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# Estimation of Target Hazard Quotients and Potential Health Risks for Metals by Consumption of Seafood in Taiwan

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**Abstract.** The purpose of this paper is to describe the impact of metal pollution on the main seafood and assess the potential health risk from consuming the contaminated seafood in Taiwan. The results of geometric mean (GM) metal concentrations in various seafood showed that the copper, zinc, and arsenic concentrations in oysters were significantly ($p < 0.001$) higher than those in the other seafood by about 1,057, 74.3, and 56.2 times, respectively. The green color found in the oysters was due to high GM copper and zinc concentrations of 909 (ranging from 113–2,805) and 1,293 (ranging from 303–3,593) μg/g dry wt, respectively. In addition, using a maximum consumption rate of 139 g/day of oysters for individuals, calculations yield target hazard quotients (daily intake/reference dose) of below 1 for cadmium and mercury and high values of 1.61, 9.33, and 1.77 for inorganic arsenic, copper, and zinc in adults, respectively. The various lifetime cancer risks for inorganic arsenic (maximum exposed individuals risk ranging from $9.93 \times 10^{-6}$ to $3.11 \times 10^{-4}$) might be caused by consuming different seafood in Taiwan. The highest risk estimate for inorganic arsenic was $5.10 \times 10^{-4}$ for consumption of oysters by Machu Islands residents. The long-term exposure of metals through consumption of oysters, especially for some high-risk groups, could be dangerous. Taking inorganic arsenic for example, a $10^{-6}$ upper limit on lifetime risk as the health protection standard would require maximum oyster residue levels of approximately 0.0076–0.056 μg/g wet wt, for consumption rates of 139–18.6 g/d. In the light of known risks to public health, the government should issue an immediate warning to the public to refrain from eating all seafood harvested from the Taiwan coastal areas, especially the Hsiangshan area and the Machu Islands.

In recent years, the pollution of various river and coastal areas by trace metals (copper, zinc, lead, cadmium, arsenic, and mercury) and organohalogen compounds (polychlorinated biphenyls [PCBs] and polychlorinated dibenzo-p-dioxins [PCDD]) have been the subject of intense public concern in Taiwan (Ling *et al.* 1995; Han *et al.* 1996). People can be exposed to toxic chemicals that accumulate in fish and shellfish taken from contaminated waters that are consumed (Svensson *et al.* 1995). Fish and shellfish are important food for supplying essential trace elements and certain vitamins; moreover, the polyunsaturated n-3 fatty acids in fattyfish species are biologically important and have been associated with a decreased risk for cardiovascular disease (Kromhout *et al.* 1985; Svensson *et al.* 1995). However, most current health risks associated with seafood safety originate in the environment. For example, Han *et al.* (1994) reported the copper intake and health threat by consuming seafood from copper-contaminated coastal environments (Erhjin Chi estuary) in Taiwan. Because of the incident of "green oysters" in the Charting coastal area, the green oysters collected from the Erhjin Chi estuary on 26 January 1989 gave the highest copper concentration of 4,401 ± 79 μg/g dry wt (Han and Hung 1990; Han *et al.* 1994). The area around the Erhjin Chi estuary was especially affected by large discharges of heavy metals from acid cleaning of metal scrap on the riverbanks. All seafood industry suffered from the green oyster incident because consumers were so afraid of its products. The estimate by Han *et al.* (1994) indicates that the average copper intake from contaminated green oysters for female individuals is 14 times more than that of international limits. Ling *et al.* (1995) reported that based on an average daily fish consumption of 15 g for an adult with 70 kg body weight, a daily intake of PCDD/PCDFs of 8 to 447 pg/kg is estimated when consuming fish caught from the Erhjin Chi river of Taiwan. The consumption of these contaminated fish will exceed the risk-based concentration of "zero" recommended by the US EPA (1996). People consuming large amounts of contaminated seafood may have elevated concentration of heavy metals in their tissues compared to the general population (Asplund *et al.* 1994; Dewailly *et al.* 1994). A correlation between blood mercury levels and methylmercury exposure via fish consumption has been shown in several different studies (Grandjean *et al.* 1992; Svensson *et al.* 1992; Oskarsson *et al.* 1996). For example, in the Faroe Islands, the community consumes much seafood, and

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the hair mercury concentration in infants increases with the duration of the nursing period (Grandjean *et al.* 1994).

