College of Tropical Agriculture
and Human Resources
University of Hawaiʻi at Mānoa

Foods and Nutrition
October 2012
FN-12

Omega-3 Fatty Acid, Selenium, and Mercury Content of Aquaculture Products in Hawaiʻi

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Numerous health benefits have been associated with increased dietary intakes of long-chain omega-3 fatty acids. Dietitians recommend consumption of at least two 4-oz servings of fish per week. Fish is the major source of selenium and long-chain ω-3 fatty acids but can also contain methylmercury. Dietitians recommending fish intake need to be familiar with omega-3, mercury, and selenium levels in commonly available fish in order to make recommendations that maximize benefits and minimize risks. The purpose of this study was to gather baseline data on the fatty acid profile and selenium and mercury concentrations of aquaculture products in Hawaiʻi.

Introduction

Fish is the major source of long-chain omega-3 polyunsaturated fatty acids (LC ω-3 PUFA), eicosapentaenoic acid (EPA, 20:5 ω-3), and docosahexaenoic acid (DHA, 22:6 ω-3) in the human diet. Numerous health benefits have been associated with increased dietary intakes of LC ω-3 PUFA, including decreases in blood pressure, serum triglycerides, and blood platelet aggregation (Kris-Etherton et al. 2003), and decreased incidence of coronary heart disease (Hu et al. 2002), cardiac arrhythmias (Calder 2004), and ischemic stroke (He 2004). DHA plays an important role in neurogenesis and neurotransmission and is thus critical for optimal neurological development (Innis 2007). Because EPA and DHA are competitive inhibitors of arachidonic acid for cyclooxygenase and lipoxygenase enzymes in lipid metabolism pathways, they may prevent excessive inflammation that is associated with negative outcomes in chronic inflammatory diseases (Calder 2006). The American Heart Association (2012) currently recommends that individuals without coronary heart disease eat fish (preferably fatty) at least twice per week. The Academy of Nutrition and Dietetics (AND) recommends at least two 4-oz (~100-g) servings of fish (preferably oily) per week, or approximately 500 mg of EPA and DHA per day, to support overall health (Kris-Etherton and Innis 2007).

LC ω-3 PUFA content varies naturally among different fish species. In aquaculture it is also affected by farming practices, particularly the nutrient composition of fish feed used. Fish require LC ω-3 PUFA for growth and development like other vertebrates, and exclusive or high use of plant-based fish feeds with high omega-6 fatty acid (ω-6 FA) content results in increased ω-6 FA and decreased LC ω-3 FA tissue concentrations in aquacultured fish (Weaver et al. 2008). The fatty acid profiles of fish are further influenced by their ability to elongate shorter-chain ω-3 FA to LC ω-3 PUFAs; for example, omnivorous fresh-water fish have a greater ability to elongate shorter-chain ω-3 FA than carnivorous marine fish (Watanabe 1982) and may therefore be raised on diets lower in LC ω-3 PUFAs.

Methylmercury is the organic form of mercury of greatest concern in human toxicology. Methylmercury is formed from inorganic mercury by anaerobic bacteria

Published by the College of Tropical Agriculture and Human Resources (CTAHR) and issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, under the Director/Dean, Cooperative Extension Service/CTAHR, University of Hawaiʻi at Mānoa, Honolulu, Hawaiʻi 96822.

in aquatic sediments and bioaccumulates in long-lived predatory fish at the top of the food chain (Clarkson et al. 2003). Human exposure to methylmercury occurs almost exclusively by consumption of seafood. Long-term health effects of chronic low-level methylmercury exposure in populations consuming large amounts of fish and seafood are an area of investigation. Main areas of concern are neurological impairment during development (Grandjean et al. 1997, Grandjean et al. 1998, Grump et al. 1998, Davidson et al. 2011, Jedrychowski et al. 2006) and risk of cardiovascular disease in adults (Ahlqwist 1999, Hallgren 2001, Guallar et al. 2002, Virtanen et al. 2005, Yoshizawa et al. 2002, Wennberg et al. 2007). Due to concerns about gestational mercury exposure, the FDA (2004) currently maintains an advisory for women who may become pregnant, pregnant women, nursing mothers, and young children, with guidelines intended to reduce mercury consumption by avoiding consumption of fish with the highest levels of methylmercury. However, a recent consultation by international experts determined that benefits of fish consumption outweigh risks, even when it is consumed in the vulnerable pregnancy period, among all geographic populations that have been studied (FAO/WHO 2011). This conclusion is consistent with the findings of other authors, who have concluded benefits outweigh risks when intake is moderate and relevant advisories are followed (Clarkson et al. 2003, Sidhu 2003, Mozaffarian and Rimm 2006, Sioen et al. 2008). Currently there are no FDA guidelines for restricted fish consumption by non-pregnant, non-nursing adults.

