Mercury Content in Pacific Troll-Caught Albacore Tuna (*Thunnus alalunga*)

Michael T. Morrissey
Rosalee Rasmussen
Tomoko Okada

ABSTRACT. Ninety-one albacore tuna (*Thunnus alalunga*) captured during the 2003 commercial fishing season were tested for total mercury content in muscle tissue. The fish were harvested between 32.72°N (off Southern California) and 48.30°N (off the northern tip of Washington) between July and November. Fish weighed from 3.14 to 11.62 kg and were 50.8-86.4 cm long. Total mercury content in the albacore muscle tissue ranged from 0.027 ppm (μg/g) to 0.26 ppm. The average total mercury content was 0.14 ± 0.05 ppm, which is below the U.S. Food and Drug Administration action level and Canadian standards (1.0 ppm methylmercury and 0.50 ppm total mercury, respectively). Total mercury concentrations showed positive correlations with length and weight of albacore ($R^2 = 0.40$ and 0.38, respectively), but there was no correlation with date of capture or lipid content. Results indicate that Pacific troll-caught albacore have low levels of total mercury in the edible flesh and are well within international safety standards for mercury levels in fish.

Michael T. Morrissey (michael.morrissey@oregonstate.edu), Rosalee Rasmussen, and Tomoko Okada are affiliated with the Oregon State University Seafood Laboratory, 2001 Marine Drive, Room 253, Astoria, OR 97103.

Funding was provided by Western Fishboat Owners Association (WFOA), Eureka, CA and the Oregon Albacore Commission, Newport, OR. Special thanks are given to Gayle Parker of Ilwaco Fish Company, Inc., for coordinating the tagging and off-loading of albacore tuna samples.

Journal of Aquatic Food Product Technology, Vol. 13(4) 2004
http://www.haworthpress.com/web/JAFPT

Digital Object Identifier: 10.1300/J030v13n04_04

KEYWORDS. Albacore tuna, mercury, weight, length, seasonality

INTRODUCTION

Albacore tuna (*Thunnus alalunga*) is a migratory fish found in the temperate and tropical oceans of the world. Three- to four-year-old albacore begin their journey off the coast of Japan and migrate across the Pacific Ocean, arriving off the coast of California in the spring (Kimura et al., 1997). During the summer months, schools of fish travel northward feeding along the West Coast upwelling front. Their offshore range is approximately twenty to a hundred nautical miles or more off the Pacific Coastline. It is this close proximity that allows small-scale troll fishing vessels to harvest albacore during summer months.

The Pacific troll-caught albacore fishery season lasts from June to October each year and the albacore is primarily sold whole-frozen and used as raw material for canned and other products in foreign and domestic markets. Efforts are currently underway to introduce troll-caught albacore into alternative domestic markets as high quality loins and steaks. The albacore industry is a small-scale fishery based in West Coast port cities and is currently diversifying into new niche markets. The stock is sustainable and the fishery contributes to the economic well-being of rural coastal communities (Cox et al., 2002). Albacore has high nutritional value in both its protein content and omega-3 lipid content (Wheeler and Morrissey, 2003). It is very high in docosahexanoic acid which has recently gained public attention for its numerous health benefits (Horrocks and Yeo, 1999; Nettleton, 1995).

Recently, warnings on the mercury concentration in seafood and more specifically, albacore tuna, have sparked the public's concern about fish consumption. The most common form of mercury in fish, methylmercury, is a potent neurotoxin (Costa, 1988) and is especially dangerous to the developing nervous system. In 2001, the U.S. Food and Drug Administration (FDA) had recommended that pregnant women, women of childbearing age, and young children avoid shark, tilefish (*Lopholatilus chamaeleonticeps*), king mackerel (*Scomberomorus cavalla*), and swordfish (*Xiphias gladius*) due to their high mercury content. California's Attorney General, in 2003, ruled that grocery stores had to post warnings for consumers regarding the health risks of mercury in tuna, swordfish, and shark (State of California, 2003). In March 2004, the Environmental Protection Agency (EPA) and the FDA released a joint advisory adding that consumption of fish low in mercury, such as shrimp, canned light tuna, and salmon should be limited to 12 ounces (two average meals) a week, and consumption of canned albacore tuna (white tuna) or tuna steak should be limited to no more than 6 ounces of the 12 total ounces of fish recommended per week (FDA, 2004a).

