northern Humboldt County Coast Area of Patrick's Point and Reading Rock (Davis et al. 2012). The ocean-caught species tested by SWAMP from the Northcoast region were: Lingcod, Black Rockfish, Blue Rockfish, Quillback Rockfish, Copper Rockfish, Gopher Rockfish, China Rockfish, Vermillion Rockfish and Cabezon (Davis et al. 2012). On a statewide level, survey results indicated that there was significant mercury contamination in coastal areas to cause risks to humans wherever they catch and eat long-lived predator fish species (Klasing and Brodberg 2018).

In 2005, Humboldt Baykeeper teamed up with the Waterkeeper Alliance and the Environmental Quality Institute at University of North Carolina, Asheville to sample three important local fish species: Chinook Salmon, Albacore Tuna, and Lingcod (Evenson 2006). The Chinook Salmon were caught in the Pacific Ocean just west of Humboldt Bay. The Albacore were caught approximately 90 miles west of Eureka and ranged in size from 22 to 31 pounds. Lingcod were caught off the coast of Cape Mendocino and these fish ranged from six to 25 pounds in size. Results of Humboldt Baykeeper's previous mercury testing were included in the 2018 report.

Methods – Selection of Species for Testing:

For this nearshore ocean waters project, the criteria for selection of focal fish species included:

- The species is commonly fished for and kept as a food source.
- The species resides in the study area for a significant part of the year.
- The species is relatively long-lived, thus more susceptible to bioaccumulation of toxins.
- The species is already associated with mercury health advisories within coastal waters of California.
- The species is an important indicator to statewide tracking of mercury levels due to its wide distribution and abundant populations.
- The sample size of the species in the 2018 Humboldt Baykeeper report was inadequate to provide recommendations based on mercury-level averages.

The fish species meeting one or more of these criteria included:

Lingcod (*Ophiodon elongatus*) – is the largest member of the greenling family, *Hexagrammidae*, and is distributed along the west coast from the Gulf of Alaska south to Baja Mexico (Kells et al. 2016). They are generally bottom-oriented fish associated with rocky reefs in depths of 50 to 500 feet. Lingcod are largely non-migratory. Prey items include just about any fish, mollusk or crustacean they can swallow, including rockfish with potentially elevated mercury levels. They are a popular sport fish due to their large size, aggressiveness and excellent taste. Lingcod can exceed 100 pounds in weight, but 10 to 30 pound fish are most commonly caught. Females mature at around age 3 to 5 years and can live up to 20 years. Males have a maximum lifespan of around 14 years. Lingcod are known to have moderately elevated to high mercury levels (Davis et al. 2012). Lingcod are widely distributed in the areas we sampled out of Eureka and Trinidad.

Pacific Halibut (*Hippoglossus stenolepis*) – is the largest species of the right-eyed flounder family, *Pleuroonectidae,* and are widely distributed from the Gulf of Alaska to northern Baja California (Kells et al. 2016). Off of northern California, most recreational fishing for Pacific Halibut occurs in 200 to 400 feet of water and is a very popular fishery. Prey items include bony fishes, crabs, krill, and octopus. Pacific Halibut is considered excellent table fare. Pacific Halibut are long-lived, with females reaching maturity at eight to 12 years and an estimated maximum lifespan of 50+ years. The all-tackle world record Pacific Halibut weighed 459 pounds and was caught out of Dutch Harbor, Alaska in 1996 (IGFA 2020). Most fish caught off of northern California are 10 to 30 pounds, with some individuals exceeding 50 to 70 pounds in weight.

Cabezon (*Scorpaenichthys marmoratus*) – is one of the largest species of sculpin and the only member of its genus. Cabezon are distributed from Alaska to northern Baja California and are found in inter-tidal areas to around 400 feet of water in mostly rocky areas and kelp forests (Kells et al. 2016). Common food items are mollusks, crustaceans and fish eggs. Their flesh is considered excellent table fare, but their eggs are toxic to humans. Cabezon are typically a by-catch, caught by fishermen targeting rockfish and Lingcod. Cabezon may grow to three feet in length and the maximum recorded weight is 25 pounds; however, most fish caught in northern California are less than 10 pounds. Cabezon are known to have moderately high mercury levels (Davis et al. 2012).

Vermillion Rockfish (*Sebastes miniatus*) – is a common species of rockfish found in California waters in depths from 100 to 500 feet and named for its bright red coloration (Kells et al. 2016). Their flesh is considered excellent table fare and Vermillion Rockfish are a sought after species by sport anglers. The all-tackle world record Vermillion Rockfish weighed 12 pounds and was caught out of Depoe Bay, Oregon in 1990 (IGFA 2020). Vermillion Rockfish may live upwards of 60 years and are known to have moderately high mercury levels (Davis et al. 2012).

Copper Rockfish (*Sebastes caurinus*) – is a common species of rockfish found in California waters in depths from 50 to 500 feet. Their flesh is considered excellent table fare and Copper Rockfish are a sought after species by sport anglers. The all-tackle world record Copper Rockfish weighed 7 lbs 15 oz. and was caught out of Shelter Cove, California in 2014 (IGFA 2020). Females mature between four to eight years of age. Tagging studies have shown that adult Copper Rockfish have high site fidelity and rarely stray far from the rocky reefs they occupy. Copper Rockfish may live upwards of 55 years and are known to have moderately high mercury levels (Davis et al. 2012).

Quillback Rockfish (*Sebastes maliger*) – is a common species of rockfish found in California waters in depths from 100 to 500 feet and are named for their prominent spines on their dorsal fins. Their flesh is considered good table fare, although their sharp and mildly venomous spines make them a challenge to filet. The all-tackle world record Quillback Rockfish weighed 7 lbs 4 oz. and was caught out of Depoe Bay, Oregon in 1990 (IGFA 2020). Quillback Rockfish are known to have moderately high mercury levels (Davis et al. 2012).

Canary Rockfish (*Sebastes pinniger*) – is a common pelagic species of rockfish found in California waters in depths from 50 to 800 feet and is notable for its orange-yellow coloration over a whitish background. Their flesh is considered good table fare. The all-tackle world record Canary Rockfish weighed 10 lbs 0 oz. and was caught out of Westport, Washington in 2001, although most Canary Rockfish caught are two to four pounds. Canary Rockfish are known to have relatively low mercury levels (Davis et al. 2012). Canary Rockfish were included in this study because between 2000 and 2016 the species was considered overfished and had to be released. However, sport harvest of Canary Rockfish was allowed in 2017 and daily bag limits have increased each year since 2017.

Bocaccio (*Sebastes paucispinis*) – is a large, slow-growing species of rockfish found in California waters in depths from 150 to 1,000 feet and are also called salmon grouper, slimy grouper or Tom cod. The quality and desirability of their flesh is debatable, with descriptions ranging from excellent table fare to wormy, mushy and smelly. The all-tackle world record Bocaccio weighed 27 lbs 14 oz. and was caught out of Elfin Cove, Alaska in 2001 (IGFA 2020). Bocaccio are a long-lived, late to mature, species and most stocks are considered overfished, with the Puget Sound sub-population listed as Endangered by the National Marine Fisheries Service. Several Bocaccios were caught during this study while angling for other species and were retained for mercury testing since little information was available for this species.

California Halibut (*Paralichthys californicus*) – is a large-toothed flounder species, distributed from Washington south to Magdalena Bay in Baja California. This flounder species is common in bays and near-shore waters and is an extremely popular sport fish due to its accessibility and excellent table fare. Most adult California Halibut reside in water depths less than 100 feet and are often caught in water depths of 10 to 30 feet in Humboldt Bay. Juveniles commonly rear in protected bays and adults opportunistically inhabit bays when forage fish are concentrated. California Halibut can grow upwards of 60 pounds, but most sport-caught fish in Humboldt Bay are in the five to 20 pound range. Females mature at about age four to five years and their maximum lifespan is approximately 30 years. California Halibut are known to have moderately elevated mercury levels (Davis et al. 2012). For this recent study, we captured an additional three California Halibut from Humboldt Bay for mercury testing, to bring our total sample size (from both studies) up to nine fish because nine is the minimum sample size required for establishing an OEHHA health advisory.

Methods - Fish Sampling and Processing:

Fish samples for the Humboldt Baykeeper's nearshore ocean mercury study were caught with sport-fishing tackle, following current regulations set by the California Department of Fish and Wildlife (https://www.wildlife.ca.gov/regulations). Our goal was to obtain at least nine tissue samples from each species so that our results could be used for establishing updated OEHHA health advisories for the Northcoast region of California. Because fish age (and size) often influences levels of methylmercury, we purposely collected tissue samples from a range of sizes for each species. Our most concerted effort at sampling a range of sizes was for Lingcod and Pacific Halibut because these species vary widely in size and we wanted to determine if statistical correlations existed between fish length and methylmercury levels for these two species with linear regressions and Pearson correlation coefficient analysis. We reviewed federal and state collection methodologies which stressed the importance of proper handling and preparation of tissue samples, thus sampling was limited to a pre-screened group of anglers that had previous experience in biological field surveys and data collection.

Methods used to handle fish and prepare samples for testing were consistent with methods described in the EPA document titled, *Guidance for Assessing Chemical Contaminant Data for use in Fish Advisories. Volume 1: Fish Sampling and Analysis* (U.S. EPA 2000). However, one deviation from the U.S. EPA methods was not testing composite samples (a mixture of flesh from more than one fish), because the use of a range of samples collected by various persons at various times and locations was potentially not suitable for composite testing. Also, testing of composite samples requires a higher level of quality control in obtaining and handling samples, as well as a more rigorous chain of custody.