Humans are exposed to inorganic and organic arsenic through environmental, medicinal, and occupational exposures. Both inorganic and organic arsenic are present in food in different amounts. Examining the food category in more detail shows that fish and other seafood account for 90% of the total food arsenic exposure with all other foods accounting for the remaining 10% (US FDA 1993). Although seafood contains a high concentration of organic arsenic, it is much less toxic than inorganic arsenic (Chiou *et al.* 1995). In a series of studies in Taiwan, an increasing mortality from cancers of the lung, liver, and bladder has been documented among residents in the endemic area of black-foot disease (BFD) (Chen *et al.* 1985, 1986, 1988, 1992). A significant dose-response relationship between the inorganic arsenic concentration in well water and the mortality from various cancers has also been reported in Taiwan (Chiou *et al.* 1995).

Chen *et al.* (1994) reported that the total dissolved arsenic concentration is $671 \pm 149$ μg/L with a range of 470–897 μg/L for all the well waters (a total of 54 samples) collected from the Putai area. The results are about 13 times greater than the maximum contaminant level (MCL) for arsenic in drinking water. The high mobility and bioavailability of dissolved arsenic may be easily taken up by humans. However, there is little information on the concentrations of arsenic in different seafood from coastal water of the BFD (Putai) area in Taiwan (Han *et al.* 1997).

The consumption of contaminated seafood has been reported as an important route of human exposure to heavy metals in Taiwan (Han *et al.* 1994, 1996). Oysters (*Crassostrea gigas*) and other seafood (*e.g.,* tilapia, tuna, and shrimps) are the most popular seafood in Taiwan. However, the possible association between seafood consumption and human exposure to many of these contaminants has not been extensively investigated. In other words, contamination of marine organisms with toxic chemicals presents the possibility that subsequent consumption of these organisms by humans may pose significant health risks. This is a well-recognized (Lipton and Gillett 1991) but poorly characterized environmental problem in Taiwan.

The study includes an evaluation of the public health risks associated with various fish and shellfish, especially for locally cultured oysters. In other words, the purpose of this study is to investigate, analyze, and evaluate metal contamination in seafood in Taiwan. The Hsianghsan area and Machu Islands were of considerable interest for a case study of oyster contamination by various metals. Furthermore, this study also estimates target hazard quotients for metals and lifetime cancer risks for inorganic arsenic from consuming seafood.

## Materials and Methods

Samples of various fish and crustaceans such as blue marlin, tuna, Pacific saury, ribbon fish, sea perch, milk fish, tilapia, carp, grass shrimps, and sand shrimps were bought from supermarkets or grocery stores of Taipei City during the period 1995–1996. The samples were bought at random at different times of the year, and were not a *priori* suspected of any contamination, nor were they regarded as being representative of each species population with respect to contaminant levels. However, they represented a normal consumer's choice. Oysters and clams were collected from different culture ponds and coastal areas during the period 1991–1996 as shown in Figure 1.

The samples were returned to the laboratory, individually scrubbed, and shucked, and the flesh was placed in weighed acid-washed Teflon beakers for reweighing to obtain individual wet-weight values. All samples were digested using a microwave digester (Model MDS-2000) with a mixture of nitric and sulfuric acids (1/1, v/v) solution, and the supernatant analyzed for copper and zinc by flame atomic absorption spectrophotometry (Han and Hung 1990). Lead, cadmium, arsenic, and mercury were measured by graphite atomic absorption spectrometry (GAAS) using nickel (for arsenic) and $TeO_2$ (for mercury) as matrix modifiers, and standard addition procedures were used for the calculation of the analyte concentrations (Han *et al.* 1997).

Determination of metals was performed with a Hitachi Zeeman AAS (model Z-8000 with an autosampler). The results generated were, in most cases, in good agreement with certified values. Standard reference materials (SRM 1566a Oyster Tissue and IAEA 350 Tuna Fish Tissue) were analyzed at regular intervals (Han *et al.* 1996, 1997).

Eight hundred and fifty residents from Taipei City were interviewed. A brief questionnaire was filled in with demographic information and data on nutritional habits. The interview questionnaire included detailed questions about various seafood consumption pertaining to amount and frequency of consumption as well as seafood preparation methods and weeks of consumption. The personal, dietary, and residential information included in this study were obtained.