Fish is one of the best sources of selenium, an essential mineral micronutrient involved in numerous metabolic pathways. In the body selenium is incorporated into selenoproteins after it is bound to the amino acid cysteine to form selenocysteine (Lu and Holmgren 2009). Some important selenoprotein families in the body include thioredoxin reductases, which play an important role in DNA synthesis; iodothyronine deiodinases, which regulate thyroid hormone activation; and glutathione peroxidases, which are major components of the body's antioxidant defenses and may reduce cardiovascular disease risk through a variety of mechanisms (Mozaffarian 2009). However, there is a lack of conclusive evidence linking increased selenium consumption to reduced cardiovascular disease risk, nor is it known what threshold level of selenium intake would be needed to confer possible protection (Mozaffarian 2009).

Evidence from animal and in-vitro studies suggests that selenium and selenoprotein antioxidant systems may protect the cardiovascular system against methylmercury-induced free-radical damage through a variety of mechanisms (Ganther 1978, Iwata et al. 1982, Sasakura and Yang et al. 2008). Because selenium has a high affinity for mercury, it is thought to scavenge methylmercury in the body (Ralston 2010). However, once selenium binds to methylmercury, it can no longer function enzymatically or as a selenoprotein; thus, selenium must be replaced through the diet (Ralston 2010). The molar ratio of mercury to selenium in seafood is thought by some to be a key mediator of potential toxicity (Kaneko and Ralston 2007, Ralston 2010). However, any putative protection against mercury exposure by selenium intake has yet to be shown in human studies, but many studies may be limited by a high baseline selenium status in the population (Mozaffarian et al. 2011).

Because of the potential variability in fatty acid content among aquacultured and wild-harvested seafood products, actual intakes of LC ω-3 PUFAs currently cannot be reliably estimated. Moreover, depending on the actual ω-6 FA and LC ω-3 PUFA content, consumption of certain aquacultured seafood products, such as catfish and tilapia, may no longer confer the health benefits associated with fish intake (Weaver et al. 2008). Although certain macroalgaes commonly sold in dry form, such as wakame and hijiki, have been shown to contain significant amounts of EPA and DHA (Dawczynski et al. 2007), there is little published data describing the fatty acid profiles of fresh seaweeds. Dietitians recommending seafood intake need to be familiar with omega-3, mercury, and selenium levels in commonly available fish and seaweeds in order to make recommendations that maximize the benefits and minimize the risks. Fatty acid, mercury, and selenium analysis of aquacultured seafood products is clearly warranted. The purpose of this study was to gather baseline data on the fatty acid profile and selenium and total mercury content of 24 aquaculture products in Hawai‘i.

Methods

Aquaculture products were obtained from May through August 2011 from sources on O‘ahu and Hawai‘i islands (Table 1). ‘Opihi (*Cellana* sp.) is a wild-collected mollusk but was included because there is a lack of published data on its fatty acid profile and selenium and mercury

