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Hazards Associated with the Consumption of Sea Turtle Meat and Eggs: A Review for Health Care Workers and the General Public

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Abstract: Sea turtle products (e.g., meat, adipose tissue, organs, blood, eggs) are common food items for many communities worldwide, despite national regulations in some countries prohibiting such consumption. However, there may be hazards associated with this consumption due to the presence of bacteria, parasites, biotoxins, and environmental contaminants. Reported health effects of consuming sea turtles infected with zoonotic pathogens include diarrhea, vomiting, and extreme dehydration, which occasionally have resulted in hospitalization and death. Levels of heavy metals and organochlorine compounds measured in sea turtle edible tissues exceed international food safety standards and could result in toxic effects including neurotoxicity, kidney disease, liver cancer, and developmental effects in fetuses and children. The health data presented in this review provide information to health care providers and the public concerning the potential hazards associated with sea turtle consumption. Based on past mortality statistics from turtle poisonings, nursing mothers and children should be particularly discouraged from consuming all sea turtle products. We recommend that individuals choose seafood items lower in the food chain that may have a lower contaminant load. Dissemination of this information via a public health campaign may simultaneously improve public health and enhance sea turtle conservation by reducing human consumption of these threatened and endangered species.

Keywords: sea turtle, human health, contaminants, bacteria, parasites

INTRODUCTION

Historically, sea turtles have served as a valuable food source to human populations worldwide, and human capture of sea turtles for this purpose has contributed to the decline of these species globally; all of the world's seven sea turtle species are threatened or in danger of extinction (Hilton-Taylor, 2000). Despite some national regulations restricting the capture of sea turtles, these species remain an important resource for communities worldwide (Mack et al., 1982). Reports of ongoing sea turtle consumption

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(legal and illegal) have emerged from many parts of the world, including Australia (Kowarsky, 1982), the Caribbean (Nietschmann, 1982), the Indian Ocean (Frazier, 1982), Papua New Guinea (Spring, 1982), the Philippines (Carrascal de Celis, 1982), Central and South America (Higginson, 1989; Guada et al., 1991; Campbell, 1998; Marshall, 2001), Mexico (Gardner and Nichols, 2001), Egypt (Nada, 2001), Vietnam (Lam, 2003), and Madagascar (Walker et al., 2004). Coastal communities that consume sea turtles generally utilize the entire animal. While turtle meat is eaten directly, internal organs such as kidney and liver are used for soup (Mack et al., 1982). Oil is extracted from the fat as a cure for respiratory problems, especially in children, and the blood is drunk raw as a remedy for anemia and asthma [Aguirre AA, personal observation] (Caldwell, 1963; Felger and Moser, 1987). Additionally, sea turtle eggs are valued as an aphrodisiac (Spotila, 2004).

In Latin America, sea turtles have historically been considered a delicacy served on special occasions such as weddings, Christmas, Mother's Day, and Easter (Caldwell, 1963; Felger and Moser, 1987; Garcia-Martinez and Nichols, 2000). In Mexico, where Catholicism is the predominant religion, the consumption of sea turtle meat and eggs increases during Lent. Many Mexican Catholics observe religious restrictions against the consumption of red meat, and consume sea turtles due to the belief that these species are fish (Nichols et al., 2003). In addition to being a valuable food source, the use of this resource is highly ingrained as part of various regions' cultural heritages and sea turtle consumption has thus gained traditional importance (Clifton et al., 1982; Figueroa et al., 1992). Recent work in four small communities in Baja California Sur, Mexico, indicates that on average approximately one-fourth of local residents consume sea turtle approximately once monthly. Given the local population of 7280 (INEGI, 2000), sea turtle is consumed approximately 20,000 times annually in just this single coastal area. However, sea turtle consumption in this region is primarily due to taste preferences, rather than traditional uses or economic necessity (Delgado, 2005).

The consumption of sea turtles may have adverse human health effects due to the presence of bacteria, parasites, and contaminants sometimes found in these animals. Potential zoonotic agents such as parasites and enteric bacteria have been detected in sea turtles and these agents can have negative human health effects. Environmental contaminants such as organochlorines and heavy metals may be transferred to humans upon consumption of contaminated seafood. Organochlorines (e.g., dichlorodiphenyltrichloroethane [DDT] and its metabolites, and polychlorinated biphenyls [PCBs]) and heavy metals persist and bioaccumulate in marine ecosystems, and these compounds reach especially high concentrations in long-lived organisms such as sea turtles.