One of the most important aspects of this project was how fish were handled upon capture, as exemplified by the following paragraph in the U.S. EPA document: *The primary QA consideration in sample collection, processing, preservation, and shipping procedures is the preservation of sample integrity to ensure the accuracy of target analyte analyses. Sample* *integrity is preserved by prevention of loss of contaminants already present in the tissues and prevention of extraneous tissue contamination.*

These steps, as recommended by the U.S. EPA, were followed when handling and processing fish caught in Humboldt County's nearshore ocean waters for testing:

1. All fish kept for a tissue sample were caught alive and were free of cuts, lacerations, tumors and other open wounds. We released any fish that appeared wounded. All fish that were not of legal size were also released.
2. All equipment used for measuring, holding, processing and storing fish and/or tissue samples were cleaned with detergent and rinsed with distilled water prior to processing each fish/tissue sample.
3. To avoid contamination with melting ice in coolers, sampled fish and/or filets were placed in waterproof (zip-lock) bags.
4. Although the U.S. EPA discourages field processing of fish (i.e. filleting and bagging), when this was done, extra care was taken to avoid contamination with any sources of gasoline, diesel, oils and grease. All knives, cleaning boards and gloves were thoroughly washed between field processing of tissue samples.
5. Individual fish of the selected target species were rinsed in ambient water to remove any foreign material from the external surface. Large fish were stunned by a sharp blow to the base of the skull with a wooden club or metal rod. This club was used solely for the purpose of stunning fish, and was cleaned to prevent contamination of the samples.
6. Once stunned, the fish's total length was measured in inches (Figure 1). Whole fish were weighed with either a digital hanging scale or a digital tray scale.
7. Photos were taken of each fish prior to processing. At least one photo had an item in the photo for scale (such as person or measuring device). Representative photos of the species caught and sampled are presented in Appendix A.
8. Field processing was done immediately and filleting was conducted by an experienced fisheries biologist. Prior to filleting, hands (or gloves) were washed with soap and rinsed thoroughly in ambient water, followed by distilled water. Specimens came into contact only with non-contaminating surfaces. Fish were filleted on a Polytetrafluoroethylene (PTFE) cutting board that was cleaned properly between each processed fish. Care was taken to avoid contaminating filet tissues with material released from inadvertent puncture of internal organs. Any dark muscle tissue in the vicinity of the lateral line should not be separated from the light muscle tissue that constitutes the rest of the muscle tissue mass.
9. After filleting and skinning the fish, we cut off a piece between eight ounces to one pound in size (225 to 450 grams), blot dried, wrapped it in aluminum foil or plastic wrap, taped it, and placed the sample in sealed zip-lock bag. This bag was then stored in a

clean cooler on ice. The samples bags were positioned in the cooler so that melted ice-water was unable to infiltrate the bags. The bags were also clearly marked with species and capture information (fish species, total length, weight of fish, capture date, capture location) with a tag consistent with the U.S. EPA protocol (Figure 2). This tag was inserted into each sample's zip-lock bag.

10. After a day of field sampling, all zip-lock bags of tissue samples were stored in a freezer (at -20ºC or -4ºF). For methylmercury testing, CDFW standards stated that samples can be frozen for up to six months prior to laboratory testing (EPA 2000).
11. Field data sheets – we used the U.S. EPA field form with one modification: numbering the fish individually (such as, Lingcod #01) and ignored the "composite sample" section of the data sheet. Also, the weight of the whole fish was entered. Data sheets were printed on water-proof paper for field use. After each field day, the data sheets were scanned and saved as PDFs.
12. Field Equipment list –the Humboldt County nearshore ocean project used a list consistent with the U.S. EPA recommendations for collection of tissue samples in the field (Appendix B).

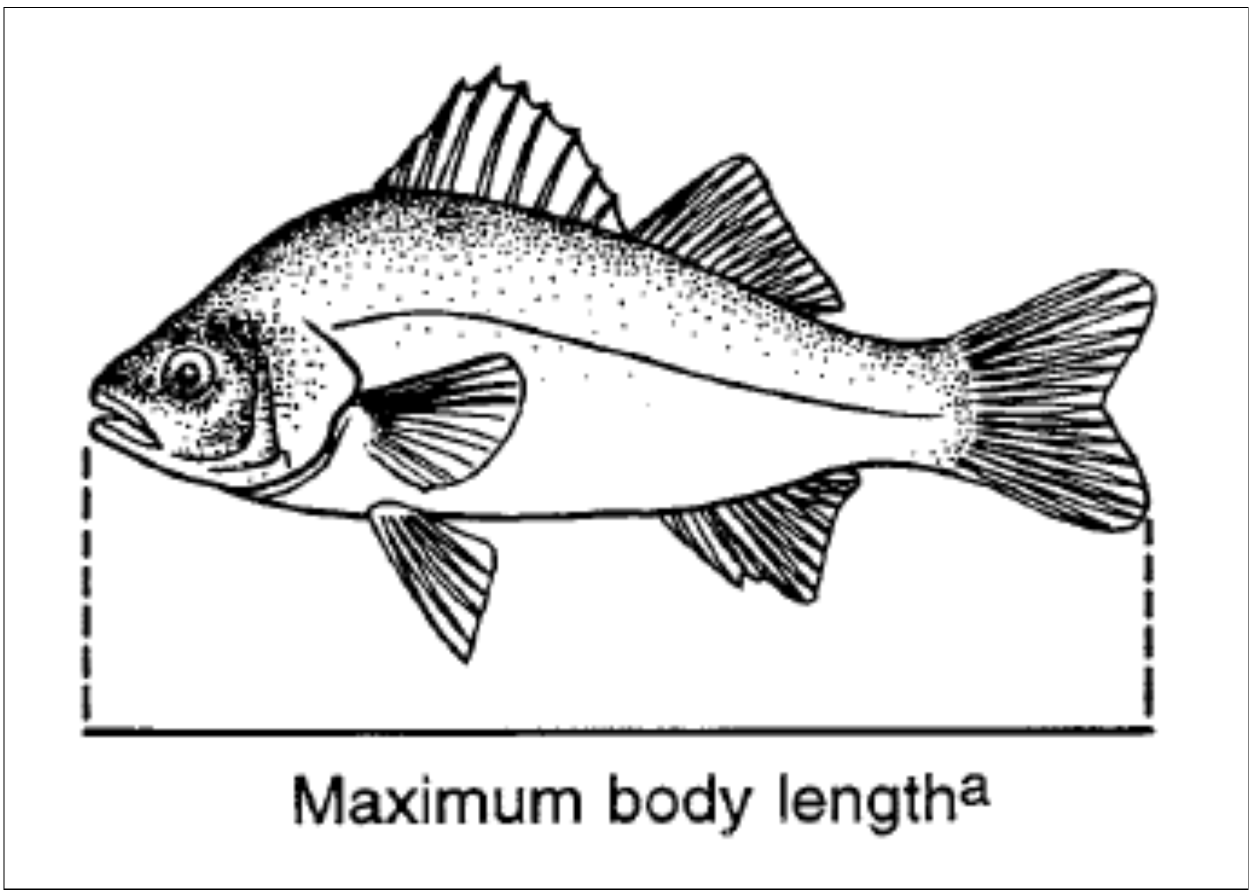

Figure 1. Example of measurement of total length (from U.S. EPA 2000).

Species Name or Code	Sample Type
Total Length or Size (mm)	Sampling Site (name/number)
Specimen Number ☐☐☐☐☐ — ☐☐☐	Sampling Date (YYYMMDD)
	Time (24-h clock)

6.2.3.2 Sample Identification Label—

A sample identification label should be completed in indelible ink for each individual fish or shellfish specimen after it is processed to identify each sample uniquely (Figure 6-7). The following information should be included on the sample identification label:

- Species scientific name or code number
- Total length/size of specimen (mm)
- Specimen number
- Sample type: F (fish fillet analysis only)
  S (shellfish edible portion analysis only)
  W (whole fish analysis)
  O (other fish tissue analysis)

Figure 2. Example of U.S. EPA sample ID label and label instructions (from U.S. EPA 2000).

Skinless filets of fish were tested, consistent with the flesh normally consumed by the Humboldt County angling community. The U.S. EPA (2000) states that, "*using skinless fillets for assessing mercury exposures for members of the general population and most recreational fishers is most conservative. Because mercury is differentially concentrated in muscle tissue, leaving the skin on the fish fillet actually results in a lower mercury concentration per gram of skin-on fillet than per gram of skin-off fillet. In addition, few consumers in the general population eat the skin of the fish, which justifies its removal for analysis, particularly when monitoring concerns are directed solely at mercury contamination.*" The tissue sample size of a filet from each captured fish was visually estimated as between eight ounces and one pound.

Methods - Tissue Sample Testing and Reporting:

Tissue samples were sent to Brooks Applied Labs, located in Bothell, Washington. The Humboldt County nearshore ocean tissue samples were analyzed for methylmercury and a subset of 30 tissue samples were analyzed for selenium. Of the total amount of mercury found in fish muscle tissue, methylmercury often comprises more than 95 percent and is also the more toxic form (Bloom, 1992). In our previous study, fish sampled from Humboldt Bay had methylmercury values that were 81% to 96% of the total mercury. Several studies have generally shown that as fish age, mercury concentrations in their flesh increase, including concentrations of methylmercury (U.S. EPA 2000). Methylmercury is typically more expensive to test for, compared to testing for total mercury. Because of these reasons, total mercury is often analyzed for most fish studies and assumed to be 100 percent methylmercury for the purposes of conservative risk assessment (Davis et al. 2012; Smith et al. 2016). However, for the Humboldt County nearshore ocean study, our results are reported as concentrations of methylmercury in parts per million (ppm).