Table 1. Common name, species, and source of sampled products

Common name, species	Source company, location in Hawai‘i	Prep method
Sablefish (butterfish), *Anoplopoma fimbria*	Troutlodge Marine Farms, NELHA – Kailua-Kona	Raw
Pacific threadfin (moi), *Polydactylus sexfilis*	Troutlodge Marine Farms, NELHA – Kailua-Kona	Raw
Ezo (Japanese Northern abalone), *Haliotis discus hannai*	Big Island Abalone Corp., NELHA – Kailua-Kona	Raw
Russian sturgeon, *Acipenser gueldenstaedti*	UH-Hilo Agricultural Farm, Pana‘ewa, Hilo	Raw
Siberian sturgeon, *Acipenser baerii*	UH-Hilo Agricultural Farm, Pana‘ewa, Hilo	Raw
Tilapia, *Oreochromis* sp.	Hawaii Fish Co., Waialua; Mari’s Garden, Mililani	Raw
Chinese catfish, *Clarias fuscus*	Mari’s Garden, Mililani	Raw
Giant freshwater prawn, *Macrobrachium rosenbergii*	Romy’s Kahuku Prawns and Shrimp Inc., Kahuku	Boiled
Pacific white shrimp, *Penaeus vannamei*	Romy’s Kahuku Prawns and Shrimp Inc., Kahuku	Boiled
Dungeness crab, *Metacarcinus magister*	Kona Cold Lobster, NELHA – Kailua-Kona	Boiled
American lobster, *Homarus americanus*	Kona Cold Lobster, NELHA – Kailua-Kona	Boiled
‘Opihi (limpet), *Cellana* sp.	Tomashiro’s Market, Honolulu—collected on Hawai‘i Island	Raw
Sea asparagus, *Salicornia virginica*	Kahuku Sea Asparagus, Kahuku	Raw
Red ogo, *Gracilaria* sp.	Kahuku Sea Asparagus, Kahuku; Royal Hawaiian Sea Farms, NELHA – Kailua-Kona	Raw
Robusta ogo, *Gracilaria salicornia*	Kahuku Sea Asparagus, Kahuku	Raw
Sea purslane, *Sesuvium portulacastrum*	Kahuku Sea Asparagus, Kahuku	Raw
Green ogo, *Gracilaria* sp.	Royal Hawaiian Sea Farms, NELHA – Kailua-Kona	Raw
Brown ogo, *Gracilaria* sp.	Kahuku Sea Asparagus, Kahuku; Royal Hawaiian Sea Farms, NELHA – Kailua-Kona	Raw
Thick green ogo, *Codium edula*	Royal Hawaiian Sea Farms, NELHA – Kailua-Kona	Raw
Spirulina powder, Spirulina Pacifica®	Cyanotech, NELHA – Kailua-Kona	Factory-processed powder
NatuRose®, *Haematococcus pluvialis*	Cyanotech, NELHA – Kailua-Kona	Factory-processed powder

concentrations. A sample was obtained from each source of each species. Prawn and shrimp samples were obtained as cooked ready-to-eat products and stored frozen (-70°C) until processing. Dungeness crab and lobster samples were obtained live and boiled immediately before processing. Russian and Siberian sturgeon samples were obtained as raw frozen fillets from 2-year-old fish weighing approximately 7 kg and 4 kg, respectively. Raw sablefish, moi, and abalone samples were obtained fresh on ice and processed for freeze-drying directly, while raw tilapia, pongee, and catfish samples were obtained fresh, frozen for 2–4 weeks (-70°C) and then thawed before processing. *Spirulina* (Spirulina Pacifica®) and *Haematococcus pluvialis* (NatuRose®) were obtained as factory-processed powders packaged for sale and were not processed further. Fresh seaweeds were puréed and then held frozen (-70°C) until freeze-drying.

Before freeze-drying, product samples were homogenized. The entire edible portion was homogenized for fish and shellfish samples, with several exceptions. For sablefish, 10-g strips from the head, middle, and tail sections of one fillet were combined and homogenized. For catfish, tilapia, lobster and crab, one lateral half of each animal was used. For both sturgeon species, only a single ~100-g fillet was provided, which was homogenized in its entirety. Duplicates of approximately 10 g per homogenized sample were weighed, freeze-dried, and then immediately re-weighed to determine dry mass. Dry samples were ground, transferred to vials, and stored at -70C prior to analysis.

The fatty acid analysis of the seafood product samples was performed as detailed recently (Li and Franke 2011). Mercury and selenium concentrations in freeze-dried samples were measured at the Hawaii Department of Health Chemical Threat Response Laboratory. Mercury was measured by thermal combustion-gold amalgamation-atomic absorption spectroscopy. The lower limit of quantitation (LOQ) was determined to be 10 ppb (μg/kg). Selenium analyses were performed using inductively coupled plasma-mass spectrometry with argon as the reaction cell gas. The LOQ was 30 µg/100 g.

