

HUMAN HEALTH SIGNIFICANCE OF ORGANOCHLORINE AND MERCURY CONTAMINANTS IN JAPANESE WHALE MEAT

M. P. Simmonds

Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent, United Kingdom

K. Haraguchi

Daiichi College of Pharmaceutical Sciences, Fukuoka, Japan

T. Endo

Department of Clinical Toxicology and Metabolism, Faculty of Pharmaceutical Sciences, Health Sciences University of Hokkaido, Hokkaido, Japan

F. Cipriano

Conservation Genetics Laboratory, San Francisco State University, San Francisco, California, USA

S. R. Palumbi

Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, Massachusetts, USA

G. M. Troisi

Wildlife and Human Toxicology Unit, Department of Mechanical Engineering, Brunel University, Uxbridge, Middlesex, United Kingdom

The concentrations of total mercury, polychlorinated biphenyls (PCBs), and organochlorine pesticides (Σ DDT, dieldrin, hexachlorobenzene [HCB], and Σ HCH) were determined in 61 whale meat products (bacon, blubber, red meat, liver, intestine, and tongue) purchased from retail outlets across Japan. Mean (range) concentrations of contaminants in all samples were: total mercury 4.17 (0.01–204); Σ PCB 1.14 (0–8.94); Σ DDT 0.98 (0–7.46); dieldrin 0.07 (0–0.35); HCB 0.06 (0–0.22); and Σ HCH 0.07 (0–0.19) μ g/g (wet weight). The data were used to calculate estimated daily intakes (EDIs) of contaminants at two hypothetical levels of whale meat consumption. These EDIs were compared with FAO/WHO “tolerable daily intake” (TDI) values for each chemical. EDIs calculated for higher levels of whale meat consumption were in some cases exceptionally high and for many products exceeded FAO/WHO-TDIs for total mercury, PCBs, and dieldrin, with exceedance factor values (EDI/TDI) for total mercury, PCBs, and dieldrin reaching maxima of 175, 5.36, and 2.1, respectively. For sensitive consumers and those with high-level con-

Received 27 August 2001; sent for revision 1 October 2001; accepted 4 February 2002.

Address correspondence to Gera Troisi, Wildlife and Human Toxicology Unit, School of Life Sciences, Kingston University, Surrey, KT1 2EE, UK. E-mail: g.troisi@kingston.ac.uk

sumption (e.g., whaling communities), exposure to mercury and to a lesser extent PCBs from certain whale blubber and bacon and striped dolphin liver products could lead to chronic health effects. The Japanese community should therefore exercise a precautionary approach to the consumption of such foods in excess, particularly by high-risk members of the population.

Whale “meat” refers to a variety of human food products originating from various tissues of animals of the mammalian order Cetacea (i.e., whales, porpoises and dolphins). In Japan, which is the primary consumer of whale meat products worldwide, whale meat is primarily an exotic, luxury food item (Simmonds & Johnston, 1994). Production and consumption of whale meat in Japan increased with the expansion of the whaling industry, with peak production in 1962 at 20,000 tons. Whale meat was the main source of protein for the population during and immediately after World War II due to food shortages (47% total animal protein in 1947), and until the mid-1970s it constituted 30% of total meat eaten (Anonymous, 1987). Currently, restaurants and whale meat and fish shops in Japan, retail a wide variety of whale meat products, including red meat, whale bacon (fatty meat from the ventral throat grooves of the head), *sarashi kujira* (blubber adjacent to the dorsal fin), fins, liver, and other organs. These are sold fresh, frozen, dried, cooked, preserved, and canned (Simmonds & Johnston, 1994).

The consumption of whale meat has decreased over the last two decades, due to a significant reduction in Japanese whaling as a consequence of the International Whaling Commission (IWC) moratorium on commercial whaling that came into force in 1986. Today, legal sources of whale meat in Japan come from “scientific whaling” (i.e., IWC member states have a right to take whales for research purposes enshrined in the International Convention for the Regulation of Whaling—which established the IWC). Japan’s research programs are highly controversial and comprise takes of North Pacific and Antarctic minke whales (*Balaenoptera acutorostrata*), extended in 2000 in the North Pacific to Bryde’s whales (*Balaenoptera edeni*) and sperm whales (*Physeter macrocephalus*). The other legal whale meat sources in Japan are the drive and harpoon fisheries of North Pacific small cetaceans, for example, pilot whales (*Globicephala melas*), Dall’s porpoises (*Phocoenoides dalli*), and striped (*Stenella coeruleoalba*) and bottlenose dolphins (*Tursiops truncatus*), and also whale meat stockpiles and stranded or by-caught animals (Haraguchi et al., 2000a). Japanese whale meat products can therefore originate from a wide range of whale and dolphin species and populations. The Japanese Fisheries Agency states that the current total supply of whale meat products “is less than 4500 tons per year” (Haraguchi et al., 2000a).

Whale meat can be highly contaminated with organic contaminants and heavy metals. Organochlorine pollutants—namely, polychlorinated biphenyls (PCBs), pesticides (DDT, dieldrin, chlordanes, and hexachloro-cyclohexane [HCH])—and mercury (inorganic and organic) are typically present in cetacean tissues (Aono et al., 1997; Prudente et al., 1997). These

environmental chemicals are ubiquitous pollutants of the marine environment and biomagnify up the marine food chain as a result of their lipophilic and persistent nature (Hagmar et al., 1998; Bjerregaard et al., 2001; Sweet & Zelikoff, 2001). Being apex predators, odontocete cetaceans (toothed whales and dolphins) are exposed to the high levels of these pollutants from the ingestion of contaminated fish, whereas mysticete cetaceans (baleen whales), feeding lower in the food chain on primarily planktonic organisms, are typically less significantly exposed.

Ingestion of pollutants that are lipophilic and persistent results ultimately in the bioaccumulation of these chemicals in lipid-rich tissues, particularly the blubber (Kawai et al., 1988; Colborn & Smolen, 1996). In the case of mercury, however, the formation of mercuric selenide (HgSe) after demethylation of methyl mercury results in mercury bioaccumulation in the cetacean liver (Wagemann et al., 1998; Das et al., 2000). In addition, the presence of metal-binding proteins, metallothioneins, further increases hepatic and renal mercury concentrations in cetaceans (Law, 1995; Das et al., 2000).

Evidence from studies with laboratory animals and marine mammals, and evidence from studies of humans accidentally poisoned with organochlorines show that PCBs and organochlorine pesticides have the potential to cause adverse health effects, such as immunosuppression, endocrine disruption, reproductive and nervous system disorders, and cancer (Reijnders, 1986; Brouwer et al., 1989; Jacobson et al., 1990; DeRosa et al., 1998; Headrick et al., 1999; Schecter et al., 2001). Inorganic mercury and organic mercury (methylmercury) have been associated with nephrotoxic effects and neurological and developmental abnormalities in both laboratory animals and humans (Ratcliffe et al., 1996; Zalups, 2000; Sweet & Zelikoff, 2001).

There is concern that the concentrations of organochlorines and mercury in whale meat products could exceed internationally established "tolerable daily intake" (TDI) limits for these contaminants in food. Levels of PCBs, DDE (the primary metabolite of DDT), and mercury have been reported, in pilot whale blubber destined for consumption by the Faroe Islanders, that exceed respective TDIs set by United Nations Food and Agriculture Organization and World Health Organization (FAO/WHO) for each chemical (Simmonds et al., 1994). Similarly, PCB levels reported in whale meat (narwhal) consumed by the Inuit, exceed the tolerable daily intake (TDI) set by the Canadian Government (Kinloch et al., 1992).

The aim of this study was to investigate whether the Japanese public, because of its consumption of Japanese whale meat products, is exposed to organochlorines and mercury at levels exceeding thresholds set by the FAO/WHO and the Japanese Ministry of Health and Welfare (JMHW). This was accomplished by analyzing concentrations of PCBs, organochlorine pesticides, and total mercury (inorganic and organic) in whale meat products representative of those available to the Japanese public in retail outlets. Data were used, in conjunction with hypothetical consumption rates, to estimate daily intakes (EDIs) of these chemicals. EDIs were compared to FAO/WHO

and JMHW TDIs to help evaluate potential health effects on consumers from the consumption of Japanese whale meat products.