The methylmercury thresholds used for the Humboldt County nearshore ocean study were consistent with Advisory Tissue Levels (ATLs) developed by OEHHA and SWAMP for mercury (Davis et al. 2012; Smith et al. 2016; Klasing and Brodberg 2018). Again, both OEHHA and SWAMP use the term mercury as interchangeable for either total mercury or methylmercury, using total mercury as a surrogate for methylmercury. The OEHHA fish advisory process considers both the health benefits of fish consumption and the risk from exposure to the chemical contaminants found in fish. Benefits are included in the advisory process because there is considerable evidence and scientific consensus that fish should be part of a healthy, well-balanced diet. Thus, the ATLs consider both the toxicity of the chemical and the potential health benefits of eating fish. OEHHA uses the ATLs to determine the maximum number of servings per week that consumers can safely eat, for each species and at each location, to limit their exposure to these contaminants. The OEHHA developed ATL thresholds to establish the recommended number of servings per week based on age and sex because fetuses and children are more sensitive to the toxic effects of methylmercury (Table 1). The lower ATL values for the sensitive population provide additional protection to allow for normal growth and development of the brain and nervous system of unborn babies, nursing infants, and children (Smith et al. 2016). For an adult, one serving is considered an eight-ounce uncooked skinless filet (four ounces cooked). A serving for a child is half that (four ounces uncooked and two ounces cooked).

Selenium levels were determined by Brooks Applied Labs for 30 tissue samples and were also reported in ppm. Calculation of selenium and methylmercury molar weights and molar ratios followed methods described in Burger and Gochfeld (2012). Mean selenium:methylmercury molar ratios were calculated from the average selenium and average methylmercury levels in the selected fish species. For these species, we divided the mean selenium concentration (ppm) by 78.96 g/mol and the mean mercury concentration (ppm) by 215.63 g/mol, multiplied these by 1,000 to calculate the molar ratios (Se/MeHg). We reported selenium:methylmercury ratios, consistent with Burger and Gochfeld (2012).

Table 1. Updated OEHHA Advisory Tissue Levels (ATLs) from Klasing and Brodberg (2018). Note: values in this table are reported in parts per billion (ppb); conversion to ppm requires moving decimal place three times to the left (1,000 ppb = 1 ppm).

TABLE 2. ADVISORY TISSUE LEVELS (ATLS) FOR SELECTED FISH CONTAMINANTS BASED ON CANCER OR NON-CANCER RISK USING AN 8 OUNCE SERVING SIZE (PRIOR TO COOKING) (PPB, WET WEIGHT)

Contaminant	Consumption Frequency Categories (8-ounce servings/week)[a] and ATLs (in ppb)							
	7	6	5	4	3	2	1	0
Chlordanes[c]	≤ 80	>80-90	>90-110	>110-140	>140-190	>190-280	>280-560	>560
DDTs**	≤ 220	>220-260	>260-310	>310-390	>390-520	>520-1,000	>1,000-2,100	>2,100
Dieldrin[C]	≤ 7	>7-8	>8-9	>9-11	>11-15	>15-23	>23-46	>46
Mercury[nc] (Women 18-45 and children 1-17)	≤ 31	>31-36	>36-44	>44-55	>55-70	>70-150	>150-440	>440
Mercury[nc] (Women > 45 and men)	≤ 94	>94-109	>109-130	>130-160	>160-220	>220-440	>440-1,310	>1,310
PBDEs[nc]	≤ 45	>45-52	>52-63	>63-78	>78-100	>100-210	>210-630	>630
PCBs[nc]	≤ 9	>9-10	>10-13	>13-16	>16-21	>21-42	>42-120	>120
Selenium[nc]	≤ 1000	>1,000-1200	>1,200-1,400	>1,400-1,800	>1,800-2,500	>2,500-4,900	>4,900-15,000	>15,000
Toxaphene[c]	≤ 87	>87-100	>100-120	>120-150	>150-200	>200-300	>300-610	>610

[c]ATLs are based on cancer risk

[nc]ATLs are based on non-cancer risk

*Serving sizes are based on an average 160 pound person. Individuals weighing less than 160 pounds should eat proportionately smaller amounts (for example, individuals weighing 80 pounds should eat one 4-ounce serving a week when the table recommends eating one 8-ounce serving a week).

**ATLS for DDTs are based on non-cancer risk for two and three servings per week and cancer risk for one serving per week.

Results – Mercury Levels of Fish Tested from Humboldt County's Nearshore Ocean Waters

The collection of 70 tissue samples for the nearshore ocean mercury testing was conducted by Jeffery Stackhouse, a licensed fishing guide, and by Ross Taylor and Associates (RTA), a consulting fisheries biology firm. Stackhouse conducted the sampling trips out of Eureka and RTA conducted the sampling trips out of Trinidad. Processed tissue samples were held in a chest freezer at RTA's place of business and when sufficient samples were accumulated we packaged a shipment for Brooks Applied Labs. Three shipments were made and these occurred on 2/11/20, 8/24/20 and 12/30/20. Shipped samples were sent in a cooler packed with ice and each shipment included a chain-of-custody form completed by Jennifer Kalt of Humboldt Baykeeper. Brooks Applied Labs analyzed all 70 of our samples for methylmercury and then retained portions of all tissue samples to allow us to select a subset of 30 tissue samples for selenium testing based on the methylmercury results.

For Lingcod, a total of 13 fish were caught in 2019 and 2020 from Cape Mendocino, Patrick's Point and Reading Rock. These 13 Lingcod ranged in size from 6.2 pounds and 28 inches to 25.6 pounds and 40 inches (Table 2). These 13 Lingcod had an average methylmercury content of 0.951 ppm with values ranging from 0.171 to 2.840 ppm (Table 2 and Figure 3). When combined with the five Lingcod caught along the Humboldt Bay jetties in 2016, the 18 fish had an average methylmercury content of 0.765 ppm. The Lingcod caught along the jetties in 2016 were smaller fish, all between 22 and 30 inches in length, with an average methylmercury content of 0.279 ppm (Table 2).

For Pacific Halibut, a total of nine fish were caught in 2020, three fish out of Eureka and six fish out of Trinidad. These nine Pacific Halibut ranged in size from 7.1 pounds and 26 inches to 49 pounds and 48.5 inches (Table 2). These Pacific Halibut had an average methylmercury content of 0.153 ppm with values ranging from 0.063 to 0.355 ppm (Table 2 and Figure 4).

Although this second mercury study was focused on nearshore ocean fish species, we collected tissue samples from three additional California Halibut, so when combined with the previous study there was a nine-fish average available for an OEHHA health advisory. Thus, the nine California Halibut tested ranged in size from 4.8 pounds and 22 inches to 36 pounds and 45.5 inches (Table 2). These California Halibut had an average methylmercury content of 0.146 ppm with values ranging from 0.051 to 0.328 ppm (Table 2 and Figure 4).

Five Cabezon were tested and all of these fish were caught on the Outer Pinnacles at Cape Mendocino. These five Cabezon ranged in size from 4.5 pounds and 19.5 inches to 9.5 pounds and 25.5 inches (Table 2). These five Cabezon had an average methylmercury content of 0.549 ppm with values ranging from 0.344 to 0.825 ppm (Table 2 and Figure 3).

A total of nine Vermillion Rockfish were caught in 2019 and 2020, six fish out of Eureka (Cape Mendocino) and three fish out of Trinidad (Patrick's Point and Reading Rock). These nine Vermillion Rockfish ranged in size from 2.2 pounds and 15 inches to 9.7 pounds and 23.5 inches (Table 2). The Vermillion Rockfish had an average methylmercury content of 0.596 ppm with values ranging from 0.153 to 1.420 ppm (Table 2 and Figure 5).

A total of ten Copper Rockfish were caught in 2019 and 2020, six fish out of Eureka (Cape Mendocino and the Outer Pinnacles) and four fish out of Trinidad (Reading Rock). These ten Copper Rockfish ranged in size from 0.84 pounds and 11 inches to 3.8 pounds and 17.8 inches (Table 2). The Copper Rockfish had an average methylmercury content of 0.695 ppm with values ranging from 0.205 to 1.910 ppm (Table 2 and Figure 5).

A total of nine Quillback Rockfish were caught in 2019 and 2020, six fish out of Eureka (Cape Mendocino and Outer Pinnacles) and three fish out of Trinidad (Reading Rock). These nine Quillback Rockfish ranged in size from 1.5 pounds and 14 inches to 4.2 pounds and 18 inches (Table 2). The Quillback Rockfish had an average methylmercury content of 0.922 ppm with values ranging from 0.128 to 1.410 ppm (Table 2 and Figure 5). Three of the nine Quillback Rockfish exceeded the "do not consume" threshold of 1.33 ppm (Table 2 and Figure 5).

A total of nine Canary Rockfish were caught in 2019 and 2020, six fish out of Eureka (Cape Mendocino) and three fish out of Trinidad (Reading Rock). These nine Canary Rockfish ranged in size from 0.8 pounds and 14 inches to 3.6 pounds and 21.5 inches (Table 2). The Canary Rockfish had an average methylmercury content of 0.238 ppm with values ranging from 0.087 to 0.620 ppm (Table 2 and Figure 5).

Three Bocaccio were caught in 2019 and 2020, one out of Eureka (Cape Mendocino) and two out of Trinidad (Reading Rock). The Bocaccio ranged in size from 4.1 pounds and 21.3 inches to 11.2 pounds and 29.5 inches (Table 2). The Bocaccio had an average methylmercury content of 0.521 ppm with values ranging from 0.109 to 1.050 ppm (Table 2 and Figure 5).

For establishing or updating OEHHA fish consumption advisories, a minimum of nine tissue samples are required. For the nearshore ocean mercury study, we analyzed at least nine samples from seven of the species that we caught and tested (Table 3).

For Lingcod and Pacific Halibut, fish lengths and methylmercury values were plotted to assess whether fish size and MeHg levels were correlated (Figures 6 and 7). For Lingcod, the R^2 value of 0.6434 and a Pearson correlation coefficient of 0.78 ($p<0.05$) confirmed a strong, positive correlation of fish length to methylmercury level (Figure 6). For Pacific Halibut, the R^2 value of 0.7388 and a Pearson correlation coefficient of 0.86 ($p<0.05$) confirmed a strong, positive correlation of fish length to methylmercury level (Figure 7). These correlations support the validity of making consumption recommendations based on lengths for these two species.

Table 2. Methylmercury testing results for nearshore Pacific Ocean fishes, Humboldt County, CA.