Results

Finfish and shellfish products contained significant amounts of EPA + DHA, whereas levels were negligible in seaweeds (Table 2). Long-chain omega-3 concentration varied widely among the fish and shellfish samples tested (Table 3). Most notably, abalone had the lowest concentration of EPA + DHA (25.4 mg/100 g), and Siberian sturgeon had the highest at 2562 mg/100 g. Other samples with high levels of EPA + DHA were Chinese catfish (577 mg/100 g) and Russian sturgeon (563.1 mg/100 g). Shrimp, moi, sablefish, lobster, and crab provided moderate amounts of EPA + DHA, which only in combination with other sources of long-chain omega-3 PUFAs could meet recommended daily intakes. All of the seaweeds/supplements tested, with the exception of NatuRose® (*Haematococcus pluvialis*), provided negligible amounts of EPA + DHA, relative to dietary recommendations (Table 4). NatuRose® provided 106.4 mg of EPA + DHA per 100 g, but the recommended daily dose of astaxanthin in products such as Bio Astin, a supplement containing *Haematococcus pluvialis*-derived astaxanthin, is 12 mg, which would translate to only 12.8 mg of EPA + DHA.

Mean methylmercury levels across categories were below 50 ppb in both finfish and shellfish and just 2.26 ppb in seaweeds (Table 2). Levels were highest in lobster (82.6 ppb) and Dungeness crab (77.6 ppb), species harvested off the eastern and western coasts of North America, respectively, and reconditioned in cold water at NELHA (Table 3). All other fish and shellfish species had levels of mercury less than 50 ppb, ranging from levels below the detectible limit in prawns and abalone to 48.5 ppb in Russian sturgeon. Mercury levels were very low (<3 ppb) in all of the seaweeds tested, with levels in eight of the ten samples below the limit of detection (Table 4). Mercury levels were also low in Spirulina Pacifica® (14 ppb) and below the detectible limit in NatuRose®.

Table 2. EPA + DHA, Hg, and Se concentration (mean ± standard deviation) in finfish, shellfish, and seaweeds.

Variable	Finfish (n=6)	Shellfish (n=6)	Seaweeds (n=10)
EPA + DHA (mg/100 g)	708.4 ± 929.5	114.4 ± 70.0	0.3 ± 0.4
Hg (ppb)	27.5 ± 13.8	49.5 ± 37.6	2.26 ± 0.63
Se (ppb)	357 ± 74.2	542 ± 392	56.3 ± 12.5

Table 3. Fatty acid concentration in mg/100 g, Hg, and Se analysis of farmed fish and shellfish in Hawai‘i

Variable	Tilapia mean	Cat-fish	Russian sturgeon	Siberian sturgeon	Shrimp	Prawns	Abalone	Moi	Sable-fish	Lobster	Dunge-ness crab	‘Opihi
Sat FA												
18:0	29.9	117.3	48.2	119.6	38.1	68.0	6.7	18.6	117.5	5.5	6.5	25.0
16:0	133.2	527.2	358.9	1,450.9	75.2	149.9	42.1	53.8	732.7	29.0	28.9	124.7
14:0	15.5	86.77	48.91	157.90	2.2	24.9	10.0	12.5	174.9	1.9	1.2	17.7
ω-9 FA												
18:1	92.0	520.3	643.1	1517.3	59.0	134.8	18.3	41.1	1,223.5	31.2	21.1	76.5
16:1	24.6	166.0	133.3	372.8	6.1	26.7	2.4	13.2	249.2	12.4	11.1	7.4
ω-6 FA												
18:2	71.4	270.2	226.8	590.5	67.2	114.1	3.2	23.9	414.0	2.6	2.1	10.5
20:2	3.1	9.1	7.6	21.7	5.4	7.1	0.4	1.0	4.6	0.6	1.0	10.3
20:4	18.5	36.9	35.8	115.7	21.4	32.8	26.2	11.8	33.6	14.5	12.5	61.0
ω-3 FA												
18:3	6.2	33.9	26.3	69.5	5.1	8.7	1.4	2.8	51.0	0.9	0.8	9.0
20:5 (EPA)	7.3	158.0	91.8	1,482.2	64.9	46.1	24.5	36.3	129.3	55.5	88.0	58.6
22:5	8.6	24.8	28.3	84.9	2.6	1.2	9.3	5.3	13.2	1.5	1.9	5.5
22:6 (DHA)	90.8	419.0	471.3	1,079.4	124.8	32.8	0.9	124.5	160.6	81.6	105.8	2.8
EPA + DHA	98.1	577.0	563.1	2,561.6	189.7	78.9	25.4	160.8	289.9	137.1	193.7	61.4
Mercury and selenium												
[a]Hg (ppb)	9.00	20.4	48.5	21.5	34.6	<2.41	<2.62	29.7	36.0	82.6	77.6	3.20
[a]Se (ppb)	345	268	482	380	962	517	130	301	368	1074	323	244
[b]Se % DRI per 100 g	63%	49%	88%	69%	175%	94%	24%	55%	67%	195%	59%	44%
Hg/Se molar ratio	0.01	0.03	0.04	0.02	0.01	<0.01	<0.01	0.04	0.04	0.03	0.09	0.01