MATERIALS AND METHODS

Sampling

In total, 61 whale meat products—red meat from muscle (uncooked/canned/processed/cooked), bacon (striated blubber and red meat strips), blubber (cooked and uncooked, some with skin), tongue *sezuri*, and intestine and liver samples—were purchased from representative Japanese retail outlets from Sendai (in the northeast) to Nagasaki (in the southwest), in February 1999. Two or three packages of whale meat products were purchased from each vendor, and no more than one of each type of product was purchased in any one shop to minimize duplicate sampling from the same animals. Every effort was made to purchase whale meat products at random to avoid any bias and to provide a representative picture of products typically available. For the purposes of contaminant analysis, two subsamples were taken from each item; one was wrapped in hexane-washed foil for organochlorine analysis and the second in plastic for mercury analysis. All samples were stored at -20°C until analysis.

The species of origin for all whale meat product samples used in this study were determined by a separate larger study using DNA analysis. Full results and methods are reported in Cipriano and Palumbi (1999). The whale meat products used in this study were found to originate from seven species of odontocete: Dall's porpoise (*Phocoenoides dalli*), striped dolphin (*Stenella coeruleoalba*), bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*), pilot whale (*Globicephala* sp.), Baird's beaked whale (*Berardius bairdii*), sperm whale (*Physeter macrocephalus*)—and three species of mysticete (baleen whales)—minke whale (*Balaenoptera acutorostrata* and *B. bonaerensis*) and Bryde's whale (*Balaenoptera edeni*). The origins of the minke whales (i.e., whether they had been caught in the Antarctic or the Pacific) were also determined. Several meat samples from Pacific minke whales were found to originate from the endangered population known as the "J-stock." Some samples could only be identified as delphinid (i.e., belonging to *Stenella*, *Tursiops*, or *Delphinus*) and some were found to contain a mixture of species. DNA amplification was not possible for two samples (one piece of tataki and one piece of red meat), so the species of origin could not be detected.

Chemicals

All chemicals and reagents, unless otherwise specified, were purchased from Wako Pure Chemicals (Osaka, Japan). All solvents for organochlorine analysis were of glass-distilled grade (GDG) or pesticide residue analysis grade (PRAG). The acids used for mercury analysis were "poisonous metal determination grade" (Wako Pure Chemical Industries Ltd., Japan).

Organochlorine Analysis

The concentrations of PCB and organochlorine pesticides were determined in 10- to 20-g subsamples of each whale meat product. Sample preparation methodology was adapted from Troisi et al. (1998). Briefly, samples were homogenized and extracted with acetone:*n*-hexane (2:1). Extracts were dried over anhydrous sodium sulfate, spiked with internal standards (seven ¹³C-labeled PCB congeners, PCB 77, 101, 118, 126, 153, 156, and 169, from Cambridge Isotope Laboratories, USA, were used to test recovery), and subsequently concentrated to dryness using a vacuum rotary evaporator. The lipid content of samples was determined gravimetrically. Lipid cleanup of extracts was achieved using gel permeation chromatography. In brief, a slurry of Bio-Beads S-X3 (200–400 mesh, 40 g; BioRad Laboratories) in *n*-hexane:dichloromethane (1:1) was packed in a Pharmacia column (450 × 25 mm ID). Solvent was eluted through the column using a high-performance liquid chromatograph (Shimadzu LC6A, SLC-6A system) at a flow rate of 4 ml/min. Extracts were injected into the column via an injector (Rheodyne 7725) fitted with a 2-ml loop. PCB and pesticide fractions were collected between 28 and 40 min. The concentrated fractions were further purified with 1 g silica gel (Wako gel S-1, Wako Pure Chemical Industries Ltd., Japan) by eluting with 20 ml *n*-hexane, and the eluate was concentrated to a volume of 1 ml under nitrogen for chromatographic analysis.

Concentrations (µg/g wet weight) of PCBs (sum of 54 congeners: 44, 47, 52, 66, 74, 85, 87, 92, 95, 97, 99, 101, 105, 107, 110, 114, 118, 128, 130, 132, 133, 135, 137, 138, 139, 141, 144, 146, 147, 151, 153, 156, 157, 158, 164, 166, 167, 170, 171, 172, 174, 177, 178, 179, 180, 182, 183, 189, 194, 195, 202, 203, 206, 209, selected on the basis of being prevalent, and/or toxic congeners that are routinely analyzed in marine mammal samples; Wells & Echarri, 1992), DDTs (sum of *p,p'*-DDE, *p,p'*-DDT, *p,p'*-DDD), HCHs (i.e., sum of α -, β -, and γ -HCH), hexachlorobenzene (HCB), and dieldrin in sample extracts were analyzed according to Mimura et al. (1999). Briefly, analysis of PCBs, DDT, and dieldrin was conducted using a gas chromatograph/mass spectrometer (GC-MS) (Shimadzu GC-17A, QP-5000) with multiple ion detection (molecular-ion M⁺ and [M+2]⁺), whereas HCB and HCH analyses were conducted using a GC with electron capture detector (GC-ECD, Shimadzu GC-14A with ⁶³Ni electron capture detector). For both gas chromatographs, injector temperature was 240°C set for splitless injection, and the GC columns used were J&W Scientific DB-5MS (60 m × 0.25 mm ID). The column temperature program employed was as follows: initial temperature 100°C for 2 min, followed by 20°C/min ramp to 250°C, then 2°C/min to 280°C final temperature, held for 20 min. Helium was used as carrier (linear velocity 30 cm/s) and nitrogen as makeup gas (30 ml/min flow rate). The limit of detection was 0.001 µg/g for PCBs, DDT, and HCH and 0.01 µg/g for HCB and dieldrin. Analytes were identified and quantified by comparing retention time and peak areas with all PCB congeners (CIL) and pesticide standards (TLC pesticide mix, Supelco). Recovery

of organochlorines from samples was 78–97% as determined by the retrieval of internal standards from each sample. Cross-contamination of glassware and sources of external contamination during sample preparation were monitored by processing blank samples with every batch of six true samples.

Total Mercury Analysis

Total mercury concentrations were determined according to Haraguchi et al. (2000b). Briefly, a 1-g subsample was weighed and digested with 20 ml concentrated acid mixture (8 ml HNO₃, 10 ml H₂SO₄, and 2 ml HClO₄) for 30 min at 200°C, or until the color of the digest changed from yellow to a clear solution. Organic mercury was decomposed to inorganic mercury without vaporization. The typical proportion of organic mercury in each product type was 70–95% for red meat, bacon, tongue, and blubber and ~10% for liver and intestine, similar to that reported in other studies (Wagemann et al., 1998). The concentration of total mercury in digest samples was determined using a flameless atomic absorption spectrophotometer (Hiranuma HG-1) calibrated with standard solutions.

RESULTS

Sources of Whale Meat Products

The majority of the whale meat products available to the public comes in the form of blubber, bacon (predominantly from minke whales), and fresh and processed/canned red meat (from both minke whales and dolphins), resulting in a high representation of these product types in this study. A small number of other products were also sampled, such as tongue, liver, and intestine. Over half of the products were found to originate from North Pacific and Antarctic minke whale populations and the remainder mainly from odontocete cetaceans, many of which likely came from Japanese coastal waters (Figure 1).

Organochlorine and Mercury Levels in Whale Meat Samples

Mean (\pm standard error) wet weight concentrations ($\mu\text{g/g}$) of contaminants for all samples were: total mercury (4.17 ± 3.33 , range: 0.01–204), ΣPCB (1.14 ± 0.29 , range: 0–8.94), ΣDDT (0.98 ± 0.24 , range: 0–7.46), dieldrin (0.07 ± 0.011 , range: 0–0.35), HCB (0.06 ± 0.007 , range: 0–0.22) and ΣHCH (0.07 ± 0.008 , range: 0–0.19). The pattern of PCB congener accumulation was consistent across all samples with PCBs 153 (15%), 138 (8%), 118 (7%), and 101 (6%) predominating and to a lesser degree PCBs 180, 149, 95, 99, 52, 170, 105, 128, 187, and 87 (ranging from 2 to 4%). Although another 40 congeners were also detected in small quantities, the major congeners described contributed over 67% to total PCB. Of the three major HCH isomers, β -HCH predominated in all cases (over 95% of total HCH), followed by α -HCH then χ -HCH (isomer-specific data not shown).