Because the consumption of sea turtles is illegal throughout most of the world, safety controls are not in effect to remove unsafe products from distribution, and cases of illness associated with sea turtle consumption are likely significantly under-reported. The purpose of this review is to alert health care providers and the general public to the hazards associated with the consumption of sea turtles. In addition to providing a public health service, the dissemination of this information may also result in a conservation benefit by reducing fishery mortality as a response to reduced market demand for these species.

Zoonotic Agents in Sea Turtles and Potential Human Health Effects

The human impacts on the world's oceans have devastated populations, species, and ecosystems at a rapid scale (Tabor et al., 2001; Aguirre and Tabor, 2004; Wilcox and Aguirre, 2004). There are several zoonotic agents spilling over from terrestrial reservoirs to marine species with severe consequences to wildlife health and, on the other hand, with potential severe zoonotic spill back to humans and domestic animals (House et al., 2002). Sea otters *(Enhydra lutris)* appear to be susceptible to a number of diseases and parasites that may have an anthropogenic origin, including toxoplasmosis, a zoonotic parasitosis. Molecular evidence has demonstrated that *Toxoplasma gondii* found in sea otters is similar to those found in humans and cats. Brucellosis is an important infectious disease of many terrestrial mammals, including humans. Members of the genus *Brucella* have recently been identified in several species of cetaceans and pinnipeds. A *Brucella* species was isolated from the aborted fetal tissue of bottlenose dolphins along the California coast (House et al., 2002). Spill back has been recently documented as a community-acquired human infection with marine mammal-associated *Brucella* spp. (Sohn et al., 2003). Several diseases have been characterized in sea turtles with zoonotic potential.

Bacterial Infections

A diverse number of Gram negative and Gram positive bacteria have been detected in sea turtles. In juvenile green turtles *(Chelonia mydas)* from Hawaii, 28 Gram negative bacteria, five Gram positive cocci, and diphtheroids were isolated from nasopharyngeal and cloacal swabs. *Aeromonas hydrophila, Vibrio alginolyticus*, *Pseudomonas fluorescens*, *Flavobacterium* spp., and *Bacillus* spp. are common in turtles from both Hawaii and Australia and are associated with ulcerative stomatitis-obstructive rhinitis-pneumonia complex (Glazebrook and Campbell, 1990; Glazebrook et al., 1993; Aguirre et al., 1994b). Many of these bacteria are opportunistic pathogens requiring predisposing factors to induce disease in sea turtles. The occurrence of the same bacteria in both females and their eggs has been observed and correlated with lower hatching success in loggerheads *(Caretta caretta)* (Wyneken et al., 1988).

Several bacterial species isolated from sea turtles, including *Salmonella*, *Mycobacterium*, *Vibrio*, and some *Escherichia coli (E. coli)*, have been identified as potentially pathogenic to humans (Raidal et al., 1998; O'Grady and Krause, 1999). *E. coli* causes diarrhea, acute renal failure, and can be fatal, particularly in children (WHO, 2002); diarrheal diseases are a major cause of mortality in infants and children under 5 years of age (WHO, 1995). In Costa Rica, individuals have been hospitalized after the consumption of raw turtle eggs contaminated with *Vibrio mimicus*; symptoms included diarrhea, vomiting, and severe dehydration (Campos et al., 1996).

Salmonella *spp. Infections*

Salmonellosis is the result of consuming undercooked foods contaminated with *Salmonella* bacteria and may result in headache, nausea, vomiting, abdominal pain, and diarrhea. The presence of these bacteria may result in human infections, particularly due to unsanitary food preparation areas and the consumption of undercooked or raw meat. Salmonellosis is the most recognized zoonotic disease of reptiles. There are over 2300 serotypes within the species *S. enteritidis*, and all should be considered pathogenic to both humans and animals, although there are some species that are specific to selected hosts. Pet turtles have transmitted the disease to infants since the early 1960s with prevalences as high as 22% of the cases diagnosed (Mader, 1996). The rate of infection in turtles is extremely high, but they do not show signs of disease as the animals may be healthy carriers (Mader, 1996). In 1988, a 1-week outbreak of gastroenteritis occurred in a coastal Aboriginal community in Northern Territory, Australia. Thirty-six cases were detected, of which 6 (17%) were hospitalized. *Salmonella chester* was isolated from eight of nine stool samples and from partially cooked turtle meat (O'Grady and Krause, 1999). Over 62% of the people interviewed reported consuming green turtle meat 24 hours prior to the onset of the symptoms.