[a]Results shown for mercury and selenium are for concentrations in the original sample, calculated by multiplying the concentration determined from the freeze-dried sample by the percent dry mass of the fresh sample before drying.

[b]Percent of DRI for selenium is based on the adult recommended daily allowance of 55 mcg/day.

Table 4: Fatty acid concentration in mg/100 g, Hg, and Se analysis of seaweed in Hawai‘i

Variable	Thick green ogo	Green ogo	Brown ogo[a]	Brown ogo[b]	Red ogo[a]	Red ogo[b]	Robusta	‘Ākulikuli	Sea purslane	Sea asparagus	Spirulina	Natu-Rose®
SFA												
18:0	0.3	0.3	0.5	0.4	0.2	0.3	0.4	1.1	1.1	1.0	13.9	102.2
16:0	3.3	3.1	5.1	3.8	1.4	5.7	5.9	12.6	12.4	9.5	308.6	2,023.0
14:0	0.4	0.1	0.9	0.5	0.1	0.6	0.3	0.3	0.5	0.3	2.2	71.9
ω-9												
18:1	2.5	0.6	2.5	0.8	0.4	1.0	1.3	2.0	6.5	1.8	13.3	1,869.7
16:1	0.6	0.1	0.9	0.4	0.4	1.2	0.2	0.1	0.1	0.1	53.5	69.6
ω-6												
18:2	1.7	0.1	0.8	0.1	0.0	0.2	0.2	10.8	7.9	12.3	120.9	2,748.5
20:2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.9	23.7
20:4	1.0	3.2	1.7	0.3	0.7	0.4	2.2	0.0	0.0	0.0	5.6	146.2
ω-3												
18:3	1.7	0.0	0.4	0.0	0.0	0.1	0.0	33.2	28.9	32.3	258.0	2,108.4
20:5 EPA	0.5	0.0	0.6	0.1	0.0	0.2	0.0	0.0	0.0	0.1	5.1	91.4
22:5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
22:6 DHA	0.7	0.1	0.6	0.0	0.0	0.1	0.1	0.0	0.0	0.1	1.2	14.9
EPA + DHA	1.2	0.1	1.1	0.2	0.0	0.2	0.1	0.0	0.1	0.2	6.3	106.4
Mercury and selenium												
cHg (ppb)	<0.65	<0.83	<1.45	2.20	<0.95	1.66	2.92	<1.08	<0.87	<1.30	14.0	<10
cSe (ppb)	<19.5	<24.9	58.9	67.3	<28.5	<40.2	42.8	<32.4	<26.1	<39.1	177	42.5
dSe % DRI per 100 g	<4%	<5%	11%	12%	<5%	<7%	8%	<6%	<5%	<7%	32%	8%
Hg/Se molar ratio	NA	NA	<0.01	0.01	NA	NA	0.03	NA	NA	NA	0.03	<0.09

[a] Kailua-Kona source

[b] Kahuku source

[a] Results shown for mercury and selenium are for concentrations in the original sample, calculated by multiplying the concentration determined from the freeze-dried sample by the percent dry mass of the fresh sample before drying.