Mercury is a natural element that is found in minute quantities in air, water and all living things. It exists in nature in two forms: inorganic mercury and organic mercury. It usually enters the environment in inorganic form as a result of natural and anthropogenic processes. Once in the environment, mercury can be methylated by water-dwelling microorganisms and converted into an organic form, which is typically methylmercury. Methylmercury can bind tightly to proteins and is a well-documented neurotoxin (Costa, 1988). Methylmercury attached to chlorine was thought to be the most prevalent form found in fish although recent studies suggest that the less toxic methylmercury- cysteine may be predominant (Harris et al., 2003). Methylmercury will bioaccumulate in oceanic organisms, resulting in significant concentrations in larger, predatory fish. Although humans can be exposed to mercury through contaminated food, drink, air, or dental amalgams, organic mercury exposure in the American diet is almost exclusively as methylmercury from fish and shellfish (Gunderson, 1995), and blood mercury concentrations have been shown to be directly related to the amount of fish consumed (Mahaffey et al., 2004).

The mercury content in fish has been shown to vary widely depending on factors such as fish species, size, place in the food chain, and location of habitat. The same species of fish tested in separate parts of the world have been shown to contain different levels of mercury. Past studies on mercury in tuna often list all tunas together with no distinction among the species (albacore, skipjack, bluefin, yellowfin, etc.). Additionally, little data have been published regarding mercury content in albacore tuna caught off the Pacific Coast of the United States. The purpose of this study was to undertake a more thorough analysis of mercury in a specific species of tuna (*Thunnus alalunga*) captured in the Pacific troll-caught fishery.

MATERIALS AND METHODS

Sample Preparation

Ninety-one albacore tuna from fifteen harvest events off the California, Oregon, and Washington coasts were troll-caught and tagged for identification during the 2003 season from June to November. This was a subset of a larger testing project undertaken by the Western Fishboat Owners' Association to measure lipid content. The tagging and landing of the albacore was coordinated by Gayle Parker of Ilwaco Fish Company, Inc. Tags included information such as catch location and harvest date. Fish were captured in the open Pacific and off the Washington, Oregon, and California coasts. Whole fish were frozen at sea, landed in Ilwaco, WA, and transferred to the Oregon State University Seafood Laboratory (OSU-SFL) in Astoria, OR, where they were stored at −30°C for later analysis. The weight, length and circumference of each albacore tuna were measured just before sample preparation. Lengths were measured from the tip of the mouth to the apex of the tail and circumference was measured around the widest part of the fish. Albacore steaks including the upper forward loin section were cut in the frozen state using a band saw, vacuum packed, frozen and stored at −30°C.

Mercury Testing

Steaks were thawed at 4°C and a 100-g sample of white muscle was taken from the upper forward loin section and homogenized in a blender at high speed for 1 minute. Aliquots of 25 g of each sample were placed into separate disposable plastic containers and frozen. The samples were transported from the OSU-SFL to AM Test Laboratories in Redmond, WA, for mercury analysis. Two-gram aliquots of each sample were digested with 2 ml HNO_3, 4 ml H_2SO_4, 1.5 g $KMnO_4$ (if the puroke color wasn't apparent ~0.5 g additional $KMnO_4$ was added), and 8 ml $K_2S_2O_8$. Samples sat overnight in reagents and were then cooked in a 98°C water bath for 2 hr. After digestion, hydroxylamine hydrochloride and stannous chloride were added and the mercury content was measured using a Perkin Elmer Atomic Absorption Spectrophotometer according to the cold-vapor atomic absorption EPA method 7471A.

Lipid Analysis

The lipid analysis was carried out according to the modified AOAC Official Method 948.15 (Crude Fat in Seafood, Acid Hydrolysis method, 1995).

Moisture Content

Moisture content of samples was determined according to AOAC Official Method 950.46 B (Convection, Gravity method, 1995) by measuring the mass of a sample before and after drying overnight in an oven.