Mycobacterium *spp. Infections*

Three species of *Mycobacterium*, including *M. marinum*, *M. avium*, and *M. tuberculosis*, have been isolated from reptiles. All three, particularly *M. marinum*, have been implicated as zoonotic agents transmitted from reptiles causing cutaneous nodular disease in humans. Potential routes of infection to humans include direct contact, inhalation, or contact with respiratory and oral mucosa (Mader, 1996). *Mycobacterium* spp. was isolated from a loggerhead turtle that died 2 days after stranding in Italy. Granulomatous lesions were identified in several organs. The zoonotic potential is unknown until the full characterization of the agent is performed (Nardini et al., 2006). Six of 220 hatchlings brought into captivity from the northwestern Hawaiian Islands developed characteristic lesions of tuberculosis. Bacterial isolation identified *M. avium* Serotype 8 (Brock et al., 1976). Given these observations, the potential of acquiring a mycobacterial infection from a sea turtle by direct contact or consumption cannot be discounted.

Chlamydophila *Infections*

The family *Chlamydiaceae* has recently been revised based on phylogenetic analyses and reclassified into two genera (formerly known as *Chlamydia* and now classified as *Chlamydophila*) and nine new species (Everett et al., 1999). *Chlamydophila psittaci* infection, a common zoonosis of mammals and birds, has been reported only once as an epizootic in captive sea turtles. However, chlamydial antigen has been detected in sea turtles from Hawaii and the British West Indies (Aguirre et al., 1994a; Homer et al., 1994).

Leptospira *spp. Infections*

Leptospirosis is the most globally widespread zoonosis and has been classified as a re-emerging infectious disease by the World Health Organization (WHO) (Bharti et al., 2003). Leptospirosis is caused by more than 250 serotypes of spirochetes in the genus *Leptospira*. Mammals are the primary hosts for leptospirosis, which occurs regularly in domestic animals and humans. In regions where the disease is epidemic, incidence is strongly seasonal. No conclusive reports have shown that *Leptospira* are present in reptiles. However, active infection based on serology and field observations suggest that sea turtles may act as reservoirs of some serotypes. For example, high antibody titers against 8 of the 10 serovars of *Leptospira interrogans* were observed in 80.7% of green turtles from Baja California, Mexico [Aguirre AA, unpublished data] (Cordero-Tapia, 2005). Further studies are necessary to elucidate the zoonotic potential of this important disease.

Acute Illness of Unknown Origin

Human fatalities and illness have been hypothesized as resulting from the consumption of sea turtles throughout the Indo-Pacific region including Zanzibar, Madagascar, India, Sri Lanka, Taiwan, Philippines, Indonesia, Papua New Guinea, Australia, Gilbert Islands, Kiribati, and Fiji (Cooper, 1964; Limpus, 1987; Bataua, 1990; Clark and Khatib, 1993; Yasumoto, 1998). In contrast, poisoning from turtle consumption has been extremely rare in the Caribbean and wider Atlantic region (Ingle and Walton Smith, 1949; Limpus, 1987). Most poisoning cases are associated with ingestion of hawksbill *(Eretmochelys imbricata)* or, less frequently, green turtles (Limpus, 1987). The same study indicated that unconfirmed poisonings have also occurred following the ingestion of loggerhead, flatback *(Natator depressus)*, olive ridley *(Lepidochelys olivacea)*, and leatherback *(Dermochelys coriacea)* turtles. Ingestion of poisonous turtle flesh or blood can be lethal for domestic animals including dogs and goats (Silas and Fernando, 1984).

In many cases, common exposure has linked illness and fatalities to the consumption of sea turtle. When food poisoning events occur in a village due to sea turtle consumption, it usually impacts groups of people, including entire families, with alarming effects. For example, in May 1961 in Sakthikulangara, southern India, meat from one hawksbill and two green turtles was shared among 130 village members. Among those that ate the hawksbill turtle meat, there were 18 fatalities and numerous others hospitalized (Silas and Fernando, 1984). The same study reported six separate incidents of village communities eating turtles from which 723 people were poisoned with an 8% fatality rate. Limpus (1987) reviewed 12 incidents with 72 fatalities for which the age structure was available, and found that children under 12 years accounted for 68% of total fatalities. Breast-fed infants who died following their mothers' ingestion of poisonous turtle flesh accounted for 11 of these fatalities, suggesting that children are more at risk from turtle poisoning than adults. In January 2005 in Papua New Guinea, it was hypothesized that five people died as a result of consuming loggerhead turtle soup and internal organs, and an additional four people were hospitalized (World News, 2005). In June 2005, it was hypothesized that 62 individuals were hospitalized as a result of consuming sea turtle meat in Cambodia, and a 38-year-old woman and three children, one of whom was breast-fed from her mother, died (Anonymous, 2005).