Collection Date	Species	Lab's Tissue Sample ID #	Total Length (inches)	Whole Weight (pounds)	Methyl-Mercury (ppm)	Sample Location and Description	Lat-Longs
10/20/2016	Lingcod	LCOD-001	22.4	3.6	0.137	South jetty	40° 45.834, -124° 14.551
10/20/2016	Lingcod	LCOD-002	29.3	9.2	0.452	South jetty	40° 45.834, -124° 14.551
7/21/2017	Lingcod	LCOD-003	26.0	6.8	0.341	North jetty	40° 46.084, -124° 14.323
7/21/2017	Lingcod	LCOD-004	25.3	4.9	0.226	North jetty	40° 46.084, -124° 14.323
7/21/2017	Lingcod	LCOD-005	26.4	6.5	0.238	North jetty	40° 46.084, -124° 14.323
8/30/2019	Lingcod	Ling-001	28.5	7.5	0.484	Reading Rock	40° 20.77, -124° 11.00
8/29/2019	Lingcod	Ling-002	29.0	9.1	0.408	Cape Mendocino	40° 27.568, -124° 29.949
8/29/2019	Lingcod	Ling-003	33.5	13.9	1.940	Cape Mendocino	40° 27.568, -124° 29.949
11/13/2019	Lingcod	Ling-004	33.5	14.6	0.789	Cape Mendocino	40°26.622, -124°30.822
8/29/2019	Lingcod	Ling-005	33.5	14.8	0.550	Cape Mendocino	40° 27.568, -124° 29.949
11/13/2019	Lingcod	Ling-006	34.0	15.7	0.720	Cape Mendocino	40°26.622, -124°30.822
11/13/2019	Lingcod	Ling-007	35.0	16.6	1.490	Cape Mendocino	40°26.622, -124°30.822
11/13/2019	Lingcod	Ling-008	38.5	25.6	1.590	Cape Mendocino	40°26.622, -124°30.822
11/13/2019	Lingcod	Ling-009	40.0	22.8	2.840	Cape Mendocino	40°26.622, -124°30.822
7/28/2020	Lingcod	Ling-010	24.8	6.2	0.193	Patrick's Point	41° 13.2265, -124° 17.6639
7/28/2020	Lingcod	Ling-011	26.5	6.6	0.171	Patrick's Point	41° 13.2265, -124° 17.6639
9/04/2020	Lingcod	Ling-012	32.5	11.7	0.537	Reading Rock	40° 20.77, -124° 11.00
9/04/2020	Lingcod	Ling-013	36.0	13.8	0.655	Reading Rock	40° 20.77, -124° 11.00
5/15/2020	Pacific Halibut	PacHal-001	42.5	35.0	0.289	West of Trinidad	41° 04.048, -124° 16.445
6/09/2020	Pacific Halibut	PacHal-002	33.0	12.0	0.070	West of Eureka	40° 42.464, -124° 27.792
6/09/2020	Pacific Halibut	PacHal-003	26.0	7.1	0.073	West of Eureka	40° 42.464, -124° 27.792
6/09/2020	Pacific Halibut	PacHal-004	29.0	11.0	0.078	West of Eureka	40° 42.464, -124° 27.792
6/09/2020	Pacific Halibut	PacHal-005	27.5	7.8	0.126	West of Trinidad	40° 56.532, -124° 17.133
6/09/2020	Pacific Halibut	PacHal-006	29.5	9.2	0.063	West of Trinidad	40° 56.532, -124° 17.133
6/09/2020	Pacific Halibut	PacHal-007	44.0	35.5	0.159	West of Trinidad	40° 56.532, -124° 17.133
7/28/2020	Pacific Halibut	PacHal-008	37.5	22.8	0.162	West of Trinidad	41° 14.5779, -124° 28.3466
7/29/2020	Pacific Halibut	PacHal-009	48.5	49.0	0.355	West of Trinidad	41° 14.5779, -124° 28.3466

Table 2 (continued). Methylmercury testing results for nearshore Pacific Ocean fishes, Humboldt County, CA.

Collection Date	Species	Lab's Tissue Sample ID #	Total Length (inches)	Whole Weight (pounds)	Total Mercury (ppm)	Sample Location and Description	Lat-Longs
8/29/2019	Cabezon	Cabezon-001	22.0	3.1	0.438	Cape Mendocino	40° 27.568, -124° 29.949
6/9/2020	Cabezon	Cabezon-002	25.5	9.5	0.825	Cape Mendocino	40° 29.767, -124° 31.104
6/9/2020	Cabezon	Cabezon-003	19.5	4.5	0.344	Cape Mendocino	40° 29.767, -124° 31.104
6/9/2020	Cabezon	Cabezon-004	22.0	6.8	0.544	Cape Mendocino	40° 29.767, -124° 31.104
6/9/2020	Cabezon	Cabezon-005	22.0	6.7	0.596	Cape Mendocino	40° 29.767, -124° 31.104
8/07/2019	Vermillion Rockfish	Vermillion-001	15.0	2.2	0.153	Cape Mendocino	40° 27.169, -124° 26.934
8/30/2019	Vermillion Rockfish	Vermillion-002	19.5	4.7	0.615	Reading Rock	40° 20.77, -124° 11.00
11/13/2019	Vermillion Rockfish	Vermillion-003	20.0	4.9	0.857	Cape Mendocino	40°26.622, -124°30.822
11/13/2019	Vermillion Rockfish	Vermillion-004	21.0	5.8	0.525	Cape Mendocino	40°26.622, -124°30.822
8/29/2019	Vermillion Rockfish	Vermillion-005	21.0	5.8	0.426	Cape Mendocino	40° 27.568, -124° 29.949
11/13/2019	Vermillion Rockfish	Vermillion-006	21.5	6.3	0.561	Cape Mendocino	40°26.622, -124°30.822
11/13/2019	Vermillion Rockfish	Vermillion-007	23.5	9.7	1.420	Cape Mendocino	40°26.622, -124°30.822
7/28/2020	Vermillion Rockfish	Vermillion-008	19.5	5.5	0.179	Patrick's Point	41° 13.226, -124° 17.663
9/4/2020	Vermillion Rockfish	Vermillion-009	20.0	6.1	0.624	Reading Rock	40° 20.77, -124° 11.00
8/7/2019	Copper Rockfish	Copper-001	16.0	2.4	0.615	Cape Mendocino	40° 26.681, -124° 30.362
8/7/2019	Copper Rockfish	Copper-002	13.3	1.3	0.406	Cape Mendocino	40° 26.836, -124° 30.502
8/7/2019	Copper Rockfish	Copper-003	18.0	3.7	1.910	Cape Mendocino	40° 26.836, -124° 30.502
8/30/2019	Copper Rockfish	Copper-004	17.8	3.4	0.965	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Copper Rockfish	Copper-005	16.8	3.8	0.706	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Copper Rockfish	Copper-006	16.0	2.8	0.785	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Copper Rockfish	Copper-007	15.5	2.9	0.401	Reading Rock	40° 20.77, -124° 11.00
6/9/2020	Copper Rockfish	Copper-008	11.0	0.8	0.205	Cape Mendocino	40° 29.767, -124° 31.104
6/9/2020	Copper Rockfish	Copper-009	14.0	1.6	0.297	Cape Mendocino	40° 29.767, -124° 31.104
6/9/2020	Copper Rockfish	Copper-010	16.0	3.0	0.662	Cape Mendocino	40° 29.767, -124° 31.104
8/07/2019	Quillback Rockfish	Quillback-001	14.5	2.1	1.040	Cape Mendocino	40° 26.681, -124° 30.362
8/07/2019	Quillback Rockfish	Quillback-002	14.5	2.4	0.747	Cape Mendocino	40° 26.681, -124° 30.362
8/07/2019	Quillback Rockfish	Quillback-003	16.5	3.5	1.400	Cape Mendocino	40° 26.836, -124° 30.502
8/07/2019	Quillback Rockfish	Quillback-004	16.0	3.1	1.410	Cape Mendocino	40° 26.836, -124° 30.502

Table 2 (continued). Methylmercury testing results for nearshore Pacific Ocean fishes, Humboldt County, CA.