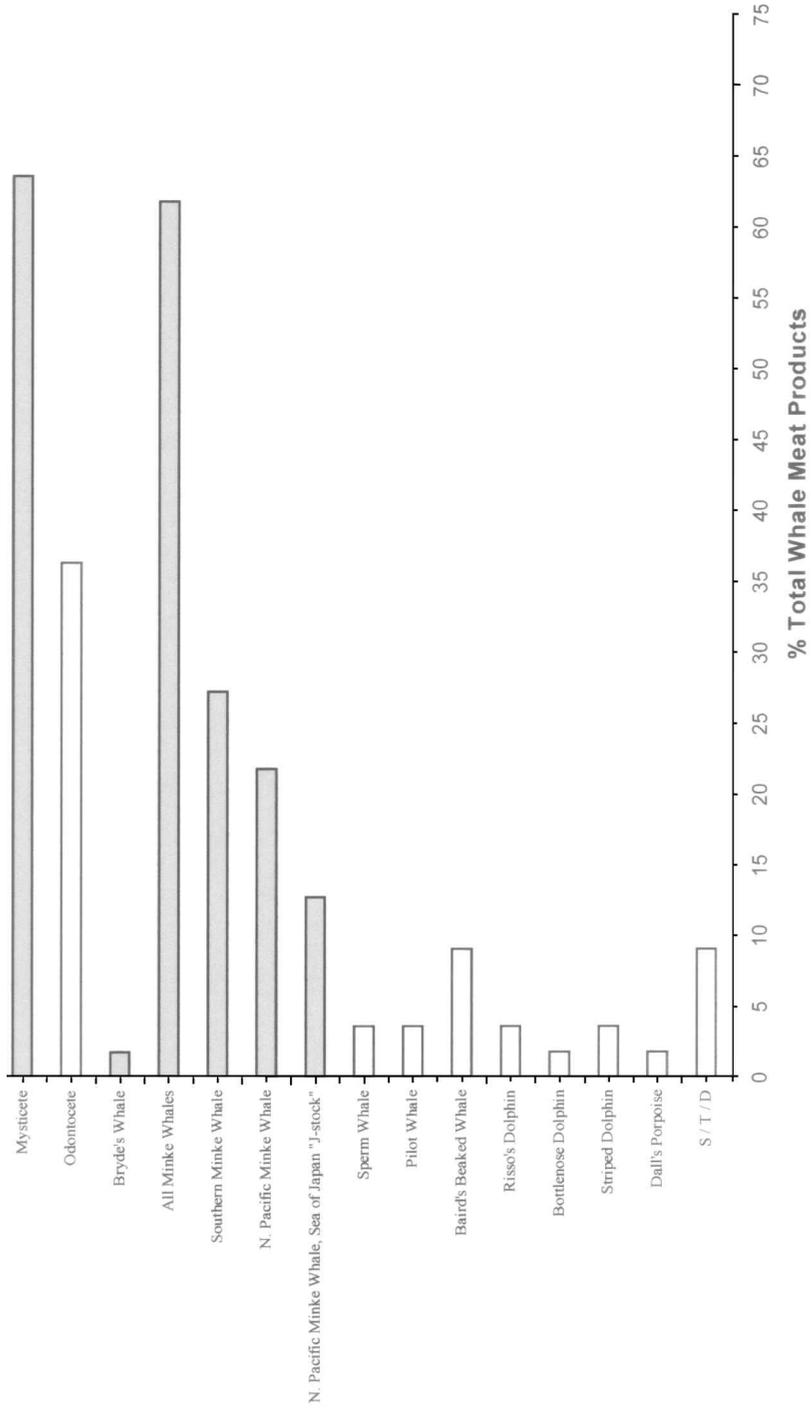


FIGURE 1. Species of origin for all whale meat products (shaded bars indicate mysticete species and open bars indicate odontocete species). S/T/D, delphinid (i.e., *Stenella*, *Tursiops*, or *Delphinus*).

Table 1 summarizes the mean concentrations of organochlorines and total mercury detected in each type of whale meat product.

Contaminant Levels in Whale Meat From Different Species

Total mercury concentrations were highest in whale meat products from odontocete species, and lower concentrations were found in products from minke whales, giving rise to higher EDIs for mercury from odontocete products in Table 2. A similar pattern was seen with Σ PCB and organochlorine pesticides, with the exception of HCB and Σ HCH, where levels were comparable in both odontocete species and North Pacific minke whales.

Contaminant Levels in Different Whale Meat Products

Lipid content data for each type of whale meat product showed that blubber and bacon products are lipid-rich products (mean lipid content 58% and 46%), while the remaining products, liver and intestine, had a low lipid content (Figure 2a). On the whole, lipid-rich products were most contaminated with organochlorines, while products with low lipid content contained the lowest levels of organochlorines (Figure 2, c to g). Organo-

TABLE 1. Mean Lipid Content, Total Mercury, Σ PCB, and Organochlorine Pesticide Concentrations in Japanese Whale Meat Products

Product	Species of origin
Fresh/frozen bacon Striated fat and meat ($n = 6$)	N. Pacific minke whale; Risso's dolphin; bottlenose dolphin; Baird's beaked whale
Fresh/frozen blubber Some with skin/meat attached ($n = 23$)	N. Pacific minke whale; S. Pacific minke whale; Japanese N. Pacific minke whale; striped dolphin; S/T/D
Cooked blubber/bacon Salted, dried or boiled ($n = 4$)	Pilot whale; Risso's dolphin; sperm whale
Fresh/frozen red meat ($n = 9$)	S. Pacific minke whale; Baird's beaked whale; S/T/D; mix of cetacean species; one sample with no ID
Cooked red meat Salted, dried and/or minced; some canned ($n = 16$)	N. Pacific minke whale; S. Pacific minke whale; Dall's porpoise; Bryde's whale; pilot whale; Baird's beaked whale; mix of cetacean species; one sample with no ID
Cooked intestine ($n = 1$)	N. Pacific minke whale
Cooked liver ($n = 1$)	Striped dolphin
Tongue ($n = 1$)	S. Pacific minke whale

Note. HEL (%) = hexane-extractable lipid; Σ DDT = sum of DDT (p,p' -DDE, p,p' -DDD, p,p' -DDT); Σ PCB = sum of 54 congeners; Σ HCH = sum of α , β , γ isomers; n/d = not detected; S/T/D = delphinid (i.e., *Stenella*, *Tursiops*, or *Delphinus*).

^aMeans used as data show normal distribution.

chlorine concentrations were low in the single sample of tongue examined, despite a relatively high lipid content in this tissue. It should be noted that this is the first study to determine organochlorine concentrations in a cetacean tongue sample. The highest total mercury concentration was detected in the single striped dolphin liver sample, which had a low lipid content (4.3%) and highlighted the significant accumulation of mercury in liver compared with products from other tissues (Figure 2b).

Contaminant Levels of Cooked Versus Uncooked Red Meat Products

In order to investigate any influence of cooking on contaminant levels in whale meat products. Lipid content and contaminant concentration were compared among uncooked and cooked/processed/canned red meat products (Figure 2). It was not possible to investigate the influence of cooking on contaminant levels in the other types of products due to the underrepresentation of cooked samples in our study. Mean levels of Σ PCB, Σ DDT, HCB, HCHs, and dieldrin on the whole were found to be lower in cooked compared with uncooked samples. In the case of mercury, however, although the same was observed for mercury levels in blubber and bacon

Mean HEL (%)	Mean ^a concentration \pm SE (range) (μ g/g wet weight)					
	Hg	Σ PCB	Σ DDT	Dieldrin	HCB	Σ HCH
4.59 \pm 10.8 (15.8–91.7)	0.21 \pm 0.07 (0.07–0.55)	3.46 \pm 1.41 (0.43–7.70)	2.98 \pm 1.16 (0.32–7.32)	0.12 \pm 0.03 (0.05–0.23)	0.87 \pm 0.02 (0.04–0.14)	0.07 \pm 0.01 (0.05–0.11)
55.7 \pm 4.5 (4.5–90.7)	0.29 \pm 0.14 (0.01–2.96)	1.84 \pm 0.57 (0.002–8.94)	1.55 \pm 0.48 (0.001–7.46)	0.09 \pm 0.02 (0.00–0.35)	0.10 \pm 0.01 (0.00–0.22)	0.12 \pm 0.01 (0.00–0.1)
10.9 \pm 4.1 (1.2–20.1)	3.27 \pm 2.27 (0.22–9.92)	0.45 \pm 0.19 (0.07–0.82)	0.36 \pm 0.20 (0.06–0.95)	0.03 \pm 0.007 (0.00–0.04)	0.01 \pm 0.003 (0.00–0.02)	0.01 \pm 0.0 (0.00–0.01)
8.0 \pm 5.7 (0.68–53.4)	1.48 \pm 0.62 (0.04–5.30)	0.26 \pm 0.21 (0.00–1.82)	0.17 \pm 0.12 (0.00–1.07)	0.02 \pm 0.01 (0.00–0.09)	0.01 \pm 0.002 (0.00–0.02)	0.003 \pm 0.0 (0.00–0.006)
2.4 \pm 0.4 (0.55–0.67)	0.92 \pm 0.35 (0.03–4.45)	0.08 \pm 0.03 (0.001–0.34)	0.09 \pm 0.04 (0.00–0.45)	0.009 \pm 0.003 (0.00–0.04)	0.009 \pm .0003 (0.00–0.04)	0.011 \pm 0.005 (0.00–0.05)
4.3	0.17	0.03	0.03	n/d	n/d	0.01
3.9	204	0.42	0.35	0.01	0.02	n/d
24.1	0.06	0.01	0.004	n/d	0.01	n/d