How individual turtles become poisonous is not clear. It is generally believed that one or perhaps multiple toxins originate in the invertebrate or algal food species of the turtles. However, the turtle tissues where the toxins accumulate have yet to be identified. Yasumoto (1998) isolated Lyngbyatoxin A from the meat of a green turtle that caused a fatality in Madagascar. This toxin probably originated from a cyanobacterium in the genus *Lyngbya* that was ingested by the grazing turtle. However, fish and turtle kills have repeatedly occurred with armored dinoflagellate *(Pyrodinium babamense)* red tides in Morobe Lagoon, Papua New Guinea and ingestion of these turtles has not been linked to any human turtle poisoning case (MacLean, 1975). Limpus (1987) concluded that the freshness of contaminated turtle meat appears to have no bearing on its toxicity and the toxic component is not removed by washing during preparation or heating during cooking. Toxicological effects initiate on the upper digestive tract during the early stages of poisoning and act on the central nervous system during the life-threatening stages of severe poisoning cases. Death has often been attributed to respiratory failure, with no direct effects on the heart or allergic responses observed to date. Likeman (1975) reported the death of a child that had eaten the "unlaid eggs" of a hawksbill turtle in Papua New Guinea. There have also been reports of a Vietnamese fisher describing many people dying after eating hawksbill turtle eggs [Hamann M, personal communication]. There are no distinctive features that allow for positive recognition of hazards associated with individual turtles. In areas where sea turtle poisonings have occurred, it is strongly recommended that humans refrain from consuming these species. Nursing mothers and children in particular should be discouraged from eating sea turtle flesh.

Parasites

Documented cases of protozoan parasites in sea turtles exist for numerous populations throughout the world. *Entamoeba invadens* is another protozoan that was described as causing mortality in green turtle hatchlings in captivity. It is a ubiquitous parasite affecting reptiles in captive situations. A brief report on a leatherback turtle describes amoebas similar to the zoonotic protozoan *E. histolitica*. We cannot rule out the possibility that this parasite may be transferred to humans (Kinne, 1985).

Cryptosporidium parvum is considered an emerging foodborne pathogen (Schlundt et al., 2004) with symptoms of infection that include diarrhea, nausea, abdominal cramps, vomiting, and fever. *Cryptosporidium* spp. has been observed in fecal and intestinal samples from free-ranging green turtles in the Hawaiian Islands as a potential source of marine waterborne oocysts. Raw sewage disposal into marine waters is a common practice in many coastal areas that has enhanced the risk of pathogen pollution and potential transmission to humans (Graczyk et al., 1997).

Spirorchid trematode infections occur frequently in sea turtles. The presence of eggs and adult trematodes in sea turtle species has been documented in numerous locations, including Panama (Caballero et al., 1950), Mexico (Perez Ponce de León et al., 1996; Cordero-Tapia et al., 2004), England (Dailey et al., 1992), Puerto Rico (Dyer et al., 1991), Australia (Gordon et al., 1998a), the southeastern USA (Keller et al., 2004), and Bermuda (Rand and Wiles, 1985), with reports of up to 85% of examined turtles infected by eggs or adult trematodes (Dailey et al., 1993). In Hawaii, seven species of digenetic trematodes were observed to infect green turtles with fibropapilloma tumors (Dailey et al., 1992). Costa Rican fishermen have reported that sea turtles with fibropapillomas are commonly consumed (Guada et al., 1991). While adult parasites are found primarily in the heart, trematode eggs have been observed invading various organs including brain, heart, liver, lung, spleen, kidney, skin, stomach, intestines, and major vessels (Rand and Wiles, 1985; Aguirre et al., 1998; Cordero-Tapia et al., 2004; Inohuye-Rivera et al., 2004).