The methodology for estimation of target hazard quotients (THQ) and target cancer risk (TR) used was provided in *USEPA Region III Risk-Based Concentration Table, January–June 1996* (US EPA 1996). For carcinogenic effects (inorganic As), risk is expressed as excess probability of contracting cancer over a lifetime (70 years). For noncarcinogenic effects, risk is expressed as a target hazard quotient, the ratio between the exposure and the reference dose. The models for estimating target hazard quotients and target cancer risks (lifetime cancer risks) are:

$$\mathrm{THQ} = \frac{\mathrm{EFr} \times \mathrm{EDtot} \times \mathrm{SFI} \times \mathrm{MCS}}{\mathrm{RfDo} \times \mathrm{BWa} \times \mathrm{ATn}} \times 10^{-3}$$

$$\mathrm{TR} = \frac{\mathrm{EFr} \times \mathrm{EDtot} \times \mathrm{SFI} \times \mathrm{MCS} \times \mathrm{CPSo}}{\mathrm{BWa} \times \mathrm{ATc}} \times 10^{-3}$$

where THQ: target hazard quotient; EFr: exposure frequency (350 days/year); EDtot: exposure duration, total (30 years); SFI: seafood ingestion (g/day); MCS: metal concentration in edible portion of seafood (μg/g); RfDo: reference dose, oral (mg/kg/day); BWa: body weight, adult (65 kg); ATn: averaging time, noncarcinogens (EDtot × 365 days/year); TR: target cancer risk; CPSo: carcinogenic potency slope, oral (risk per mg/kg/day); ATc: averaging time, carcinogens (25,550 days)

For statistical analyses, left-skewed data were normalized by logarithmic transformation. Accordingly, geometric mean (GM) values were reported. Student's *t* test was used to study differences of various metal concentrations between different organisms (Han *et al.* 1997).

## Results and Discussion

### *Various Metal Concentrations in Different Seafood*

In Taiwan, people's demand for protein increases when their standard of living rises. Figure 2 shows the total values and