TABLE 2. Estimated Daily Intake (EDI; µg/kg body weight/d) of Total Mercury, ΣPCB, and Organochlorine Pesticides for Low (0.1 g/person/d) and High (36 g/person/d) Rates of Consumption of Japanese Whale Meat

Product	Species	Hg	
		A	B
Bacon	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0002	0.0780
Bacon	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0002	0.0600
Bacon	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0001	0.0414
Bacon sliced	Bottlenose dolphin (<i>T. truncatus</i>)	0.0005	0.1680
Shredded bacon	Baird's beaked whale (<i>B. bairdii</i>)	0.0009	0.3300
Frozen bacon	Risso's dolphin (<i>G. griseus</i>)	0.0002	0.0840
Frozen bacon	Risso's dolphin (<i>G. griseus</i>)	0.0165	5.9520 ^a
Blubber	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0001	0.0420
Blubber	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	n/d	0.0120
Blubber and black skin	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0001	0.0240
Fresh blubber	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0002	0.0840
Fresh blubber	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0480
Frozen blubber	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0001	0.0180
Frozen blubber	N. Pacific minke whale (<i>B. acutorostrata</i>)	n/d	0.0120
Frozen blubber	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	0.0001	0.0420
Frozen blubber	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	n/d	0.0060
Frozen blubber	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	0.0001	0.0300
Frozen blubber	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	n/d	0.0120
Frozen blubber	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0300
Frozen blubber	Southern minke whale (<i>B. bonaerensis</i>)	n/d	0.0120
Frozen blubber & black skin	Southern minke whale (<i>B. bonaerensis</i>)	0.0002	0.0540
Frozen blubber & black skin	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0420
Frozen blubber & grey skin	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	n/d	0.0120
Frozen blubber & grey skin	N. Pacific minke whale (<i>B. a. davidsoni</i>), Sea of Japan "J-stock"	n/d	0.0120
Frozen blubber & skin	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0480
Fresh blubber & red meat	Striped dolphin (<i>S. coeruleoalba</i>)	0.0024	0.8520 ^a
Fresh blubber & red meat	S/T/D	0.0011	0.3840
Fresh blubber & red meat	S/T/D	0.0012	0.4320
Frozen blubber & red meat	S/T/D	0.0019	0.6900
Frozen blubber & red meat	S/T/D	0.0049	1.7760 ^a
Blubber, salted & seasoned	Pilot whale (<i>G. macrorhynchus</i>)	0.0040	1.4280 ^a
Boiled & dried blubber	Sperm whale (<i>P. macrocephalus</i>)	0.0004	0.1320
Cooked blubber	Sperm whale (<i>P. macrocephalus</i>)	0.0009	0.3300
Fresh red meat	S/T/D	0.0061	2.1900 ^a
Fresh red meat	Southern minke whale (<i>B. bonaerensis</i>)	0.0002	0.0780
Fresh sashimi	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0480
Fresh sashimi ("tataki")	No ID	0.0014	0.5160
Fresh singed sashimi ("tataki")	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0240

ΣPCB		ΣDDT		Dieldrin		HCB		ΣHCH	
A	B	A	B	A	B	A	B	A	B
0.0018	0.6348	0.0015	0.5550	00001	0.0360	0.0001	0.0216	0.0002	0.0642
0.0007	0.2562	0.0005	0.1932	0.0001	0.0306	0.0001	0.0240	0.0001	0.0348
0.0008	0.2922	0.0008	0.2940	0.0001	0.0300	0.0002	0.0600	0.0001	0.0318
0.0128	4.5930 ^a	0.0073	2.6160	0.0004	0.1380 ^a	0.0002	0.0840	0.0002	0.0612
0.0058	2.0820 ^a	0.0122	4.3920	0.0002	0.0780	0.0002	0.0720	0.0001	0.0276
0.0128	4.6224	0.0075	2.6880	0.0003	0.1020 ^a	0.0001	0.0498	0.0001	0.0438
0.0012	0.4380	0.0005	0.1800	n/d	0.0096	n/d	0.0048	n/d	0.0012
0.0030	1.0914	0.0023	0.8220	0.0001	0.0360	0.0002	0.0840	0.0002	0.0702
0.0017	0.5940	0.0015	0.5520	0.0001	0.0300	0.0001	0.0480	0.0003	0.1080
0.0028	0.9978	0.0021	0.7500	0.0001	0.0420	0.0002	0.0594	0.0002	0.0864
0.0037	1.3422	0.0034	1.2060	0.0002	0.0780	0.0003	0.0960	0.0003	0.0942
n/d	0.0012	n/d	0.0005	n/d	0.0003	n/d	n/d	n/d	n/d
0.0025	0.8820	0.0023	0.8280	0.0002	0.0720	0.0002	0.0840	0.0002	0.0588
0.0006	0.1998	0.0004	0.1380	0.0001	0.0240	0.0002	0.0570	0.0001	0.0270
0.0008	0.2958	0.0007	0.2580	0.0001	0.0180	0.0001	0.0360	0.0002	0.0630
0.0001	0.0330	0.0001	0.0192	n/d	0.0018	n/d	n/d	n/d	0.0042
0.0009	0.3096	0.0008	0.2700	0.0001	0.0294	0.0001	0.0492	0.0001	0.0492
0.0024	0.8538	0.0022	0.8040	0.0002	0.0720	0.0004	0.1320	0.0002	0.0702
0.0001	0.0354	0.0001	0.0216	n/d	0.0108	0.0001	0.0270	n/d	n/d
0.0001	0.0312	0.0001	0.0306	n/d	0.0090	0.0001	0.0390	n/d	n/d
0.0001	0.0234	n/d	0.0138	n/d	n/d	n/d	0.0120	n/d	n/d
n/d	0.0012	n/d	0.0006	n/d	n/d	n/d	0.0006	n/d	n/d
0.0011	0.3882	0.0010	0.3420	0.0001	0.0522	0.0003	0.0900	0.0002	0.0828
0.0005	0.1824	0.0003	0.1200	0.0001	0.0300	0.0002	0.0660	0.0001	0.0510
n/d	0.0126	n/d	0.0072	n/d	n/d	n/d	0.0090	n/d	n/d
0.0016	0.5580	0.0007	n/d	n/d	n/d	n/d	0.0072	n/d	n/d
0.0089	3.1992	0.0081	2.8980	0.0004	0.1440 ^a	0.0002	0.0780	0.0002	0.0750
0.0107	3.8394 ^a	0.0100	3.6120	0.0002	0.0840	0.0002	0.0720	0.0003	0.1014
0.0143	5.1552 ^a	0.0111	3.9900	0.0005	0.1740 ^a	0.0002	0.0720	0.0003	0.1164
0.0149	5.3646 ^a	0.0124	4.4760	0.0006	0.2100 ^a	0.0002	0.0780	0.0003	0.1044
0.0014	0.4914	0.0016	0.5700	0.0001	0.0216	n/d	0.0090	n/d	0.0059
0.0001	0.0444	0.0001	0.0330	n/d	n/d	nd	n/d	n/d	n/d
0.0003	0.0954	0.0002	0.0840	n/d	n/d	n/d	n/d	n/d	n/d
0.0030	1.0908 ^a	0.0018	0.6408	0.0001	0.0510	n/d	0.0096	n/d	n/d
n/d	0.0054	n/d	0.0066	n/d	0.0011	n/d	0.0022	n/d	0.0003
n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
0.0001	0.0192	n/d	0.0132	n/d	n/d	n/d	n/d	n/d	0.0036
n/d	0.0006	n/d	0.0007	n/d	n/d	nd	n/d	n/d	n/d