After reports of turtle meat consumption in Torres Strait Island, Australia, Aboriginal children were found harboring schistosome-like eggs in their stools, which were later identified as spirorchid trematodes. Although the children were not ill, researchers wanted doctors in rural areas to be aware of the risk of infection. These findings represent a case of spurious parasitism. It is important to understand the life cycle and distribution of sea turtle parasites, as their pathogenic effects are unknown to humans (Blair and Miller, 1992).

Environmental Contaminants in Sea Turtles and Potential Human Health Effects

Metals

In environmental assessments of heavy metals, cadmium and mercury warrant special attention because of their vast global distribution and high potential toxicity and carcinogenicity in humans. Data from numerous studies of these metals in sea turtles have indicated that their concentrations vary greatly by species, region, and tissue type (Table 1; for a review, see: Storelli and Marcotrigiano, 2003). Cadmium, mercury, and lead have been documented in sea turtle eggs and hatchlings in concentrations known to cause toxic effects in other vertebrates (Vazquez et al., 1996; Godley et al., 1999).

Cadmium

In northwestern Mexico, the concentrations of cadmium measured in kidney of green turtles (652 μg/g dry weight [dw]) and olive ridley turtles (274 μg/g dw) were the highest ever reported for these species (Gardner et al., 2006). Elevated cadmium concentrations were also measured in sea turtles from Japan (mean of 39.4 ± 16.2 μg/g wet weight in Sakai et al., 1995) (Sakai et al., 2000; Anan et al., 2001), Europe (up to 243 μg/g dw) (Caurant et al., 1999), and Australia (mean of 28.3 μg/g wet weight) (Gordon et al., 1998b). These concentrations are far above the levels generally reported for other marine vertebrates (Beck et al., 1997; Cardellicchio et al., 2002; Méndez et al., 2002). Bicho et al. (2006) measured heavy metals in green turtle livers and eggs. The concentrations found in their study were higher than levels reported in other sites in the world. For example, 1408 ± 814 ppm wet weight for cadmium and 535 ± 225 ppm wet weight for copper were measured in liver tissue. Gordon et al. (1998b) found that cadmium levels in livers from stranded green turtles in Australia were up to three times higher than the levels reported in commercial seafood products. The tissue cadmium levels found in sea turtles from these regions exceeded established safety standards for seafood products (25 μg/g) (USFDA, 1990) and may warrant concern for

Table 1. Presence of contaminants in sea turtles, including regulatory safe levels, geographic distribution in which these contaminants have been found, and human health effects of the hazards

Contaminant	Range found in sea turtles	Regulatory safe levels	Geographic distribution of studies reporting contaminants in sea turtles	Known human harms associated with contaminant exposure
Cadmium	18.1 µg/g wet weight–652 µg/g dw (Sakai et al., 1995, 2000; Gordon et al., 1998b; Caurant et al., 1999; Anan et al., 2001; Gardner et al., 2006)	25 µg/g (USFDA, 1990)	Australia, Europe, Japan, Mexico	Renal dysfunction, increased risk of osteoporosis, possible link to type-2 diabetes, probably renal and prostate carcinogen (Jarup et al., 1998; Goyer et al., 2004; Kazantzis, 2004)
Chlordane	<0.3–65 ppb (Mckenzie et al., 1999; Gardner et al., 2003)	2 ppb maximum residue limits in food products (FAO/WHO, 2000)	Mediterranean, Mexico	Gastrointestinal effects; immune deficiency; neurological symptoms such as headaches, dizziness, muscle dysfunction, and convulsions with increased exposure; damage to the nervous system and liver (ATSDR, 1994)
DDT	Not detected–1210 ppb (Rybitski et al., 1995; Mckenzie et al., 1999; Gardner et al., 2003)	20–50 ppb in food products (EEC, 1986; FAO/WHO, 2000)	Mediterranean, Mexico, US North Atlantic coast	Neurotoxicity, breast cancer, modulation of immune responses in humans (Garcia, 2003; Cooper et al., 2004; Zumbado et al., 2005)
Mercury	BDL–8.15 µg/g wet weight (Davenport and Wrench, 1990; Sakai et al., 1995; Storelli et al., 1998; Godley et al., 1999)	0.3 µg/g dw (USFDA 1990); the WHO recommends that food with mercury concentrations >0.5 µg/g wet weight should not be sold for human consumption	Europe, Japan, Mediterranean, Mexico	Neurotoxicity, negative effects on the cardiovascular and immune systems, vision impairment, loss of feeling, developmental delays in children, male subfertility (Clarkson, 1993; Grandjean et al., 1995; Dickman and Leung, 1998)
PCBs	<2–1730 ppb (Lake et al., 1994; Rybitski et al., 1995; Corsolini et al., 2000)	200–3000 ppb total PCB limit (ATSDR, 1997)	Mediterranean, US North Atlantic coast	Developmental effects on fetuses, behavioral and neurological effects in children, developmental and toxic effects to the gastrointestinal system, endocrine system, immune system, nervous system, reproductive system, blood, and skin (Feeley, 1995; Weisglas-Kuperus et al., 1995; Grandjean et al., 2003)