Collection Date	Species	Lab's Tissue Sample ID #	Total Length (inches)	Whole Weight (pounds)	Total Mercury (ppm)	Sample Location and Description	Lat-Longs
8/30/2019	Quillback Rockfish	Quillback-005	14.8	1.6	1.380	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Quillback Rockfish	Quillback-006	14.0	1.5	0.128	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Quillback Rockfish	Quillback-007	14.3	2.0	0.853	Reading Rock	40° 20.77, -124° 11.00
6/09/2020	Quillback Rockfish	Quillback-008	18.0	4.2	1.050	Cape Mendocino	40° 29.767, -124° 31.104
6/09/2020	Quillback Rockfish	Quillback-009	14.0	2.2	0.286	Cape Mendocino	40° 29.767, -124° 31.104
8/07/2019	Canary Rockfish	Canary-001	14.0	0.8	0.087	Cape Mendocino	40° 26.681, -124° 30.362
8/07/2019	Canary Rockfish	Canary-002	14.0	1.3	0.175	Cape Mendocino	40° 26.836, -124° 30.502
8/29/2019	Canary Rockfish	Canary-003	16.0	2.3	0.109	Cape Mendocino	40° 27.568, -124° 29.949
8/30/2019	Canary Rockfish	Canary-004	16.3	2.3	0.321	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Canary Rockfish	Canary-005	16.5	2.4	0.213	Reading Rock	40° 20.77, -124° 11.00
8/30/2019	Canary Rockfish	Canary-006	17.0	2.6	0.177	Reading Rock	40° 20.77, -124° 11.00
8/29/2019	Canary Rockfish	Canary-007	19.0	3.6	0.219	Cape Mendocino	40° 27.568, -124° 29.949
8/07/2019	Canary Rockfish	Canary-008	20.00	3.60	0.218	Cape Mendocino	40° 26.496, -124° 30.899
11/13/2019	Canary Rockfish	Canary-009	21.50	N/A	0.620	Cape Mendocino	40°26.622, -124°30.822
11/13/2019	Boccaccio	Bocaccio-001	26.50	6.83	0.405	Cape Mendocino	40°26.622, -124°30.822
8/30/2019	Boccaccio	Bocaccio-002	29.50	11.20	1.050	Reading Rock	40° 20.77, -124° 11.00
9/4/2020	Boccaccio	Bocaccio-003	21.25	4.10	0.109	Reading Rock	40° 20.77, -124° 11.00
8/24/2016	California Halibut	CAHAL-001	24.0	5.4	0.121	North of Samoa Bridge in west channel	40° 49.32, -124° 09.94
8/24/2016	California Halibut	CAHAL-002	23.6	5.4	0.088	North of Samoa Bridge in west channel	40° 49.29, -124° 10.05
8/24/2016	California Halibut	CAHAL-003	22.8	4.8	0.192	North of Samoa Bridge in west channel	40° 49.40, -124° 09.39
8/24/2016	California Halibut	CAHAL-004	22.8	5.1	0.141	North of Samoa Bridge in west channel	40° 49.39, -124° 09.32
8/24/2016	California Halibut	CAHAL-005	24.8	5.7	0.328	North of Samoa Bridge in west channel	40° 49.40, -124° 09.01
9/24/2017	California Halibut	CAHAL-006	45.5	36.0	0.186	Near Coast Guard Station	40° 76.58, -124° 21.39
8/16/2019	California Halibut	CAHAL-007	29.3	9.1	0.115	Humboldt Bay	40° 49.504, -124° 09.045
8/16/2019	California Halibut	CAHAL-008	29.0	9.3	0.092	Humboldt Bay	40° 49.504, -124° 09.045
8/16/2019	California Halibut	CAHAL-009	24.7	6.4	0.051	Humboldt Bay	40° 49.504, -124° 09.045

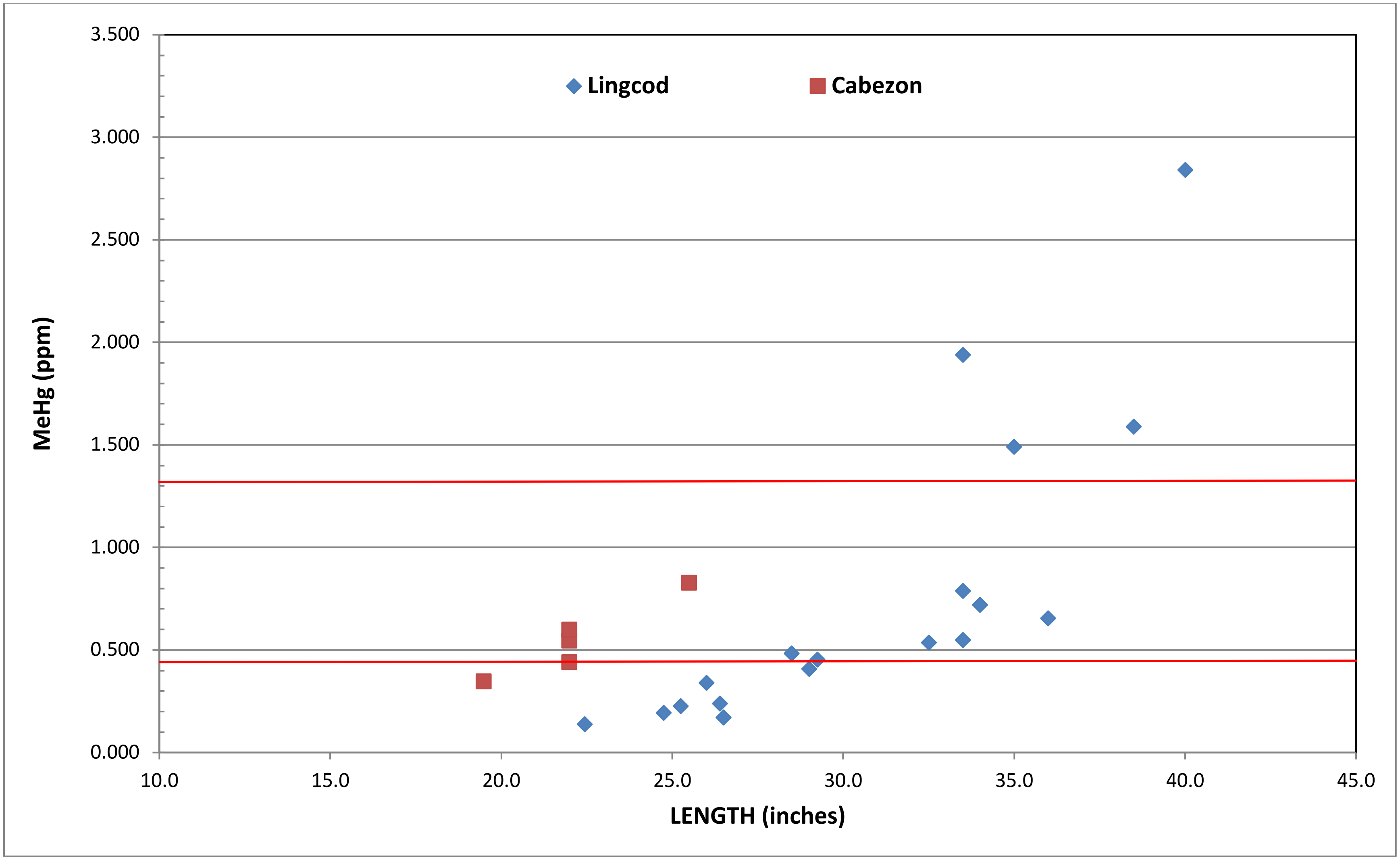

Figure 3. Methylmercury (ppm) versus fish length (inches) for Lingcod and Cabezon. Lower red line = 0.44 ppm "do not consume" for women < 45 years old and children. Upper red line = 1.31 ppm "do not consume" for women >45 years old and adult men.

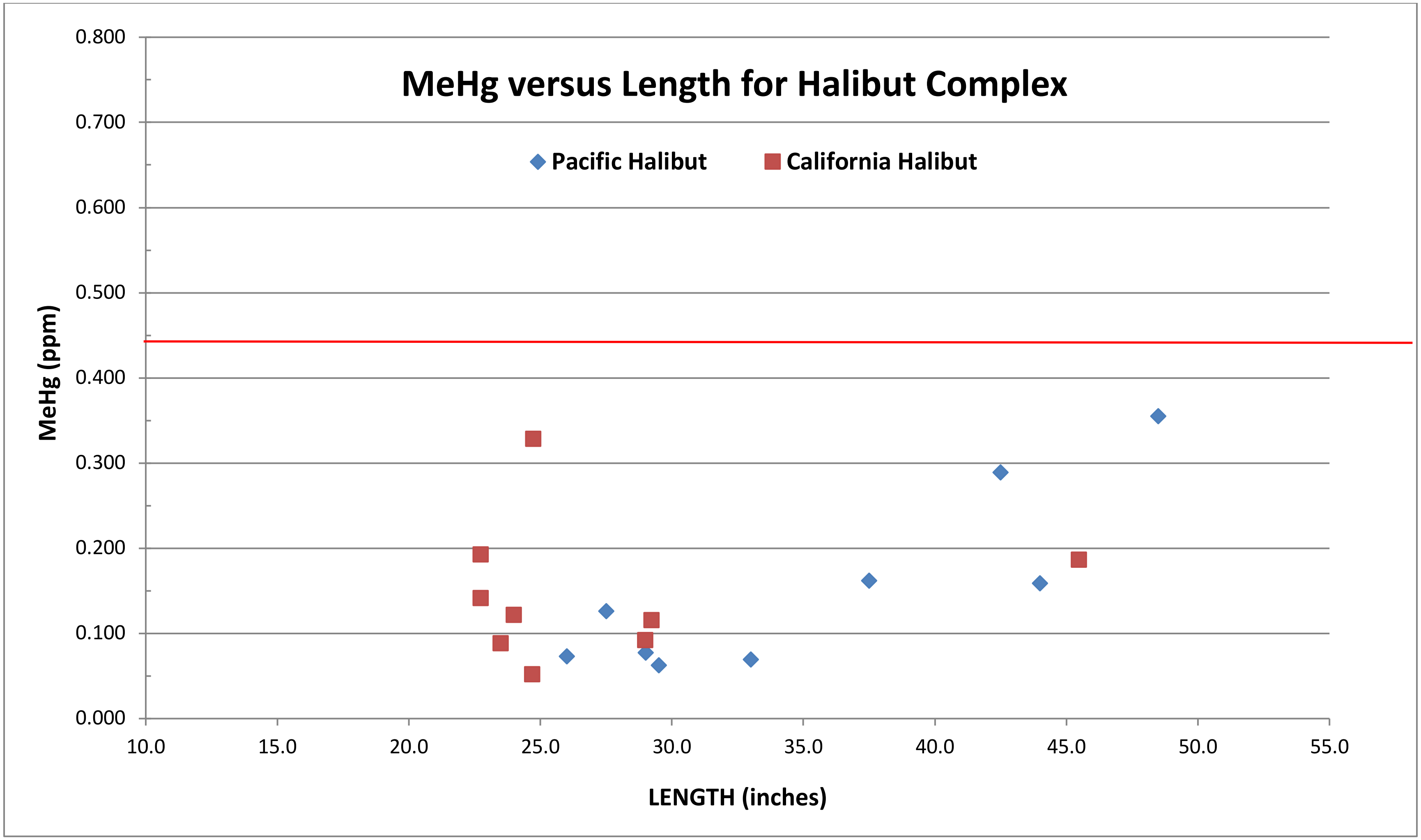

Figure 4. Methylmercury (ppm) versus fish length (inches) for Pacific Halibut and California Halibut. Red line = 0.44 ppm "do not consume" for women < 45 years old and children.