RESULTS

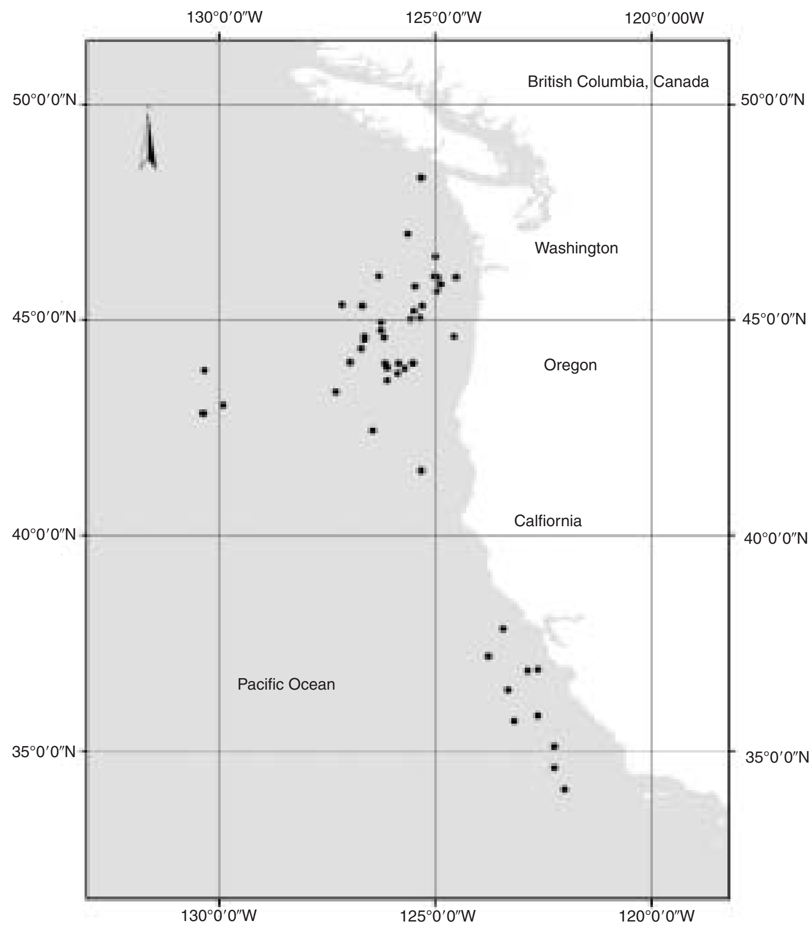
Figure 1 shows the coastal range of geographical catch locations for individual albacore. Fish were caught between 32.72°N (off Southern California) and 48.30°N (off the northern tip of Washington). Although the majority of the fish were caught between 122 and 131°W (within one hundred miles of the U.S. Pacific Coast), six albacore not shown on the map were caught between 171°W and 174°E (mid-Pacific Ocean). As shown in Table 1, there is a wide range of weight, length and lipid content in the analyzed fish. The fish were from 50.8 to 86.4 cm long, averaging 69 ± 8.6 cm, and weighed between 3.14 and 11.62 kg, with an average weight of 6.47 ± 2.17 kg. The average percent lipid in the tuna muscle tissue was 10.6 ± 4.47% (range 1.33-18.74%), while the moisture content averaged 63.48 ± 3.46% (range 56.93-72.36 %). Moisture content has been shown to have a strong, inverse correlation with lipid content (Wheeler and Morrissey, 2003). The total mercury concentration ranged from 0.027 ppm to 0.26 ppm, with a mean value of 0.14 ± 0.05 ppm and a median value of 0.14 ppm.

Figure 2 shows the correlation between fish weight and mercury content. There was a general trend for larger fish to have higher mercury content, but the correlation was only moderate ($R^2 = 0.38$). There was also a moderate positive correlation between length of albacore and mercury content ($R^2 = 0.40$) as shown in Figure 3. There was no correlation between mercury concentration and the time of year captured (seasonality) (Figure 4), and no significant correlation between mercury content and percent lipid (Figure 5); however, fish higher in lipid content showed less variation in mercury concentration.

TABLE 1. Mercury content, lipid, moisture, weight, length, and circumference measurements for 91 samples of albacore tuna.