people who consume sea turtle tissue with high cadmium concentrations.

The maximum provisional tolerable weekly intake (PTWI) of cadmium recommended by the WHO for a person weighing 60 kg is 0.42 mg/kg (0.42 ppm) (WHO, 2003). The average cadmium concentration in most foods ranges from 0.01 to 0.05 ppm (WHO, 2003); however, the high concentrations of cadmium found in sea turtle tissues (up to 652 ppm) exceed this level by over three orders of magnitude. Individuals with lower body weights, such as children, are more at risk of exceeding the PTWI.

Mercury

Long-range atmospheric transport of mercury can result in contamination of aquatic systems in otherwise pristine areas (Ullrich et al., 2001). Mercury enters aquatic systems largely as inorganic mercury and is microbially transformed to methylmercury, which is a potent neurotoxin with a strong tendency to biomagnify within food chains. The general human population is exposed to mercury predominantly through food consumption, with fish and shellfish as the main dietary sources of methylmercury. Methylmercury is found in highest concentrations in the muscle of marine organisms and cooking increases the mercury content (EPA, 2001). Numerous reports of mercury concentrations in sea turtles from Europe (0.39 ± 0.04 μg/g dw in liver; Davenport and Wrench, 1990), the Mediterranean (Storelli et al., 1998; median levels ranged from below detection level [BDL] to 2.41 μg/g dw in Godley et al., 1999), Mexico [Kampalath R, unpublished data], and Japan (mean of 1.51 ± 2.93 μg/g wet weight in liver; Sakai et al., 1995) were higher than other seafood (e.g., 0.3 μg/g dw in Hawaiian yellowfin tuna) (Kraepiel et al., 2003) and exceed safety limits for human consumption (0.3 μg/g dw) (USFDA, 1990).

Fetuses and infants appear to be at the highest risk for methylmercury toxicity. Methylmercury readily passes through the placenta and breast milk (Clarkson, 1993; Grandjean et al., 1995). Evaluations of human health risks from methylmercury in fish using epidemiological studies indicate that even relatively low exposures may be harmful to fetuses (Clarkson, 1990). Adverse effects to the fetus, such as psychomotor retardation, would be predicted at daily intakes above 36 μg Hg/day for a 60 kg pregnant female (Clarkson, 1990)—consumption of only 4 g of sea turtle tissue could exceed this level. The WHO has adopted the US Environmental Protection Agency (EPA) guideline levels for mercury and recommends that food with mercury concentrations of 0.5 ppm or more should not be sold for human consumption, suggesting that the levels found in sea turtles (up to 8.15 ppm) could be hazardous to human health.

Organochlorine Compounds

Despite restrictions on the production and use of organochlorine compounds (such as PCBs and certain classes of pesticides), these lipophilic chemicals continue to persist in marine environments (Forget, 1991; Páez-Osuna et al., 2002). The accumulation of organochlorine insecticides in coastal environments continues to be a concern in many tropical countries where the DDT/DDE ratios have increased (Borrell and Aguilar, 1999; Tavares et al., 1999).

Organochlorines are known to accumulate in animal tissues, particularly those with high lipid content (Fox, 2001). In sea turtles, as in other vertebrates, adipose tissue tends to accumulate the highest organochlorine concentrations followed by liver, kidney, and pectoral muscle, corresponding to the triglyceride content of the tissue (Rybitski et al., 1995; Mckenzie et al., 1999). Species differences in organochlorine levels appear to be related to diet, with more carnivorous sea turtles accumulating higher concentrations (Aguirre et al., 1994a; Mckenzie et al., 1999).