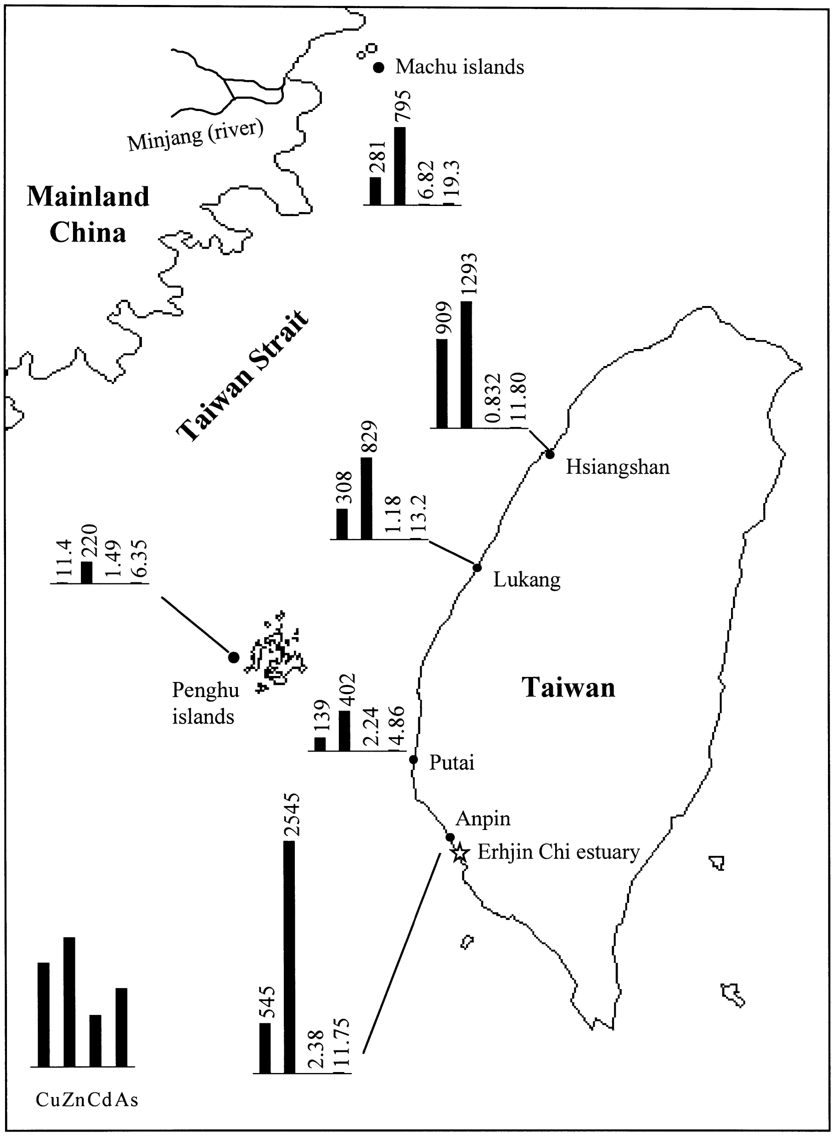


**Fig. 1.** Sampling locations and distribution of GM metal concentrations (μg/g dry wt) in oysters (*Crassostrea gigas*) collected from different coastal areas of Taiwan

amounts of production of 11 major kinds of seafood in Taiwan, as reported by the Council of Agriculture, ROC. The oyster was not only in the top 10, but also the only shellfish in the top 11 (Han *et al.* 1994). Because oysters are one of the most popular seafoods in Taiwan and the Hsianghsan coastal area is one of the major oyster-producing areas, we assume that all of the oysters consumed by some high-risk group were cultured along the Hsianghsan coastal area.

Table 1 shows the geometric mean (GM) metal concentration (μg/g dry wt) in various seafood with the following ranges: copper 0.860–909, zinc 17.4–1,293, lead 0.025–1.43, cadmium 0.010–0.830, arsenic 0.210–11.8, and mercury 0.180–10.3 μg/g dry wt. Maximum copper and zinc concentrations (GM = 909 and 1,293 μg/g dry wt, respectively) in oysters are much higher than those of the other seafood by about 48.6–1,057 and 10.7–74.3 times, respectively. It can be seen that the ranges of copper and zinc concentrations in the oysters differ significantly ($p < 0.001$) from the other seafood. The result indicates that the ability of oysters to concentrate copper and zinc is much stronger than that of other seafood. In addition, the results reveal that relatively high arsenic concentrations (GM = 11.8 μg/g dry wt) in oysters are found as compared with those in other seafood (range from GM = 0.210 to 4.46 μg/g dry wt). Therefore, the potential risk of consuming oysters is relatively higher than that of other seafood due to the high bioaccumulation of oysters. These high concentrations of copper and zinc may not affect oysters directly (Han and Hung 1990), but high concentrations of copper, zinc, and arsenic may transfer toxicity to humans through the food chain and may render people consuming the shellfish more susceptible to bacterial and viral infection (Okazaki and Panietz 1981). This is because in most cases those oysters live in an environment with heavy metal and domestic waste water (high in *E. coli*) pollution.

Fish have been identified as a significant source of human exposure to various compounds although Kimbrough (1991) cautions against assuming that this is a serious hazard. We also discuss this in the context of overall health risk assessment. From Table 1 we also found that mean mercury concentrations ranged from 0.180 to 10.3 μg/g dry wt in the different seafood. The highest concentrations of mercury were observed in blue marlin (GM = 10.3 μg/g dry wt) and tuna (GM = 9.75 μg/g dry wt). These values are higher than those in other seafood