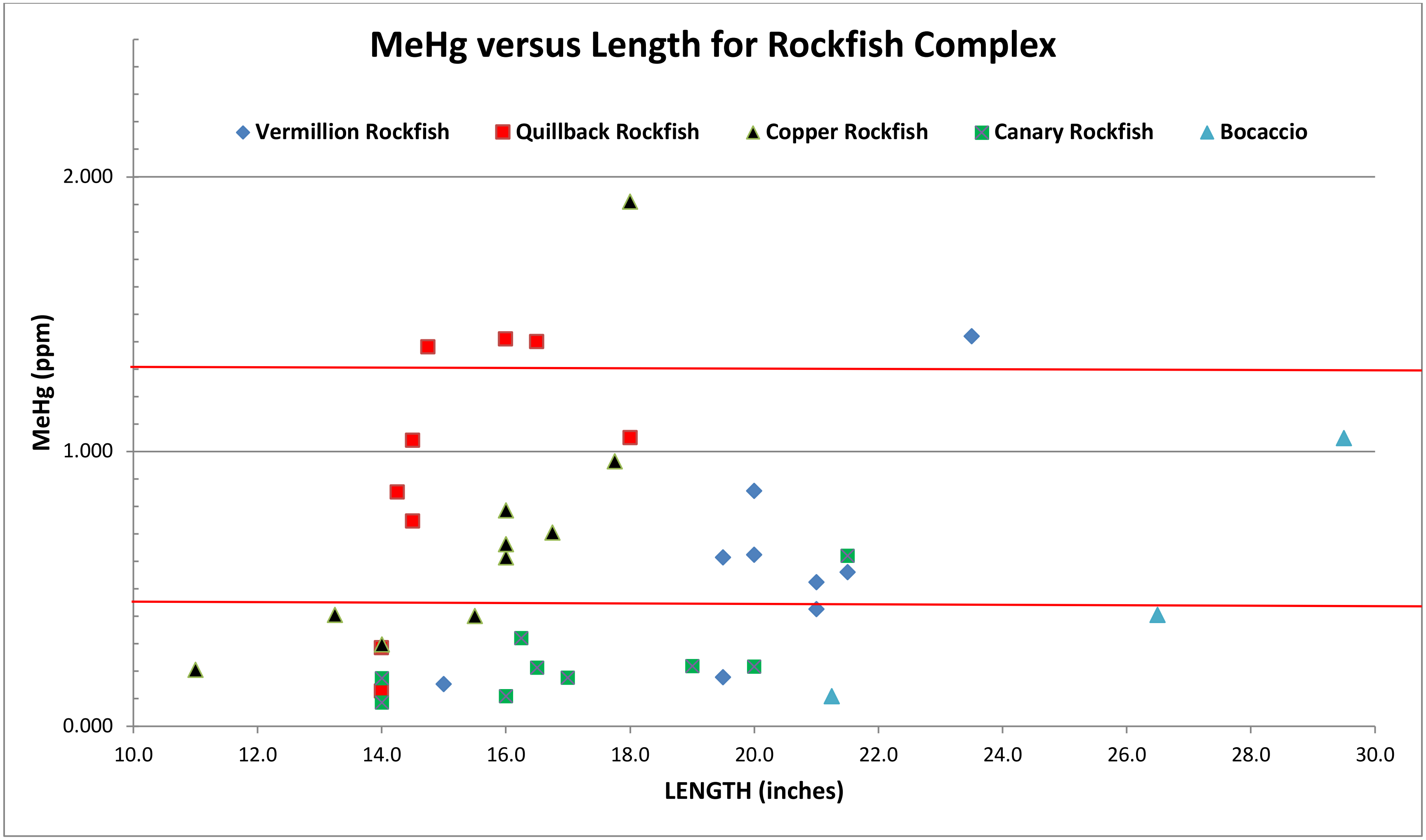

Figure 5. Methylmercury (ppm) versus fish length (inches) for five species of rockfish. Lower red line = 0.44 ppm "do not consume" for women < 45 years old and children. Upper red line = 1.31 ppm "do not consume" for women >45 years old and adult men.

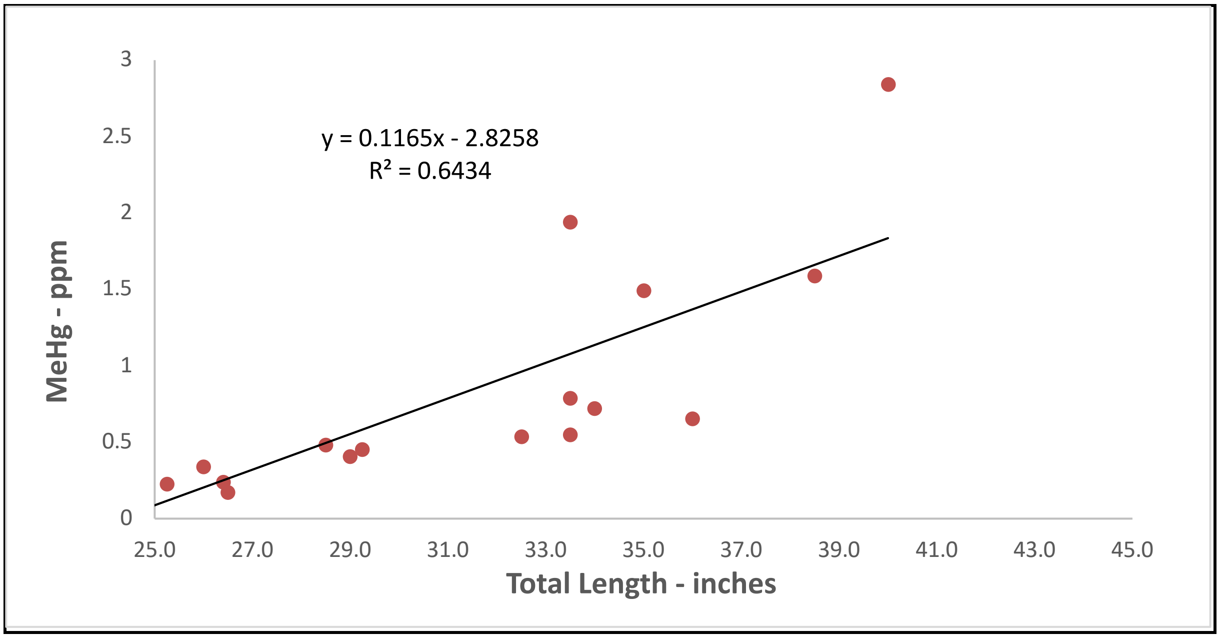

Figure 6. Linear regression of total length and methylmercury for Lingcod (n=18) captured in Humboldt Bay and nearshore ocean waters of northern California.

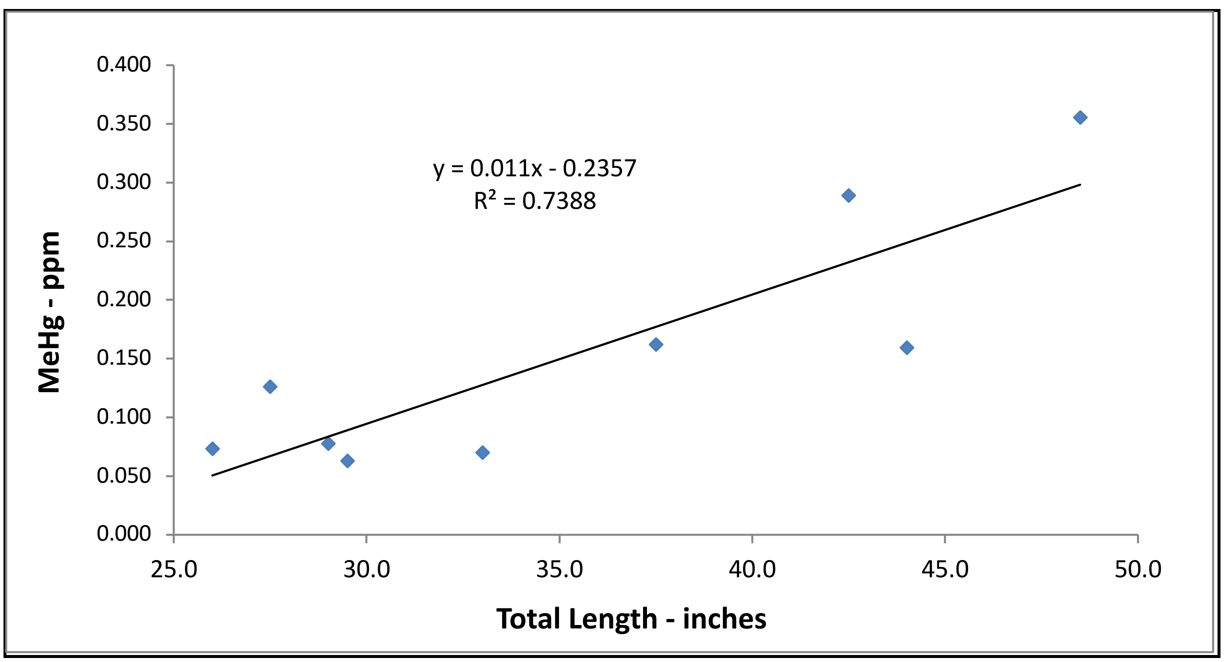

Figure 7. Linear regression of total length and methylmercury for Pacific Halibut (n=9) captured in nearshore ocean waters of northern California.

Table 3. Average methylmercury levels and summary statistics for seven species of nearshore ocean fishes with at least nine samples for establishment of OEHHA health advisories.