Organochlorine levels in sea turtles are generally similar to those found in other seafood products, and most often, are probably below levels likely to adversely affect human health. However, some segments of the population are at higher risk, particularly those subsisting largely on a seafood diet (Smith and Gangolli, 2002). In particular, sea turtle oils, if consumed in substantial quantities by infants and young children, might present potential health problems.

A current major human health concern is the potential ability of many of these chemicals to act as endocrine disruptors at low doses. There is increasing evidence that some organochlorines (e.g., metabolites of DDT and some PCB congeners) have estrogenic activity in animals and are capable of disrupting reproductive and endocrine function in fish, birds, reptiles, and mammals, including humans. Exposure to such endocrine-disrupting compounds during embryonic development, even at very low concentrations, can affect sexual differentiation and cause other reproductive disruptions including reductions in fertility, viability of offspring, alterations in hormone levels, and adult sexual behaviors (Portelli et al., 1999). Because endocrine disruption can occur at very low exposure concentrations, no safe level has been established for these compounds. Therefore, their presence, even at the low concentrations observed in sea turtles, may warrant concern for the health of these species and the humans that consume them.

Polychlorinated Biphenyls

The distribution of individual PCB congeners within sea turtles is related to their lipophilicity. The higher-chlorinated, more lipophilic congeners have been detected in adipose tissue, while lower-chlorinated congeners (such as congeners 8 and 18) have only been detected at higher concentrations in the leaner tissues such as kidney and muscle (Corsolini et al., 2000; Gardner et al., 2003). Total PCB levels in adipose tissue of loggerhead and Kemp's ridley *(Lepidochelys kempii)* turtles from the North Atlantic coast of the US reached 1730 ppb and averaged 1250 ± 985 ppb, respectively (Lake et al., 1994; Rybitski et al., 1995). Corsolini et al. (2000) measured mean ΣPCBs in loggerhead turtles from the Mediterranean at 119 ± 60 ppb in liver and 334 ± 179 ppb in adipose and suggested that these levels warrant concern for local communities that consume this species.

Although the human health effects of consuming food contaminated with PCBs are not well understood, the EPA has classified PCBs as probable human carcinogens. In humans, PCBs can mobilize during pregnancy and lactation and can be transferred to the offspring through the placenta and breast milk. PCBs have been shown to have negative human health effects such as lower IQ scores, low birth weight, and reduced postnatal growth on children and developing fetuses (Weisglas-Kuperus et al., 1995; Grandjean et al., 2003). Behavioral and neurological effects have been reported in children and ascribed to the consumption of PCB-contaminated foods, including fish (Smith and Gangolli, 2002). The US Food and Drug Administration (FDA) established a limit of 200–3000 ppb total PCBs in food to protect from non-cancer harmful health effects (ATSDR, 1997). Total PCB levels reported in adipose tissue of sea turtles are within that range. Similar mean concentrations of ΣPCBs in Japanese whale meat (1140 ppb) generated warnings that its consumption could lead to chronic health effects (Simmonds et al., 2002).

Pesticides

Dichlorodiphenyltrichloroethane, DDT. Concentrations of a DDT derivative, 4,4′ DDE, were detected as high as 1210 ppb in sea turtles from the US Atlantic coast (Rybitski et al., 1995) and total DDT concentrations of 739 ppb have been reported in the Mediterranean (Mckenzie et al., 1999). These levels greatly exceed the FAO/WHO and the European Economic Community guidelines for maximum residue limits of total DDT (20–50 ppb in food products) (EEC, 1986; FAO/WHO, 2000).

Chlordane. Heptachlor epoxide, a toxic metabolite of chlordane, was the most prevalent organochlorine compound found in turtles from the Pacific coast of Mexico; chlordane concentrations reached 65 ppb in these sea turtles (Gardner et al., 2003) and 33 ppb in sea turtles from the Mediterranean (Mckenzie et al., 1999). Because of the high toxicity of chlordane, FAO/WHO set maximum residue limits in food products as low as 2 ppb and a provisional tolerable daily intake of less than 0.0005 mg/kg body weight (FAO/WHO, 2000). Chlordane concentrations measured in sea turtles far exceed these safety limits.