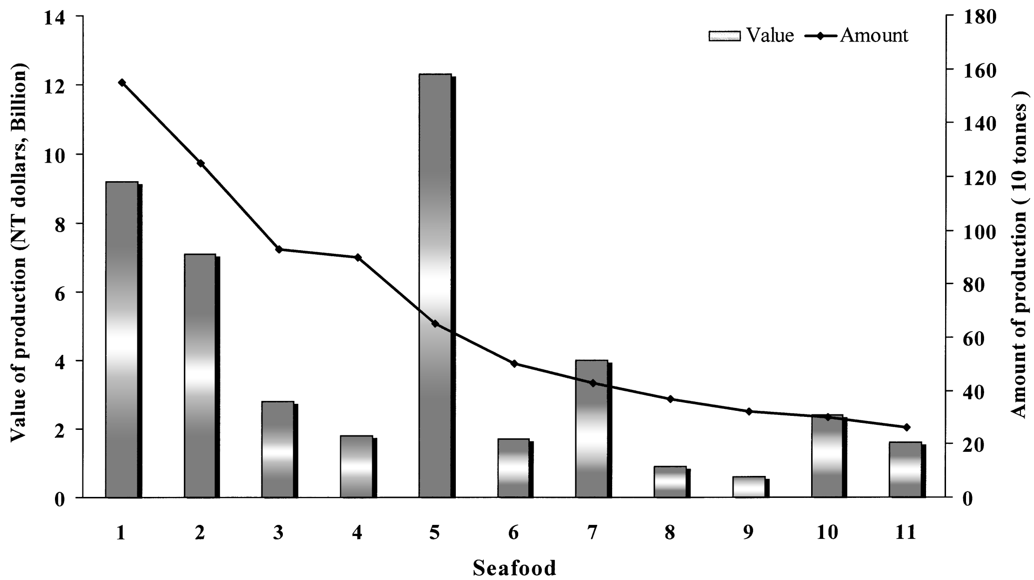


**Fig. 2.** Production (in value and amount) of major seafood in Taiwan. 1: Squid, 2: *Thunnus alalunga,* 3: Milkfish, 4: Skipjack bonito, 5: Japanese eel, 6: Tilapia, 7: Yellowfin tuna, 8: Scomber somber, 9: Pacific saury, 10: Oyster, 11: Loligo

**Table 1.** Geometric mean metal concentration (µg/g dry wt) in fish, crustaceans, and shellfish collected from supermarkets and the Hsiangshan culture area

| Species | Cu | Zn | Pb | Cd | As | Hg |
|---|---|---|---|---|---|---|
| Blue marlin (*Makaira mazara*) | 1.08 (0.860–1.72) | 34.8 (33.5–34.8) | 1.43 (0.111–0.685) | 0.120 (0.015–0.031) | 0.630 (0.068–0.273) | 10.3 (1.71–22.9) |
| Tuna (*Thunnus albacores*) | 0.860 (0.005–0.860) | 17.4 (17.4–17.4)[a] | 0.210 (0.170–0.315) | 0.070 (0.035–0.135) | 0.210 (0.010–1.48) | 9.75 (8.80–10.4) |
| Pacific saury (*Cololabis saira*) | 4.66 (3.43–6.85) | 63.0 (52.0–78.5) | 0.055 (0.015–0.260) | 0.030 (0.020–0.035) | 4.39 (3.67–5.35) | 1.58 (0.300–4.62) |
| Ribbon fish (*Trichiurus lepturus*) | 0.985 (0.005–1.72) | 20.6 (17.4–33.5) | 0.130 (0.005–0.425) | 0.130 (0.030–0.325) | 0.935 (0.210–1.74) | 1.28 (0.140–6.85) |
| Sea perch (*Lateolabrax japonicus*) | 1.30 (0.005–2.58) | 38.0 (17.4–52.0) | 0.145 (0.045–0.875) | 0.035 (0.005–0.180) | 0.560 (0.045–1.48) | 1.045 (0.145–4.96) |
| Milkfish (*Chanos chanos*) | 3.06 (1.72–4.29) | 60.5 (43.5–78.5) | 0.300 (0.005–1.91) | 0.035 (0.005–0.270) | 0.375 (0.010–1.43) | 1.96 (0.245–4.62) |
| Tilapia (*Tilapia mossambica*) | 1.56 (0.860–3.43) | 64.0 (43.5–87.0) | 0.125 (0.005–2.50) | 0.105 (0.020–0.460) | 0.355 (0.130–1.45) | 2.54 (1.36–3.95) |
| Carp (*Cyprinus carpio*) | 4.85 (3.43–6.86) | 121 (105–139) | 0.045 (0.040–0.050) | 0.010 (ND–0.010) | 4.64 (4.05–5.30) | 2.41 (2.19–2.66) |
| Grass shrimp (*Penaeus mondon*) | 15.5 (9.45–25.8) | 69.0 (61.0–87.0) | 0.095 (0.010–0.255) | 0.145 (0.090–0.220) | 0.760 (0.100–5.15) | 2.19 (0.690–5.40) |
| Sand shrimp (*Metapenaeus monoceros*) | 18.7 (14.6–27.5) | 60.5 (52.0–69.5) | 0.025 (ND–0.025) | 0.050 (0.045–0.065) | 0.345 (0.230–0.650) | 2.21 (1.89–2.60) |
| Clam (*Meretrix lusoria*) | 12.3 (8.41–16.9) | 54.5 (48.1–69.4) | 11.0 (8.22–14.7) | 0.232 (0.181–0.344) | 13.7 (9.48–20.1) | 0.180 (0.112–0.287) |
| Oyster (*Crassostrea gigas*) | 909 (113–2,805) | 1,293 (303–3,595) | 0.810 (0.050–3.33) | 0.830 (0.165–2.93) | 11.8 (7.15–16.3) | 0.180 (0.030–1.33) |