	Hg (ppm)	Lipid %	Moisture %	Wt (kg)	Length (cm)	Circ (cm)
Ave.	0.14 ± 0.05	10.6 ± 4.47	63.48 ± 3.46	6.47 ± 2.17	69 ± 8.6	49.1 ± 5.5
Range	0.03-0.26	1.33-18.74	56.93-72.36	3.14-11.62	50.8-86.4	38.1-61.0

FIGURE 1. Geographic catch locations along the U.S. Pacific Coastline for albacore tuna analyzed in the present study.



DISCUSSION

Test results showed mercury levels in Pacific troll-caught albacore tuna well below mandated action levels for the U.S. FDA (1.0 ppm methylmercury) and Canadian Food Inspection Agency (0.5 ppm total mercury). The average total mercury concentration for albacore in the present study was 0.14 ± 0.05 ppm. This is lower than mercury levels

FIGURE 2. Correlation between weight and mercury concentration.

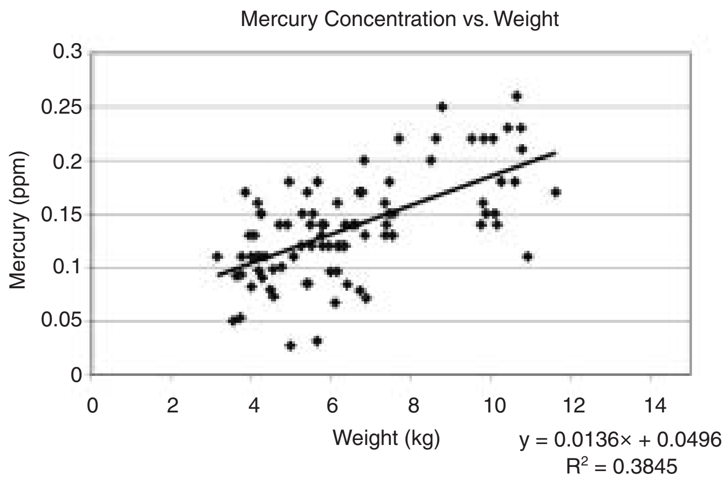
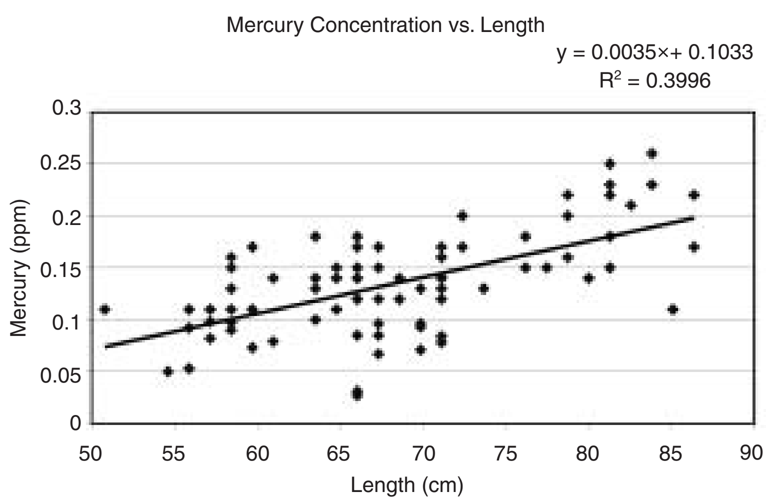


FIGURE 3. Correlation between length and mercury concentration.



recently published for albacore in both fresh/frozen and canned (white tuna) samples, and compares favorably with canned light tuna.

Part of the confusion of fully understanding the mercury concentrations in tuna is that reported data has often not been species or area specific. In a recent compilation of data spanning the years 1990-2002, the FDA reported an average total mercury of 0.38 ppm (ranging from un-

FIGURE 4. Correlation between mercury concentration and seasonality.