Other organochlorine pesticides. Mckenzie et al. (1999) found that dieldrin was second only to 4,4′ DDE among the organochlorines they analyzed from sea turtles in the Mediterranean and Atlantic. Hexachlorobenzene is known as the most toxic and persistent of the chlorobenzene compounds and was detected in liver and muscle of green and olive ridley turtles (Gardner et al., 2003). Lindane (the gamma isomer hexachlorocyclohexane) is neurotoxic and has been found in sea turtles from the Pacific coast of Mexico and the Mediterranean (Gardner et al., 2003; Mckenzie et al., 1999). Various organochlorine pesticides have also been measured in sea turtle eggs from the Great Barrier Reef, Australia (Podreka et al., 1998).

The presence of contaminants in marine organisms has been documented worldwide, and the contaminant levels found in other seafoods are often below those found in sea turtles. In Kenya, the maximum mean cadmium level observed in fish muscle was 3.4 ± 0.71 ppm wet weight (Mwashote, 2003). Trace metal and chlorinated hydrocarbon levels in fish landed at Irish ports were also low, with a mean mercury concentration of 0.09 ppm wet weight and a maximum level of 0.42 ppm wet weight (Tyrell et al., 2003). The mean cadmium levels in fish species consumed in

Finland were 5.8 ppb wet weight (Tahvonen and Kumpulainen 1996). In Egypt, cadmium and lead levels were found to be within safety consumption limits (Rashed, 2001). Compared to sea turtles, which can have cadmium levels up to 652 ppm (Gardner et al., 2003), these levels are much lower and should be considered as an alternative seafood item. However, large predatory fish such as marlin and swordfish have been found to have mercury levels that exceed the FAO guideline level of 1 mg/kg (1 ppm) (Kumar et al., undated). Other species such as invertebrates accumulate large amounts of cadmium.

Conclusions and Recommendations

Scientific studies from around the globe indicate that sea turtles harbor various contaminants, parasites, bacteria, and biotoxins. These hazards have been shown to have deleterious human health effects and, in some instances, cases of illness and death from sea turtle consumption have been documented. The documented cases of human health problems associated with the consumption of sea turtle products may be cause for concern given the worldwide prevalence of this practice. Much of the knowledge of documented health effects as a result of sea turtle consumption is scattered and has been the domain of the scientific community, and not the general public or even public health community. Accordingly, it is important to effectively communicate pertinent information regarding the potential human health hazards associated with sea turtle consumption in areas where this practice is common. Some heavy metals, organochlorines, parasites, and bacteria are most likely to affect nursing women and children who consume contaminated sea turtle products. The impact of sea turtle consumption on human health is an emerging area of inquiry for which further investigation and monitoring is recommended.

Individuals should not shift their consumption of sea turtle to other marine organisms with high contaminant levels, such as large predatory fish. Rather, individuals should consume seafood items that are shorter-lived, and thus likely to have lower contaminant loads. Swordfish, marlin, fresh/frozen tuna, and sharks in particular are recognized as having high mercury levels (Lyle, 1986; Penedo de Pinho et al., 2002; Forsyth et al., 2004). Studies evaluating the benefits and risks of consuming sea turtle have not been conducted, and this may be an avenue for future research. While it is unknown whether awareness of these potential human health hazards will decrease sea turtle consumption, the link between environmental concerns and social practices may serve as a means to concomitantly promote environmental conservation and personal well-being.

It is unknown if consumption advisories for finfish with the same set of hazards found in sea turtles has influenced the long-term consumption of these finfish. Following the publication of an article concluding that contaminants in farmed salmon are higher than in wild salmon (Hites et al., 2004), fresh farmed salmon imports decreased in value by US $20 million for a 3-month period compared to the previous year (Johnson, 2004). The US mercury advisory issued by the FDA in 2001 resulted in decreased fish consumption for certain groups of individuals over the short-term (Shimshack et al., 2005). In another study, pregnant women decreased their fish consumption in at least the 2 years following the 2001 mercury advisory (Oken et al., 2003). Shimshack et al. (2005) found that access to information was an important response factor to the advisory. Thus, a public health campaign in the countries where sea turtle is consumed should provide information in a form that is easily accessible by the general public. A public health campaign in a country such as Mexico should utilize common communication tools like comics. Press releases may not be effective for all audiences; finfish consumption advisories for immigrants in the US include translations, signs, educational videos, and workshops (Shubat et al., 1996).

Recommendations for future research include a greater synthesis of similar data for other sentinel species, especially those that are also human food sources. Effective communication of this information to the general public and public health community should be used to build greater awareness of human-wildlife-ecosystem relationships, as well as a potential tool for improved conservation of threatened and endangered species by mitigating consumption of these animals.

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