Species	Sample Size	Ave. MeHg (ppm)	Standard Deviation	Variance	95% Conf. Interval
Lingcod (ocean)	n = 13	0.951	0.787	0.620	± 0.428
Lingcod (bay and ocean)	n = 18	0.765	0.730	0.537	± 0.339
Quillback Rockfish	n = 9	0.922	0.471	0.222	± 0.308
Copper Rockfish	n = 10	0.695	0.487	0.237	± 0.302
Vermillion Rockfish	n = 9	0.596	0.379	0.144	± 0.248
Canary Rockfish	n = 9	0.238	0.158	0.025	± 0.104
Pacific Halibut	n = 9	0.153	0.104	0.011	± 0.068
California Halibut	n = 9	0.146	0.082	0.007	± 0.054

Results – Selenium Levels of Fish Tested from Humboldt County's Nearshore Ocean Waters

Out of the 70 tissue samples tested for methylmercury, 30 samples were also tested for selenium. These 30 samples were selected from the five species with the highest average methylmercury values: Lingcod, Quillback Rockfish, Copper Rockfish, Vermillion Rockfish and Cabezon (Table 4). Because our budget was limited, we selected the individuals from each of the five species that had the highest concentrations of methylmercury for selenium testing (Tables 2 and 4). Selenium concentrations for the 30 fish tested ranged from a low of 0.288 ppm for Cabezon-005 to a high of 0.630 ppm for Quillback-001, thus none of the fish tested had any ATL restrictions for selenium defined as ≥1.00 ppm by OEHHA (Tables 2 and 5).

The 30 fish tested for both selenium and methylmercury had Se:MeHg molar ratios between 0.48 and 3.63, and an overall average molar ratio of 1.53 (Table 5). For the five species tested for selenium, the average Se:MeHg molar ratios were all greater than 1.0, but none were greater than 2.0 (Table 4). Lingcod were barely above 1.00 and Vermillion Rockfish had the highest molar ratio of 1.61 (Table 4). In comparison to a similar study conducted for 19 sport-caught fish species off of the New Jersey coast, our selenium to mercury molar ratios were much lower. The New Jersey study had one species with a molar ratio of <1.0 (Mako Shark), one species with a molar ratio between 1.0 and 2.0 (Striped Bass), nine species with molar ratios between 2.0 and 5.0, four species with molar ratios between 5.0 and 10.0, and four species with selenium to mercury molar ratios greater than 10.0 (Burger and Gochfeld 2012). A closer examination of the New Jersey data revealed that these higher molar ratios were not caused by higher selenium levels than our northern California study, but by the New Jersey fish species having overall lower levels of mercury than the northern California fish species we tested (Burger and Gochfeld 2012). Besides Mako Shark with a mean mercury level of 1.96 ppm, the remaining 18 species had mean mercury levels from 0.01 ppm to 0.52 ppm (Burger and Gochfeld 2012). These 18 species are either shorter-lived than most of the species tested for our northern California study, or they typically feed at lower trophic levels. For example, Tautog can live upwards of 25 years, but feed on crustaceans and mollusks.

Table 4. Mean selenium (Se) and methylmercury (MeHg) levels in ppm (w/95% C.I.) and molar ratios of Se:MeHg for five species of fish caught in Humboldt County nearshore ocean waters.

Fish Species	# of Samples	Se (ppm) Mean	MeHg (ppm) Mean	MeHg (n mol/g)	Se (n mol/g)	Se:MeHg
Lingcod	n=8	0.502 ± 0.049	1.291 ± 0.577	5.987	6.358	1.06
Quillback RF	n=7	0.575 ± 0.040	1.126 ± 0.203	5.222	7.282	1.39
Copper RF	n=6	0.381 ± 0.410	0.941 ± 0.393	4.364	4.825	1.11
Vermillion RF	n=5	0.446 ± 0.049	0.758 ± 0.354	3.515	5.648	1.61
Cabezon	n=4	0.321 ± 0.036	0.601 ± 0.160	2.787	4.065	1.46

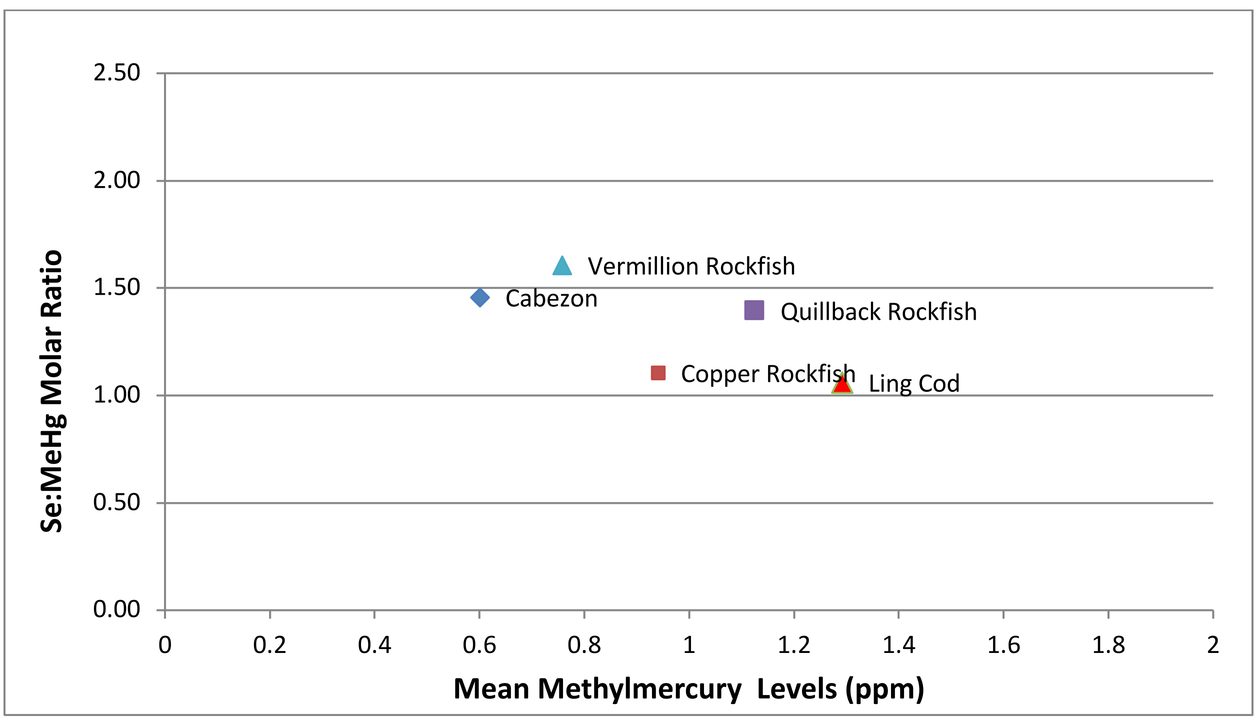

Figure 6. Relationship of mean selenium:methylmercury molar ratios to mean levels of methylmercury in five species of Humboldt County, nearshore ocean fish.

Table 5. Selenium (Se) and methylmercury (MeHg) levels in ppm, molar weights and molar ratios of Se:MeHg for 30 fish caught in Humboldt County nearshore ocean waters.

Fish #	Fish Length (in)	Se (ppm)	MeHg (ppm)	MeHg (n mol/g)	Se (n mol/g)	Se:MeHg
Cabezon-001	22.0	0.364	0.438	2.031	4.610	2.27
Cabezon-002	25.5	0.337	0.825	3.826	4.268	1.12
Cabezon-004	22.0	0.293	0.544	2.523	3.711	1.47
Cabezon-005	22.0	0.288	0.596	2.764	3.647	1.32
Copper-001	16.0	0.373	0.615	2.852	4.724	1.66
Copper-003	18.0	0.467	1.910	8.858	5.914	0.67
Copper-004	17.8	0.414	0.965	4.475	5.243	1.17
Copper-005	16.8	0.344	0.706	3.274	4.357	1.33
Copper-006	16.0	0.365	0.785	3.640	4.623	1.27
Copper-010	16.0	0.325	0.662	3.070	4.116	1.34
Ling-002	29.0	0.543	0.408	1.892	6.877	3.63
Ling-003	33.5	0.427	1.940	8.997	5.408	0.60
Ling-004	33.5	0.464	0.789	3.659	5.876	1.61
Ling-005	33.5	0.429	0.550	2.551	5.433	2.13
Ling-006	34.0	0.452	0.720	3.339	5.724	1.71
Ling-007	35.0	0.608	1.490	6.910	7.700	1.11
Ling-008	38.5	0.591	1.590	7.374	7.485	1.02
Ling-009	40.0	0.503	2.840	13.171	6.370	0.48
Quillback-001	14.5	0.630	1.040	4.823	7.979	1.65
Quillback-002	14.5	0.535	0.747	3.464	6.776	1.96
Quillback-003	16.5	0.615	1.400	6.493	7.789	1.20
Quillback-004	16.0	0.585	1.410	6.539	7.409	1.13
Quillback-005	14.8	0.539	1.380	6.400	6.826	1.07
Quillback-007	14.3	0.490	0.853	3.956	6.206	1.57
Quillback-008	18.0	0.629	1.050	4.869	7.966	1.64
Vermillion-003	20.0	0.382	0.857	3.974	4.838	1.22
Vermillion-004	21.0	0.534	0.525	2.435	6.763	2.78
Vermillion-005	21.0	0.456	0.426	1.976	5.775	2.92
Vermillion-006	21.5	0.414	0.561	2.602	5.243	2.02
Vermillion-007	23.5	0.442	1.420	6.585	5.598	0.85

Recommendations – Consumption Guidelines:

The ultimate purpose of this study is to provide the public who fish the nearshore ocean waters of northern California with information about mercury levels in the fish they and their families catch and consume. The guidelines provided are based on OEHHA's recommended number of servings per week for the two previously mentioned populations: (1) women under the age of 45 and children, and (2) women older than 45 and men older than 18 years of age (Table 2). Because of the lower ATLs set for women under the age of 45 and children, the following species should be avoided, regardless of fish size: Quillback Rockfish, Vermillion Rockfish, Copper Rockfish, Bocaccio, and Cabezon (Table 6). In accordance with the lower ATLs set for women under the age of 45 and children, Lingcod greater than 28 inches in length or more than 10 pounds in weight should be avoided (Table 6). For women over age 45 and adult men, the only fish to avoid because of mercury levels >1.31 ppm are Lingcod greater than 35 inches in length or greater than 20 pounds in weight (Table 6). Canary Rockfish had an average methylmercury level of 0.238 ppm, which corresponds to one serving per week for women under the age of 45 and children, and two servings per week for women over age 45 and adult men (Table 6). However, when the one outlier with a methylmercury level of 0.615 ppm was removed, the remaining eight Canary Rockfish had an average level of 0.190. Thus smaller Canary Rockfish (under 20 inches in length) should be limited to no more than two servings per week for women under the age of 45 and children and no more than three servings per week for women over age 45 and adult men. For Pacific Halibut, our recommended consumption guidelines are broken down into two groups, fish less than 35 inches in length or under 12 pounds and fish greater than 35 inches and between 12 and 50 pounds (Table 6). Because we failed to collect samples from any Pacific Halibut greater than 50 pounds, we have no concrete consumption recommendations for larger fish, other than methylmercury levels tend to increase with fish size and age. However, based on average methylmercury levels, Pacific Halibut are a good alternative to most rockfish species (Tables 2 and 6). California Halibut are also a good alternative to most rockfish species (Tables 2 and 6).