(Table continues on next page)

TABLE 2. Estimated Daily Intake (EDI; $\mu\text{g}/\text{kg}$ body weight/d) of Total Mercury, ΣPCB , and Organochlorine Pesticides for Low (0.1 g/person/d) and High (36 g/person/d) Rates of Consumption of Japanese Whale Meat (*Continued*)

Product	Species	Hg	
		A	B
Frozen red meat	Baird's beaked whale (<i>B. bairdii</i>)	0.0088	3.1800 ^a
Frozen red meat	Baird's beaked whale (<i>B. bairdii</i>)	0.0029	1.0260
Frozen red meat	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0300
Frozen red meat	Mixed cetacean species	0.0025	0.8880 ^a
Frozen, salted, cooked red meat	Pilot whale (<i>Globicephalus</i> sp.)	0.0074	2.6700 ^a
Canned red meat	Baird's beaked whale (<i>B. bairdii</i>)	0.0015	0.5340
Canned red meat	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0002	0.0780
Canned red meat	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0300
Canned red meat	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0480
Canned red meat	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0180
Canned red meat	Mixed cetacean species	0.0001	0.0300
Canned red meat	Mixed cetacean species	0.0001	0.0300
Canned, cooked red meat	Dall's porpoise (<i>P. dalli</i>)	0.0030	1.0860
Canned, cooked red meat	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0004	0.1560
Canned meat & vegetables	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0300
Cooked red meat	No ID	0.0064	2.2920
Cooked red meat, miso paste	Mixed cetacean species	0.0014	0.5040
Cooked, dried red meat	Baird's beaked whale (<i>B. bairdii</i>)	0.0029	1.0500 ^a
Cooked, salted red meat	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0006	0.2100
Cooked steak	Bryde's whale (<i>B. edeni</i>)	0.0002	0.0780
Cooked liver	Striped dolphin (<i>S. coeruleoalba</i>)	0.3396	122.25 ^a
Frozen intestine	N. Pacific minke whale (<i>B. acutorostrata</i>)	0.0003	0.1020
Sezuri (tongue)	Southern minke whale (<i>B. bonaerensis</i>)	0.0001	0.0360
	Mean	0.0070	2.5273
	\pm Standard error	0.0056	2.0333
	Minimum value	n/d	0.0060
	Maximum value	0.3396	122.25

Note. ΣDDT = sum of *p,p'*-DDE, *p,p'*-DDD, *p,p'*-DDT; ΣPCB = sum of 54 congeners; ΣHCH = sum of α , β , γ isomers n/d = not detectable—therefore no EDI; S/T/D = delphinid (i.e., *Stenella*, *Tursiops*, or *Delphinus*).

^aExceeds FAO/WHO TDI ($\mu\text{g}/\text{kg}$ body weight/d).

products, mean levels in cooked red meat products tended to be lower in cooked than uncooked products. This may be due to the heat destruction of metal-binding proteins, causing mercury to be released from the tissue. Due to the small data sets for each product type in this study and lack of published information on cooking effects, these inferences are speculative and further research is warranted.

Estimated Daily Intake of Organochlorines and Inorganic Mercury

In order to calculate EDIs, it is necessary to know the average daily consumption rate for the population in question. However, there are no

ΣPCB		ΣDDT		Dieldrin		HCB		ΣHCH	
A	B	A	B	A	B	A	B	A	B
0.0001	0.0348	0.0001	0.0312	n/d	0.0009	n/d	0.0006	n/d	n/d
0.0002	0.0582	0.0004	0.1260	n/d	0.0031	n/d	0.0032	n/d	0.0005
n/d	0.0018	n/d	0.0018	n/d	n/d	nd	n/d	nd	n/d
0.0001	0.0210	n/d	0.0168	n/d	n/d	n/d	0.0060	nd	0.0036
n/d	0.0150	n/d	0.0138	n/d	0.0011	n/d	0.0010	n/d	n/d
0.0001	0.0522	0.0001	0.0498	n/d	0.0020	n/d	0.0032	n/d	n/d
0.0001	0.0216	n/d	0.0168	n/d	0.0007	n/d	0.0011	n/d	0.0012
n/d	0.0006	n/d	0.0006	n/d	n/d	n/d	n/d	n/d	n/d
n/d	0.0006	n/d	n d	n/d	n/d	n/d	0.0003	n/d	n/d
n/d	0.0006	n/d	0.0009	n/d	n/d	n/d	n/d	n/d	n/d
n/d	0.0012	n/d	0.0006	n/d	n/d	n/d	n/d	n/d	n/d
n/d	0.0006	n/d	0.0006	n/d	n/d	n/d	n/d	n/d	0.0006
0.0002	0.0882	0.0003	0.0990	n/d	0.0027	n/d	0.0038	n/d	n/d
0.0005	0.1884	0.0008	0.2700	n/d	0.0090	n d	0.0102	n/d	n/d
n/d	0.0006	nd	0.0003	n/d	n/d	n/d	n/d	n/d	n/d
0.0008	0.2808	0.0006	0.2100	0.0001	0.0228	0.0001	0.0228	0.0001	0.0324
0.0001	0.0252	n/d	0.0168	n/d	n/d	n/d	n/d	n/d	0.0024
0.0002	0.0684	0.0003	0.1062	n/d	0.0025	n/d	0.0023	n/d	0.0004
n/d	0.0162	n/d	0.0114	n/d	0.0015	n/d	n/d	n/d	0.0016
n/d	0.0042	n/d	0.0028	n/d	n/d	n/d	n/d	n/d	n/d
0.0007	0.2532	0.0006	0.2100	n/d	0.0078	n/d	00108	n/d	n/d
n/d	0.0156	n/d	0.0150	n/d	n/d	n/d	n/d	n/d	0.0028
n/d	0.0048	n/d	0.0024	n/d	n/d	n/d	0.0084	n/d	n/d
0.0019	0.6890	0.0017	0.5970	0.0001	0.0417	0.0001	0.0372	0.0001	0.0423
0.0005	0.1760	0.0004	0.1492	n/d	0.0066	n/d	0.0045	n/d	0.0049
n/d	0.0006	n d	0.0003	n/d	0.0003	n/d	0.0003	n/d	0.0003
0.0149	5.3646	0.0124	4.4760	0.0006	0.2100	0.0004	0.1320	0.0003	0.1164

current and relevant data available on the composition of the Japanese daily diet and variations in diet according to season. Therefore, it was necessary to make assumptions regarding the number and size (mass) of whale meat meals per person in Japan, by extrapolating from limited published data. Annual production of whale meat in Japan has been estimated at 4500 tons per year (Haraguchi et al., 2000a). With the Japanese population over 126.5 million, this might be taken to equate to 30–36 g whale meat available to each person per year. However, such a value is clearly not truly representative, as there will be many who do not eat whale meat at all, and others with high consumption levels. The latter particularly pertains to