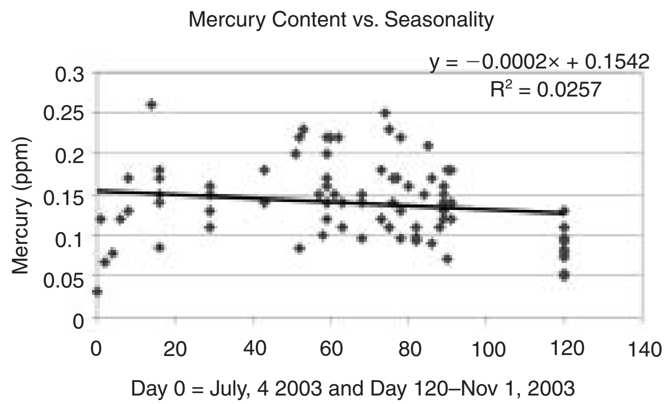
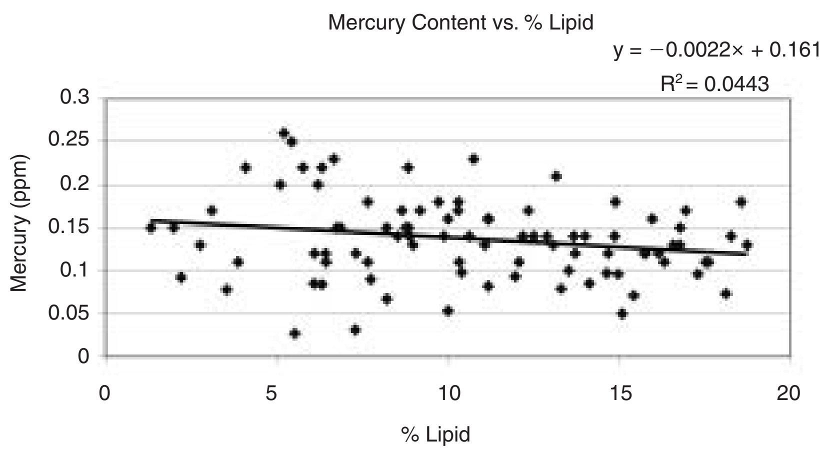


FIGURE 5. Correlation between mercury concentration and % lipid.



detectable to 1.30 ppm) for 131 samples of fresh/frozen (unspecified) tuna (FDA, 2004b). Recent studies have, at the minimum, identified the species as well as general location and size. Brooks (2004) reported mercury levels between 0.25 and 0.60 ppm in 20 individual albacore harvested in the Hawaiian commercial fishery. Samples were taken from muscle tissue in the far caudal region and the fish ranged in size from 17-32 kg, which is considerably larger than the fish tested in this study. A survey of albacore caught in the Mediterranean sea from June to August of 1999 (Storelli et al., 2002) reported an average total mercury concentration of 1.17 ppm (ranging from 0.84 to 1.45 ppm) for 127 muscle tissue samples taken from the anterior of the fish. These fish ranged in weight from 4.0 to 8.7 kg with an average of 6.3 kg. This is similar to the fish in the present study, which ranged in weight from 3.14 to 11.62 kg and averaged 6.47 kg. The high mercury levels observed in the Mediterranean albacore might be explained, in part, by the fact that the Mediterranean sea is located over one of the richest natural reserves of mercury in the world (Bacci, 1989) and it is a semi-enclosed body of water in which toxic compounds from both anthropogenic and environmental sources can accumulate. A study from the Azores Islands in the Atlantic Ocean (Andersen and Depledge, 1997) reported an average total mercury concentration of 0.37 ppm (range 0.22-1.13 ppm) in 46 samples of albacore muscle taken from just below the front dorsal fin. The fish samples were collected from 1993-1994 and had an average forklength of 95.6 cm (range 87 to 117 cm). These albacore were larger than those in the present study, which had an average forklength of 69 cm (range 50.8 to 86.36 cm). A survey in New Zealand (Vlieg et al., 1993) reported an average total mercury concentration of 0.49 ppm for six samples of albacore muscle tissue taken from the caudal end. The fish were caught from May to July of 1990 and were slightly longer than the fish in the present study, ranging in length from 95 to 97 cm. The albacore from New Zealand were slightly lower in lipid content, ranging from 0.6 to 13.4% as compared to 1.33 to 18.74% in the present study.