[b] Percent of DRI for selenium is based on the adult recommended daily allowance of 55 mcg/day.

Finfish and shellfish had much higher concentrations of selenium than seaweeds (Table 2). All of the locally farmed fish and shellfish species tested were excellent sources of selenium, with the lowest levels in the mollusks—abalone and ʻopihi (Table 3). A 100-g serving would provide between 24% of the adult DRI of 55 mcg/day (abalone) and 195% (lobster). Seaweeds, on the other hand, were poor sources of selenium, with a 100-g serving providing less than the detectable limit in seven out of ten samples, with a maximum of 12% of the DRI (brown ogo, Kahuku) (Table 4). Although levels were slightly higher in Spirulina Pacifica® and NatuRose®, at recommended doses selenium levels would be insignificant. For example, Spirulina Pacifica® recommends a dose of 3 g/day, which would provide less than 1% of the adult DRI for selenium. Molar ratios of mercury to selenium were calculated for each product. The Hg/Se molar ratio was <0.1 for all fish and shellfish species (Table 3) as well as Spirulina Pacifica® and NatuRose® (Table 4). The Hg/Se molar ratio was 0.003 or less for all seaweed/algae species with data allowing this calculation (Table 4).

Discussion

The results of our analysis demonstrate a wide range of long-chain omega-3 fatty acid contents among fish and shellfish species but negligible amounts of EPA + DHA in all of the seaweed or algae species/products tested, which is consistent with a previous report on algae (Ako 1995). For most of the fish and shellfish species examined, two 100-g (~4-oz) portions per week would provide less than the AND/DC recommended intake of 500 mg/day of EPA + DHA (Kris-Etherton and Innis 2007) and would need to be combined with other sources of long-chain omega-3 PUFAs to achieve the recommended daily intake. For tilapia, prawns, and abalone, other sources would have to provide almost the entire daily requirement. For Chinese catfish and both sturgeon species, on the other hand, all of the daily recommended intake could be achieve through consumption of one 4-oz portion, but only Siberian sturgeon would average 500 mg/day of EPA + DHA for the week if two 100-g portions were consumed.

There is limited published data on the fatty acid profile of Chinese catfish. Qin et al. (1998) examined the effect of ploidy level, temperature, and feed on growth of Chinese catfish and reported levels of EPA + DHA ranging from 2,460 to 3,500 mg/100 g dry weight. In our study the Chinese catfish sample contained 2,218 mg EPA + DHA per 100 g dry weight, which suggests that our findings are not an anomaly. Published data on farmed channel catfish, on the other hand, indicates low levels of long-chain omega-3 fatty acids. The USDA Nutrient Database lists farmed channel catfish as having 74 mg EPA + DHA per 100 g sample (wet weight). Given the unfavorable fatty acid profiles that have been observed in farmed freshwater aquaculture species such as tilapia (Weaver et al. 2008), the high levels of long-chain omega-3 fatty acids we observed in locally produced Chinese catfish represent an important finding that deserves further investigation. The Chinese catfish sampled in this study was grown on Silver Cup™ Trout Feed (Skretting USA, Tooele, UT), a commercial feed produced with fishmeal to provide high levels of EPA and DHA.

Another interesting finding in our study is the extremely high level of long-chain omega-3 fatty PUFAs in Siberian sturgeon (>2,500 mg/ 100 g). This level of EPA + DHA is higher than levels found in many of the carnivorous marine species, such as salmon species, touted for their favorable fatty acid profiles (Watters 2012). Badiani et al. (1997) tested the fatty acid profiles of three species of farmed sturgeon, including Siberian sturgeon but not Russian, and found Siberian sturgeon to have 1,097 mg of EPA + DHA per 100-g edible portion and the lowest levels of saturated fats among the species tested. High levels in our sample may be related to the fact that it was taken from one part of one fish, while more extensive sampling might show reduced levels. Both sturgeon species were fed a propriety feed. Along with Chinese catfish, Siberian sturgeon deserves further investigation as an aquaculture species that could be promoted for its high long-chain omega-3 PUFA content.