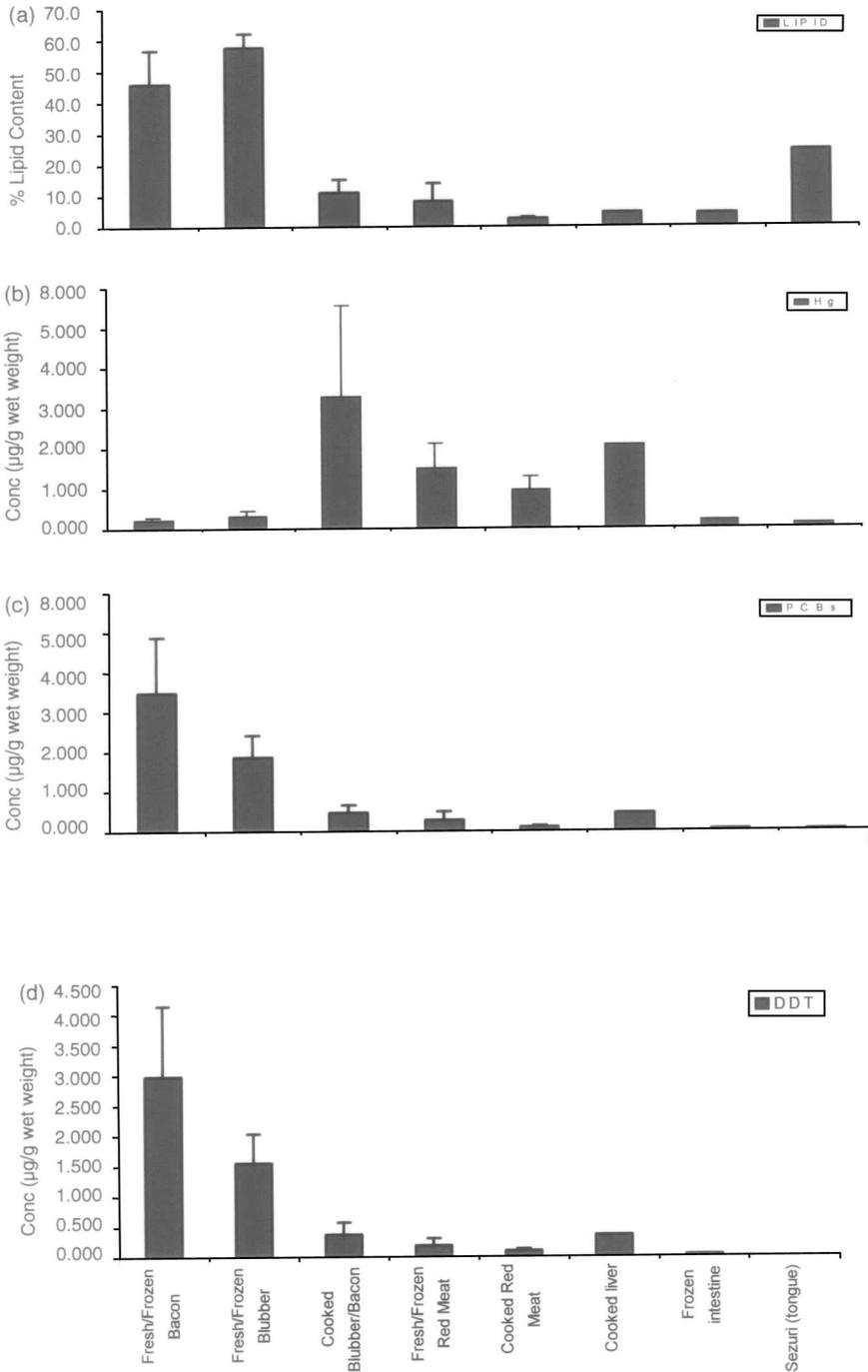


FIGURE 2. Mean (\pm SE) percentage lipid content and concentrations in $\mu\text{g/g}$ (wet weight) of total mercury, ΣPCB , ΣDDT , dieldrin, HCB, and ΣHCH in different whale meat products.

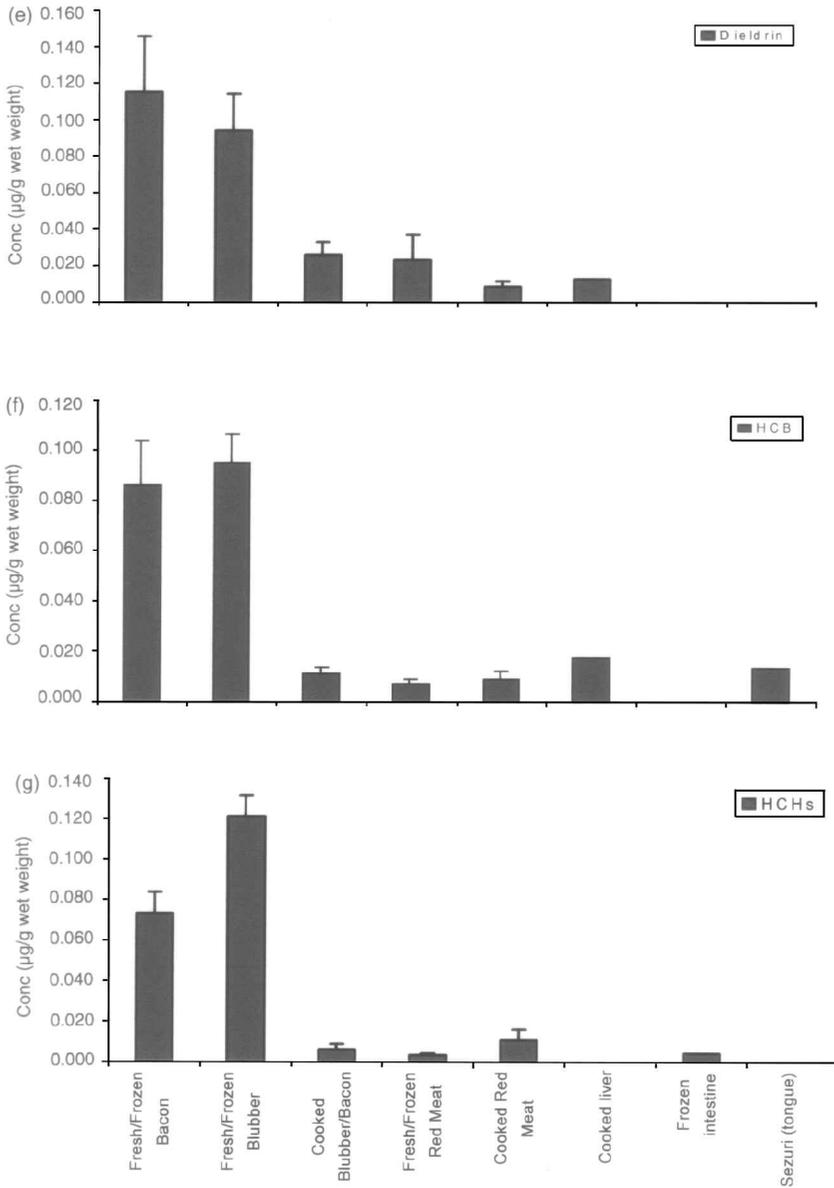


FIGURE 2. (Continued) Mean (\pm SE) percentage lipid content and concentrations in $\mu\text{g/g}$ (wet weight) of total mercury, ΣPCB , ΣDDT , dieldrin, HCB, and ΣHCH in different whale meat products.

coastal villages and towns with a tradition of whaling. Here, whale meat is an important part of the local diet and is eaten more frequently than beef, pork, or poultry compared with urban communities, due to availability, cost, tradition, and cultural habits (Manderson & Akatsu, 1993; Wada et al., 1999). For example, in the town of Ayukawa (northeast Honshu, Japan), a

large proportion of the population formerly worked in whaling and whaling-related industries until the IWC moratorium. Prior to 1987, whale meat was eaten with every meal and even as a snack, and was the main source of animal protein. However, in the years following the moratorium (1988 to 1990), consumption rates declined to meals of 50–100 g, 2–3 times/wk (Manderson & Akatsu, 1993).

To address the disparate patterns of whale meat consumption pattern in Japan, EDIs were calculated for two hypothetical groups with different consumption rates. The characterization of “extreme consumers” is a necessary approach that is recommended in order to define target groups for informative or preventive actions (Chambolle, 1999):

- A. “Low Consumption”: The value of approximately 30 g whale meat/person/yr taken from Haraguchi et al. (2000a) equates to a consumption rate estimated at 0.1 g/person/d and is calculated from the Japanese population size and annual Japanese whale meat production.
- B. “High Consumption”: According to Manderson and Akatsu (1993), meal sizes are 50–100 g and are eaten 2–3 times/wk in a typical Japanese post-IWC moratorium whaling community (Ayukawa). For an intermediate-sized meal of 85 g, eaten 3 times a week, daily consumption can be estimated at 36 g/person/d.

EDI values were calculated in units of micrograms per kilogram body weight per day. Since TDIs for all of the contaminants studied were only available from WHO and not from JMHW, the average person’s body mass was assumed to be 60 kg as recommended by FAO/WHO (1990) to ensure standardization. EDIs were calculated for groups A and B, from the micrograms per kilogram wet weight concentrations of contaminants (summarized in Table 1) as follows:

Group A—Low Consumption: $(\text{Conc} \times 0.1)/60$

Group B—High Consumption: $(\text{Conc} \times 36)/60$

EDIs for total mercury, PCBs, and organochlorine pesticides for groups A and B are presented in Table 2. Mean EDIs were highest for total mercury, followed by Σ PCB and Σ DDT, while lowest EDI values were obtained for Σ HCH.