In studies reported for canned tuna, it is virtually impossible to determine the location of the harvests as well as the size of the fish used in the canning process. The FDA reported a total mercury value of 0.35 ppm (ranging from undetectable to 0.85 ppm) for 179 samples of canned albacore tuna, and 0.12 ppm (undetectable to 0.85 ppm) for 131 samples of light canned tuna analyzed over the years 1990-2003 (FDA, 2004b). A 1982 study (Cappon and Smith, 1982) reported a mean total mercury concentration of 0.27 ppm (ranging from 0.17-0.47 ppm) for 8 samples of canned albacore. A study in New Jersey (Burger and Gochfeld, 2004) reported an average total mercury content of 0.407 ppm (max. 0.997 ppm) in 123 samples of canned albacore, and an investigation undertaken by the FDA in 1991 reported mean methylmercury concentrations of 0.31 ppm for 19 cans of chunk white tuna and 0.26 ppm for 71 cans of solid white tuna (Yess, 1993). Although total mercury concentrations were not reported, methylmercury has been shown to be anywhere from 67-95% of the total mercury in fish (Andersen and Depledge, 1997; Cappon and Smith, 1982; Vlieg et al., 1993).

Few studies have determined the correlation between size of albacore and mercury concentration. Results of the present study show a moderate relationship between size of the fish and mercury content. Although there is a wide range of values, the general trend is that larger fish (weight range 3.14 to 11.62 kg) contain more mercury ($R^2 = 0.38$ for weight vs. mercury and $R^2 = 0.40$ for length vs. mercury). Although the correlation value is moderate, it is consistent with reports from several previous studies, which have found correlations between tuna size and mercury content. A positive correlation between mercury and fish size is consistent with the concept that mercury bioaccumulates in the food chain, resulting in higher mercury concentrations in larger, predatory fish. In the Mediterranean, Storelli et al. (2002) reported weight/total mercury correlations of 0.77 for 127 samples of albacore and 0.84 for 161 samples of bluefin (*Thunnus thynnus*). As discussed previously, the albacore were similar in size to those in the present study, but were much higher in mercury content. The bluefin weighed between 5 and 83 kg (average 36 kg) and had an average total mercury concentration of 1.18 ppm. In the Azores Islands study mentioned previously, a correlation factor of 0.56 was reported for forklength/total mercury among 46 albacore that were slightly larger than those in the present study. A study in 1977 found weight/total mercury correlations of 0.93 for 16 samples of yellowfin tuna (*Thunnus albacares*) and 0.92 for 8 samples of bigeye tuna (*Parathunnus sibi*) (Menasveta and Siriyong, 1977). These fish had similar total mercury concentrations (0.026-0.223 ppm) to those in the present study and a larger weight range (5-75 kg for yellowfin and 3-55 kg for bluefin). Another study (Boush and Thieleke, 1983) reported weight/total mercury correlations of 0.54 for 100 samples of yellowfin and 0.557 for 104 samples of bigeye. The fish were larger than the tuna in the present study, weighing between 9 and 101 kg, with average weights of 45 kg for the yellowfin and 57 kg for the bigeye. Although the recent study on albacore tuna in Hawaii (Brooks, 2004) reported no correlation between tuna weight and mercury concentration, the fish were significantly larger than those in the present study, and correspondingly showed considerably higher levels of mercury in the flesh.

There was no correlation between mercury content and the time of year the Pacific troll-caught albacore were captured. Mercury content and percent lipid in the muscle tissue also did not show a strong relationship, although samples lower in lipid did show more variation in mercury concentrations.

Mercury in tuna and other fish species is a critical issue for the seafood industry and the consumer. The Pacific troll-caught albacore troll fishery is an important fishery for the Pacific Northwest including Northern California. These albacore are 3-4 years in age and range from 4-12 kg in size. A recent report showed that the troll-caught albacore tend to be high in lipid content (4-16%) and are rich in omega-3 fatty acids (Wheeler and Morrissey, 2003). In the past, the majority of the capture was transshipped to large canning operations that produce high quality albacore pack. The Pacific Coast albacore industry has been developing alternative markets and a significant portion of the catch is sent to Europe for small canning operations and to micro-canners throughout the Pacific Northwest. Mercury is a concern for the industry maintaining a viable albacore fishery for the Pacific Northwest and developing new markets. This study shows that these smaller Pacific troll-caught albacore are low in mercury. Combined with its high level of omega-3 fatty acids, Pacific troll-caught albacore is a healthy food choice for the majority of consumers.