Mercury levels were low but variable among the fish and shellfish species but were consistently low in seaweeds and supplements, which would be expected given that seaweeds, algae, and cyanobacteria are autotrophs lacking a mechanism for bioaccumulation. Lobster and crab had the highest mercury levels in this study, but these products are unique, since the animals are captured in the wild from North American coastal waters and only refreshed in local aquaculture systems. The mercury levels likely reflect accumulation prior to their arrival in Hawaiʻi. Levels were similar to those published by the FDA (2011) for Northern/American lobster (107 ppb) and crab (65 ppb). Mercury levels in fish are strongly correlated with age (Burger and Gochfeld 2007). Accelerated production cycles in aquaculture that reduce the age of the harvested fish relative to its wild-caught counterpart could reduce mercury uptake, depending on the levels of mercury in the feed. Low levels in freshwater fish tilapia (9 ppb) and Chinese catfish (20.4 ppb) in the present study were similar to those reported by the FDA (2011) for tilapia (13 ppb) and catfish (25 ppb). On the other hand, sablefish had very low levels in the present study (36 ppb), compared to much higher levels (361 ppb) reported by the FDA (2011). Age differences might explain the lower levels of mercury in our farmed sablefish sample compared to levels documented for wild-caught representatives of the species (FDA, 2011).

The FDA (2004) advises women who are or who may become pregnant, nursing mothers, and young children to avoid species very high in mercury (shark, swordfish, king mackerel, and tilefish) and "eat up to 12 ounces…a week of a variety of fish and shellfish that are lower in mercury." More recently the FAO/WHO (2010) concluded that neurodevelopmental benefits of maternal fish consumption outweigh the risks for up to seven 100-g servings per week, if the methylmercury concentration of the fish is below 500 ppb. All of the fish and shellfish products tested in this study were well below this level.

Seafood is considered a major source of dietary selenium. Kaneko and Ralston (2007) measured mercury and selenium in 15 wild-caught pelagic fish species near Hawai‘i and observed selenium concentrations ranging from 320 ppb to 1,590 ppb with a median value of 650 ppb. In the present study levels in fish and shellfish ranged from 130 ppb to 1,074 ppb, with a median of 357 ppb (Table 2). These results are consistent with observations that farmed fish typically have reasonably high levels of selenium but lower levels than wild-caught fish (Cahu et al. 2004). Given the high levels of selenium and low- to mid-range levels of mercury in the farmed fish and shellfish species in this study, molar ratios of mercury to selenium were below 0.1, the lowest ratio observed in wild pelagic species from the region (Kaneko and Ralston 2007).

Limitations

Limitations include lack of replication for most items, sampling and sample-processing variability and limited collection of data on cultural methods, such as the nutrient composition of feeds and the age and size of the products sampled. All of these factors could be expected to influence fatty acid, selenium, and mercury concentrations to some extent.

Conclusions

The results indicate a wide range in EPA and DHA levels among aquacultured fish and shellfish, with several species showing potential as excellent sources, in particular Chinese catfish and Russian and Siberian sturgeon. Levels of mercury in fish and shellfish species tested were low, and levels of selenium were high. Overall, our data suggest that aquaculture in Hawai‘i has the potential to provide an increasing number of foods that are excellent sources of long-chain omega-3 fatty acids and selenium, with low to moderate levels of methylmercury. The seaweeds, algae, and cyanobacteria sampled were uniformly poor sources of EPA and DHA and were low in selenium but were also low in mercury.

Acknowledgments

We thank Gerald Pitz and Steven Bailey of the Hawaii Department of Health Chemical Threat Response Laboratory for performing the total mercury and selenium determinations. We also thank Xingnan Li for measuring the fatty acid profiles by LCMS. We gratefully acknowledge the reviewers of this paper, Dr. Rachel Novotny, PhD, RD, professor of Nutrition at the University of Hawai‘i and a member of the World Health Organization Expert Consultation on Risks and Benefits of Fish Consumption; and Dr. John Kaneko, DVM, Program Manager for the Hawaii Seafood Council.

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