In order to investigate whether human exposure to organochlorines and mercury from whale meat consumption could potentially lead to adverse health effects in consumers, EDIs for each chemical were compared with respective FAO/WHO and JMHW TDIs. The TDI was originally developed by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and is defined as “the amount of a food additive, expressed on a body weight basis that can be ingested daily over a lifetime, without appreciable health risk on the basis of all facts known at the time” (“without appreciable health

risk" refers to practical certainty that injury will not result, even after a lifetime of exposure) (WHO, 1987). TDIs are based on a scientific evaluation of all available human and animal toxicological data on a specific contaminant. However, more often than not, only animal test data are available, and the no-observed-effect level (NOEL) is typically used. The NOEL is divided by a safety factor (usually 100) to provide a large safety margin in the resultant TDI value.

TDIs are a practical means to achieving uniformity of approach in regulatory control internationally to ensure actual human intakes of contaminants are well below toxic thresholds. However, it should be borne in mind that many factors affecting the toxicity of a chemical (e.g., gender, reproductive state, nutritional condition, age, disease, and genetic polymorphism) cannot be taken into account in the determination of the TDI due to paucity of suitable data and this is addressed by the use of the safety factors (Renwick, 1996, 1998; Larsen & Richold, 1999). Furthermore, validity of TDIs is further affected by error introduced by interlaboratory variation (e.g., in precision, completeness of study, duration, etc.) during their determination.

FAO/WHO and JMHW TDI values are typically expressed in units of milligrams per kilogram body weight per day. To facilitate a direct comparison of EDI and TDI values, TDIs were converted to units of micrograms per kilogram body weight per day (Table 3). There is no FAO/WHO or JMHW value available for the TDI of HCB. The proportions of each product where EDIs for Group B exceed respective TDIs for specific contaminants are presented in parentheses in Table 4. For all products, EDI for total mercury exceeded respective TDI more frequently than for any other contaminant investigated, followed by Σ PCB and dieldrin. EDIs for the remaining contaminants (Σ DDT, HCB, and Σ HCH) did not exceed respective FAO/WHO or JMHW TDI values in any sample. In the case of total mercury, the EDI for liver, and to a lesser degree red meat products, tended to exceed the FAO/WHO TDI more than for any other product type. In the case of fat-rich prod-

TABLE 3. International (FAO/WHO) and Japanese Ministry of Health and Welfare (JMHW) Tolerable Daily Intakes (TDIs) for PCBs, Organochlorine Pesticides, and Total Mercury

Chemical	TDI ($\mu\text{g}/\text{kg}$ body weight/d)	
	FAO/WHO	JMHW
Σ PCB	1 ^a	5
Σ DDT	20	5
Dieldrin	0.1	0.1
HCB	n/d	n/d
Σ HCH	8	12.5
Total mercury	0.7	n/d

Note. n/d = No data currently available from JMHW.

^aFDA (1998) TDI.

TABLE 4. Exceedance Factors (EDI/TDI) for Total Mercury and Organochlorines in Whale Meat Products for Group B Consumption Rates

Product	Exceedance factors (EDI/TDI) for group B			
	Hg, FAO/WHO	Σ PCB		Dieldrin, FAO/WHO & JMHW
		FAO/WHO	JMHW	
Fresh/frozen Bacon	—	2.08–4.62 (3/6)	—	1.02–1.38 (216)
Fresh/frozen blubber	1.21–2.54 (2/23)	1.09–5.36 (6/23)	1.03–1.07 (2/23)	1.44–2.10 (3/23)
Cooked blubber	2.04–8.50 (2/4)	—	—	—
Fresh/frozen red meat	1.26–4.54 (4/9)	1.09 (1/9)	—	—
Cooked red meat	1.50–3.81 (4/16)	—	—	—
Cooked intestine	—	—	—	—
Cooked liver	174.7 (1/1)	—	—	—
Cooked tongue	—	—	—	—

Note. Parentheses indicate the proportion of each product type where EDI exceeded TDI.

ucts (blubber and bacon) the EDIs for Σ PCB and dieldrin exceeded respective FAO/WHO TDIs more than for any other product type. Of particular interest, EDI of Σ PCB from uncooked red meat products did exceed the FAO/WHO TDI for Σ PCB, but this was not the case for cooked red meat.

Exceedance factors (EF; the times the TDI is exceeded by EDI, calculated from EDI/TDI) for total mercury, Σ PCB, and dieldrin were calculated for all products where Group B EDIs exceeded respective TDIs (Table 4). The EFs show that EDIs exceeded respective FAO/WHO TDIs, by factors of 1.21 to 175 for total mercury, 1.09 to 5.36 for Σ PCB, and 1.02 to 2.10 for dieldrin. The JMHW TDI for Σ PCB is 5 times higher than that adopted by FAO/WHO (Table 3). Consequently, lower EFs were obtained and subsequently the EDI for only two samples exceeded the JMHW TDI for Σ PCB (Table 4). FAO/WHO and JMHW EFs for dieldrin were identical since FAO/WHO and JMHW adopt the same TDI for this Pesticide. In Japan a TDI for total mercury has not been set.

DISCUSSION

Contaminant Levels in Whale Meat Products

The pattern of accumulation reported here reflects the persistence of each chemical and its association with lipid-rich tissues (organochlorines) or metal-binding proteins known as metallothioneins (mercury) that are found in cetacean tissues (Kawai et al., 1988; Law, 1995; Das et al., 2000). The relative abundance of these pollutants in the marine food chain is an important factor contributing to this contamination pattern. PCBs and mercury, for example, are more widespread and persistent marine pollutants than are organochlorine pesticides (Hagmar et al., 1998; Sweet & Zelikoff, 2001). DDT is still the most abundant pesticide in the marine environment,

despite international bans on its use. The relatively high DDT concentrations found in North Pacific-sourced whale meat may indicate the ongoing use of DDT in this region. HCH, dieldrin, and HCB are less ubiquitous in the marine food chain as they are less intensively used, or have been banned, and are also more readily metabolized. This has resulted in lower environmental levels of HCH, dieldrin, and HCB and lower potential for biomagnification of these chemicals. The PCB congener pattern was highly similar for all samples and was typical of patterns reported in cetacean tissues and is an artifact of the relative persistence and lipophilicity of each PCB congener (Boon et al., 1994).

It is well established that cetaceans have a poor capacity to detoxify organic xenobiotics (Tanabe et al., 1988; Watanabe et al., 1989). Although cetaceans possess hepatic microsomal cytochrome P (CYP) 1A needed for the metabolism of planar organic chemicals such as dioxins and coplanar PCBs (congeners 77, 126 and 169), their CYP 1A activity is lower than that of pinnipeds and also of terrestrial mammals (Tanabe et al., 1998). CYP 1A enzymes can convert substrates to more toxic arene oxide intermediates that attack DNA, before they are further metabolized by phase I and II detoxification and subsequently excreted (Headrick et al., 1999). Cetaceans lack or have inactive CYP 2B isozymes, which are needed to detoxify more bulky, globular xenobiotics, such as DDT and PCBs 153 and 180, causing these chemicals to persist and accumulate in cetacean tissues (Boon et al., 1994).

Species-Dependent Trends in Contaminants

On the whole, levels of organochlorines and total mercury tend to be much greater in odontocete species (toothed whales and dolphins) than mysticete species (baleen whales). This is because odontocetes are piscivorous apex predators of the marine food chain and therefore are more significantly exposed to biomagnified levels of lipophilic persistent pollutants. Mysticete species, however, are primarily planktivorous, or have a mixed diet of plankton and fish, and therefore generally feed at lower trophic levels where biomagnification of pollutants is less significant. In the case of HCB and Σ HCH, however, levels in samples were similar for odontocete and mysticete species. This is likely due to the shorter half-lives of these pollutants in the marine environment and food chain compared with the more persistent organochlorines (PCB and DDT), leading to reduced biomagnification.