REFERENCES

Andersen, J.L. and Depledge, M.H. 1997. A survey of total mercury and methylmercury in edible fish and invertebrates from Azorean waters. Marine Environmental Research 44: 331-350.

Bacci, E. 1989. Mercury in the Mediterranean. Mar. Pollut. Bull. 20: 59-63.

Boush, G.M. and Thieleke, J.R. 1983. Total mercury content in yellowfin and bigeye tuna. Bull Environ Contam Toxicol. 30: 291-297.

Brooks, B. 2004. Mercury levels in Hawaiian commercial fish. *http://www.epa.gov/waterscience/fish/forum/2004/presentations/monday/brooks-barbara.pdf*

Burger, J. and Gochfeld, M. 2004. Mercury in canned tuna: White versus light and temporal variation. Environmental Research 96(2): 239-249.

Cappon, C.J. and Smith, J.C. 1982. Chemical form and distribution of mercury and selenium in canned tuna. J Appl Toxicol. 2: 181-189.

Costa, L.G. 1988. Interactions of neurotoxicants with neurotransmitter systems. Toxicology 49: 359-366.

Cox, S.P., Martell, S.J.D., Walters, C.J., Essington, T.E., Kitchell, J.F., Boggs, C., and Kaplan, I. 2002. Reconstructing ecosystem dynamics in the Central Pacific Ocean, 1952-1998. Canadian Journal of Fisheries and Aquatic Sciences 59: 1724-1735.

FDA. 2004a. Backgrounder for the 2004 FDA/EPA consumer advisory: What you need to know about mercury in fish and shellfish. *www.fda.gov/oc/opacom/hottopics/mercury/backgrounder.htmla*

FDA. 2004b. Mercury levels in commercial fish and shellfish. *www.cfsan.fda.gov/~frf/sea-mehg.html*.

Gunderson, E.L. 1995. Dietary intakes of pesticides, selected elements, and other chemicals: FDA total diet study, June 1984-April 1986. Journal of AOAC International 78: 910-921.

Harris, H.H., Pickering, I.J., and George, G.N. 2003. The chemical form of mercury in fish. Science 301: 1203.

Horrocks, L.A. and Yeo, Y.K. 1999. Health benefits of docosahexaenoic acid (DHA). Pharmacol Res. 40: 211-225.

Kimura, S., Nakai, M., and Sugimoto, T. 1997. Migration of albacore, *Thunnus alalunga*, in the North Pacific Ocean in relation to large oceanic phenomena. Fisheries Oceanography 6: 51-57.

Mahaffey, K.R., Clickner, R.P., and Bodurow, C.C. 2004. Blood organic mercury and dietary mercury intake: National health and nutrition examination survey, 1999 and 2000. Environ Health Perspect. 112: 562-570.

Menasveta, P. and Siriyong, R. 1977. Mercury content of several predacious fish in the Andaman Sea. Mar. Pollut. Bull. 8: 200-204.

Nettleton, J.A. 1995. Omega-3 fatty acids and health. New York: Chapman & Hall. xiii, 359 p.

Storelli, M.M., Stuffler, R.G., and Marcotrigiano, G.O. 2002. Total and methylmercury residues in tuna-fish from the Mediterranean sea. Food Addit Contam. 19: 715-720.

Vlieg, P., Murray, T., and Body, D.R. 1993. Nutritional data on six oceanic pelagic fish species from New Zealand waters. Journal of Food Composition and Analysis 6: 45-54.

Wheeler, S. and Morrissey, M.T. 2003. Quantification and distribution of lipid, moisture, and fatty acids of West Coast albacore tuna (*Thunnus alalunga*). J. Aquatic Food Product Technol. 12: 3-16.

Yess, N.J. 1993. U.S. Food and Drug Administration survey of methyl mercury in canned tuna. J. AOAC Int. 76: 36-38.