Portion sizes are also important when navigating Table 6 or similar health advisory guidelines for fish consumption. Several studies have shown that people who catch their own fish typically consume larger serving portions than people who purchase commercially caught fish or eat fish in restaurants (Harris et al. 2009; Burger and Gochfeld 2012).

Table 6. Average mercury levels in parts per million (ppm) for fish species caught in Humboldt Bay and/or near-shore ocean waters and guidelines for consumption.

Species and/or Size	Average Mercury Levels, ppm	Recommended Servings* per Week, Women <45 & Children[1]	Recommended Servings* per Week, Women >45 & Men[1]
Pacific Halibut <35 inches or <12 pounds	0.082	2	6
California Halibut	0.146	2	4
Lingcod <28 inches or under 10 pounds	0.218	1	3
Canary Rockfish	0.238	1	2
Pacific Halibut >35 inches or 12-50 pounds	0.241	1	2
Bocaccio**	0.521	**AVOID**	1
Cabezon**	0.549	**AVOID**	1
Vermillion Rockfish	0.596	**AVOID**	1
Copper Rockfish	0.695	**AVOID**	1
Lingcod 28-35 inches or 10-20 pounds	0.727	**AVOID**	1
Quillback Rockfish	0.922	**AVOID**	1
Lingcod >35 inches or >20 pounds	1.644	**AVOID**	**AVOID**

*Serving sizes: adults = 8 ounces uncooked (4 ounces cooked); children = 4 ounces uncooked (2 ounces cooked).
**Note that these recommendations are based on smaller sample sizes than the other species included in the study (n=3 for Bocaccio and n=5 for Cabezon).
[1] California Office of Environmental Health Hazard Assessment's Nov. 2017 Advisory Tissue Levels https://oehha.ca.gov/media/downloads/fish/report/atlmhgandothers2008c.pdf

Recommendations – Selenium to Methylmercury Molar Ratios:

The selenium results for the northern California nearshore ocean waters study showed that molar ratios of selenium to methylmercury were between 1.0 and 2.0 for the five species where both substances were tested. The utility of developing health advisories or risk assessments based on the molar ratios is unclear and lacks consensus in the peer-reviewed literature. Burger and Gochfeld (2012) stated, "*there is no consensus as to how much selenium is needed to reduce the risk of mercury toxicity, nor is it clear whether there is a linear relationship between the hypothesized protective ratio and mercury levels. The intraspecific variability in selenium and mercury concentrations complicates the process of developing fish advisories. Since* *selenium varies less than mercury, the admonition to avoid fish that are high in mercury is still more useful to the consumer and risk manager than information about the ratio*". Burger and Gochfeld (2012 and 2013) were also concerned about the difficulty in communicating clear and concise health advisories to the public regarding molar ratios given that it is not merely a matter of knowing both the mercury and selenium levels, but of also knowing the molar relationships in specific fish as a function of species and size, and establishing the molar ratios that are protective for different populations (e.g. pregnant women, fetuses, young children or adults) and for different tissues (especially the brain).

Conversely, Ralston et al. (2019) advocates that selenium to mercury ratios offer a reliable index of seafood health benefits to risks; "*consumption of ocean fish containing Se in molar excess of MeHg will prevent interruption of selenoenzyme activities, thereby alleviating Hg-exposure risks. Because dietary Se is a pivotal determinant of MeHg's effects, the Selenium Health Benefit Value (HBV) criterion was developed to predict risks or benefits as a result of seafood consumption. A negative HBV indicates Hg is present in molar excess of Se and may impair Se availability while a positive HBV indicates consumption will improve the Se status of the consumer, thus negating risks of Hg toxicity*". Ralston et al. (2019) contends that a regular consumer of fish will have an enriched intake of selenium, thus when they eat an occasional meal of a fish with a Se:MeHg molar ratio less than 1.0, it is likely that their enriched selenium levels would protect them. Burger and Gochfeld (2012 and 2013) took the opposite view when discussing sensitive populations, such as pregnant women and their fetuses, where a single exposure to a high dose of methylmercury could cause harm. The concept of a single high dose of methylmercury ingested by a pregnant woman causing fetal harm was also proposed by Ginsberg and Toal (2000).

Regardless if selenium in marine fish can offset the harmful effects of methylmercury, a sensitive consumer would have to know the molar ratio before consumption, which is impractical. Our results confirmed that four of the 30 tissue samples (13.3% of the samples) tested for selenium had Se:MeHg molar ratios less than 1.0, in combination with high levels of mercury. Two of the eight Lingcod (25% of the samples) tested for selenium also had Se:MeHg molar ratios less than 1.0, suggesting that avoidance of consuming larger Lingcod is a prudent decision, especially for more vulnerable groups such as younger women and children.

We support the recommendations of Burger and Gochfeld (2012): *"The message is (1) fish high in mercury have lower selenium:mercury molar ratios than fish generally low in mercury, (2) as fish of a given species increase in size, the selenium:mercury molar ratio decreases as mercury increases, and (3) larger fish species higher on the food chain tend to have lower molar ratios. Thus, we suggest that consumers should be very cautious in consuming high mercury fish, regardless of selenium concentrations, and advisories should be written accordingly".*

Recommendations – Periodic Testing and Comparisons to Earlier Data:

We recommend that methylmercury levels of commonly caught and consumed nearshore ocean fish from the Northcoast are periodically tested and compared to previous results. This type of testing would allow the tracking of mercury levels over time and would also provide data for updates of OEHHA fish consumption guidelines (provided that at least nine samples per species are collected and tested). Frequency of periodic testing should occur approximately once per decade.

Our study's tissue sample collection occurred in 2019-2020 and the SWAMP report's samples were collected in 2009-2010; exactly a decade apart. We had hoped to compare our results with SWAMP's 2010 results; however we were unable to locate the SWAMP report's raw data sets for the northern region of California, specifically to determine the individual lengths of all the fish they tested for mercury. Summary data of minimum, maximum and median lengths of all the species tested were presented in Table 1 of the report (Davis et al. 2012); however, all regions of California were lumped together. Also, for key species such as Lingcod and members of the rockfish complex, SWAMP tested only composite samples (of three to five individuals per composite sample), whereas we tested individual fish. Our raw data are presented in this report with the specific purpose of providing the public access to all of our results. These raw data should allow for the tracking of mercury levels over time by future researchers, as long as sampling and testing methods are consistent and the size distributions of tested fish species are similar.

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APPENDIX A:

PHOTOGRAPHS OF SAMPLED FISH FOR THE HUMBOLDT BAYKEEPER'S NEARSHORE OCEAN MERCURY TESTING PROJECT

Figure A-1. California Halibut (29 inches in length) caught on August 16, 2019 in Humboldt Bay.

Figure A-2. Cabezon (22 inches in length) caught on June 9, 2020 at Cape Mendocino.

Figure A-3. Lingcod (38.5 inches in length) caught on November 13, 2019 at Cape Mendocino.

Figure A-4. Pacific Halibut (42.5 inches in length) caught on May 15, 2020 out of Trinidad.

Figure A-5. Quillback Rockfish (14 inches in length) caught on August 30, 2019 at Reading Rock.

Figure A-6. Copper Rockfish (18 inches in length) caught on August 7, 2019 at Cape Mendocino.

Figure A-7. Vermillion Rockfish (23.5 inches in length) caught on November 13, 2019 at Cape Mendocino.

Figure A-8. Canary Rockfish (16.5 inches in length) caught on August 30, 2019 at Reading Rock.

Figure A-9. Bocaccio (29.5 inches in length) caught on August 30, 2019 at Reading Rock.

<u>Appendix B:</u>

Recommended Equipment List for Collecting Tissue Samples in the Field for Methylmercury Testing - Developed for Boat-based Sampling in Humboldt County, California.

1. Field Log book.
2. Data sheets.
3. Sample ID labels.
4. Clip board.
5. Handheld GPS unit (or boat-based unit).
6. Depth finder on boat to measure depth(s) at collection location(s).
7. Indelible pens.
8. Collection equipment – rods, reels, bait, lures, landing net, club, etc.
9. Digital camera for taking specimen photos.
10. Measuring device – tape or board.
11. Scale for weighing fish.
12. Scale for weighing tissue samples.
13. Filet knives and sharpening stone.
14. Aluminum foil – extra-heavy duty.
15. Freezer tape.
16. Gallon zip-lock bags for tissue samples.
17. Folding table for processing fish and samples.
18. Plastic sheet or tarp to cover folding table.
19. Cleaning board.
20. Cooler with ice for temporary storage of tissue samples.
21. Liquid dish soap - for cleaning hands, knives and other processing equipment between samples.
22. Distilled water for rinsing hands, knives and other processing equipment between samples. Several gallons (at least).
23. Paper towels (two or three rolls).