Japanese odontocete products sold in Japanese markets originate mainly from drive fisheries and harpoon hunts predominantly in the local Japanese coastal area. Due to high levels of industrial and agricultural activity in the adjacent areas, the local marine food chain is heavily contaminated with pollutants. This results in high concentrations of contaminants in odontocete products from the coastal region. In contrast, Japanese mysticete products originate mainly from whale populations of the oceanic North Pacific and the Antarctic, which are less polluted (Aono et al., 1997; Prudente et al., 1997). This is another reason, aside from trophic differences, causing

mysticete products to be less contaminated than odontocete products on the whole. As mentioned earlier, a high proportion of the products in this study were mislabeled (Cipriano & Palumbi, 1999). This is of importance to regulators who may wish to restrict or regulate consumption of some whale meat products to minimize potential exposure to contaminants or to enforce legislation which renders it illegal to sell contaminated or mislabeled food. This will empower consumers to exercise informed choice in their purchasing.

Product-Specific Trends in Contaminant Levels

Blubber and bacon products were found to be the most contaminated with organochlorines. Accumulation of these persistent and lipophilic organochlorines in these products, compared with other products, occurs due to the high lipid content of blubber and bacon (+46%) compared with other products. Lipid content, particularly the content of triglyceride fatty acids, has been demonstrated in the past generally to be the main factor determining the bioaccumulation and partitioning characteristics of lipophilic contaminants in cetacean tissues and therefore whalemeat products (Aguilar, 1985; Kawai et al., 1988).

The single liver product analyzed from a striped dolphin was found to have an excessively high total mercury concentration. High levels of mercury are reported in striped dolphins and other apex predators (odontocetes) because of both significant exposure to biomagnified quantities of mercury in the marine food chain and demethylation of methylmercury to inorganic mercury in the cetacean liver. Demethylation is a physiological mechanism to decrease the methylmercury in the bloodstream and its circulation to sensitive organs such as the brain (Wagemann et al., 1998). In addition, the presence of metallothionein also causes significant hepatic inorganic mercury accumulation (Law, 1995; Das et al., 2000). This observed preferential accumulation of inorganic mercury in the liver is in agreement with studies of tissue and organ distribution of mercury in cetaceans (André et al., 1990). Further associated studies have been undertaken to investigate more thoroughly the concentrations of mercury in Japanese cetacean liver and kidney products (Endo et al., 2000; Haraguchi et al., 2000b). From these studies, it is evident that the total mercury concentration detected in the single liver sample of this study was not exceptional, since mean concentrations of total and methylmercury in cetacean liver products ($n = 9$) were 275 ± 227 and 11.0 ± 5 $\mu\text{g/g}$ (wet weight) (Endo et al., 2000).

Effects of Cooking on Contaminant Levels in Red Meat Products

Precooked red meat products were less contaminated with ΣPCB , dieldrin, HCB, and DDT than uncooked/processed red meat, suggesting that cooking or processing possibly has some influence on organochlorine levels, although HCH provides an exception to this. The method of cooking red

meat varies according to product supplier. It can be boiled or fried, whereas blubber is typically boiled or eaten raw (Manderson & Akatsu, 1993). Boiling meat liberates lipids and associated lipophilic organochlorines, and heat can cause the thermal degradation and evaporation of lower molecular weight PCB congeners and the less stable pesticides. Thus, it is plausible that cooked red meat contained lower concentrations of organochlorines than uncooked red meat, due to lipid removal and a subsequent lower lipid content, chemical degradation, and evaporation achieved from the cooking of whale meat products.

In contrast, total mercury concentrations were generally higher in cooked than uncooked red meat. Mercury is resistant to thermal degradation and may be concentrated by cooking methods, such as boiling, because they reduce the moisture content in meat. This is supported by the fact that tissue wet weight mercury concentrations are typically orders of magnitude lower than equivalent dry weight concentrations (Das et al., 2000). Due to insufficient information available on specific cooking/preparation methods of whale meat products in this study, inadequate product labeling/lack of it, and the small sample size, it was not possible to make firm conclusions on the influence of cooking on contaminant levels in these products. Further studies are necessary to investigate the effects of different types of cooking and processing on contaminant concentrations in whale meat.

Estimated Daily Intakes

Some of the samples used in this study were also included in a separate associated study, which aimed to investigate contamination of Japanese whale meat with coplanar PCBs, dioxins, and dibenzofurans (Haraguchi et al., 2000a). Concentrations of coplanar organochlorines were converted to Toxic Equivalency Quotients (TEQs; according to the method of Van den Berg et al., 1998), to obtain EDI levels comparable with established TDI levels for coplanar organochlorines. The TEQs were found to be highest in bacon and blubber products (mean 232 pg-TEQ/g wet weight; range 27.1–691). These TEQ levels are much higher than those reported for a range of meat, fish, and dairy products from the United States in 1995 (range 0.33–0.51 pg-TEQ/g wet weight) by Schecter et al. (2001) and Guo et al. (2001). It was estimated by Haraguchi et al. (2000a) that for the coplanar organochlorines the consumption of one 50-g blubber/bacon meal per month would on average exceed the TDI set by WHO (1998) and JMHW of 200 pg-TEQ/person/d.

Group B FAO/WHO exceedance factors (EFs) show that consumption of whale meat products by whaling communities (Group B) can result in intakes of total mercury, Σ PCB, and dieldrin that are sufficiently high to reduce or even completely remove the safety margin. The EDI of total mercury from the consumption of the striped dolphin cooked liver product, produced such a high EF (174.7; Table 4) that clinical manifestations of

mercury poisoning would be likely to occur in consumers (Endo et al., 2000). In reality the rate of consumption hypothesized for whaling communities (Group B) can easily be exceeded in Japan, thereby elevating EDIs for total mercury, Σ PCBs, and dieldrin even further. For example, prior to the IWC moratorium, Ayukawa villagers used to eat whale meat daily (2–3 times/d), and although consumption has declined (1 meal, 2–3 times a week), villagers have commented that they would eat whale meat every day if they could obtain adequate supplies (Manderson & Akatsu, 1993). There can also be peaks in whale meat consumption on special occasions as part of Japanese tradition, such as New Year's Eve and the spring equinox (Manderson & Akatsu, 1993; Wada et al., 1999), when consumers can be exposed to high levels of contaminants over a short period of time. For example, in Ayukawa, 13 tons of whale meat were purchased to celebrate New Year in 1990, equating to 3.75 kg meat per household (Manderson & Akatsu, 1993).

Assuming a household consists of 4 adults, this equates to 940 g of whale meat consumed per person on New Year's Eve. On this basis (assuming a 50-kg body weight; JMHW) consumption of cooked liver, bacon, and blubber products (according to maximum contaminant concentrations in these products: Table 1), gives EDIs of total mercury (3835, 186.5, and 55.6 $\mu\text{g}/\text{kg}$ body weight/d) and Σ PCB (7.9, 144.8, and 168.1 $\mu\text{g}/\text{kg}$ body weight/d), which exceed TDIs set for these contaminants. Most alarming, the total mercury concentration detected in the cooked liver product, gives an EF for total mercury of 5479 and exceedance factors for Σ PCB (for fresh/frozen blubber products) of 168.1 (FAO/WHO) and 33.6 (JMHW).

CONCLUSION

Consumption of some of the whale meat products investigated in this study at a rate of 30 g/d, can lead to EDIs of mercury, PCBs and dieldrin that exceed respective TDIs for these chemicals, raising questions on their safety for human consumption. Although the use of TDIs as benchmarks is not ideal, they are internationally accepted and offer standardization to the process of assessing potential health effects for consumers. It should be borne in mind that the EDIs calculated in this study do not account for additional sources of organochlorine and mercury exposure such as other foods. In this respect, the use of EDIs and TDIs is not representative of daily exposure to these contaminants. Neither does this approach account for synergistic/additive/antagonistic effects between contaminants present whale meat. However, the principal effect from high level consumption of Japanese whale meat is that the internal dose of mercury, PCB, and dieldrin will increase proportionally with intake.

The exposure estimates from this study indicate a need for risk assessment of potential incidental exposure to organochlorine and mercury, and possible health effects for consumers of Japanese whale meat. This is espe-

cially necessary for “high-risk,” more sensitive consumers and those with high consumption rates (e.g., traditional whaling and fishing communities). A comprehensive study of exposure by direct measurement of contaminant burdens (e.g., blood and adipose levels) in consumers and a surveys of national household whale meat purchasing patterns are necessary components of such as assessment. Consideration should also be given to the possible effects of cooking on contaminant levels in whale meat products. Food health and safety agencies may wish to communicate information on possible risks associated with the consumption of Japanese whale meat and recommend reduced intake and enforce contaminant monitoring and accurate labeling of whale-meat products.

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