ND: Pb and Cd $<$ 0.005 µg/g
All data are 6–56 determinations for various seafoods
[a] Only three determinations, data were rounded to three significant figures

($p < 0.05$, which is significant) because both blue marlin and tuna are predators on small fish and occupy a higher trophic level than other seafood (Burger *et al.* 1992). In general, consumption of fish is an important source of exposure to methylmercury for humans (Svensson *et al.* 1995). Lipton and Gillett (1991) reported that tuna were sufficiently high in mercury to warrant health concern for high-risk groups with very high consumption rates.

The results of various metals found in oysters collected along the western coast of Taiwan from 1991 to 1996 are shown in Table 2 and Figure 1. The highest GM copper and zinc concentrations of 909 and 1,293 µg/g dry wt, respectively, were

**Table 2.** Geometric mean metal concentrations (μg/g dry wt) in oysters (*Crassostrea gigas*) collected from different coastal areas of Taiwan

| Location | Cu | Zn | Pb | Cd | As | Hg |
|---|---|---|---|---|---|---|
| Hsiangshan | 909<br>(113–2,805) | 1,293<br>(303–3,593) | 0.810<br>(0.050–3.33) | 0.832<br>(0.167–2.93) | 11.8<br>(7.15–17.6) | 0.178<br>(0.030–1.28) |
| Lukang | 308<br>(60.3–948) | 829<br>(263–1,772) | 0.220<br>(0.050–2.88) | 1.18<br>(0.165–3.75) | 13.2<br>(0.025–29.3) | 0.147<br>(0.049–0.454) |
| Putai | 139<br>(124–158) | 402<br>(280–525) | ND | 2.24<br>(1.21–4.15) | 4.86<br>(3.15–7.00) | 0.100<br>(0.070–0.090) |
| Anpin | 545<br>(378–1,867) | 2,545<br>(574–3,662) | ND | 2.38<br>(1.47–4.48) | 11.8<br>(8.41–18.5) | 0.150<br>(0.120–0.185) |
| Penghu Islands | 11.4<br>(8.20–15.7) | 220<br>(187–259) | ND | 1.49<br>(1.45–1.52) | 6.35<br>(6.25–6.45) | 0.175<br>(0.130–0.235) |
| Machu Islands | 281<br>(131–477) | 795<br>(514–835) | ND | 6.82<br>(3.12–6.00) | 19.3<br>(6.45–25.8) | 0.175<br>(0.070–1.73) |

ND: Pb $<$ 0.005 μg/g
Wet weight = dry weight $\times$ 5
All data are 6–56 determinations

obtained from the Hsiangshan culture area. In general, when the copper concentration in oysters was over 500 μg/g dry wt, the color of the oysters became green (Han and Hung 1990). The results indicate that local and regional inputs of copper and zinc are the major cause of green oysters in this area. There were low copper and zinc concentrations in the oysters collected from the Penghu Islands (Table 2 and Figure 1), probably because their location is far from pollution sources. It is interesting that abnormally high cadmium and arsenic concentrations (GM = 6.82 and 19.3 μg/g dry wt, respectively) in the oysters were found in the Machu Islands, which are very close to the Minjang estuary in the Fu-Chien province of southeastern China. Hung *et al.* (1998) reported that the average heavy metal concentrations in mud ($<$63 μm), sand, and seawater collected from the Minjang estuary were high compared with those concentrations observed in other areas of Taiwan. This may be due to the fact that the heavy metal pollutant discharges from the Minjang River, which was near the urban areas of Fu-Chou City, PRC. In general, bivalve molluscs are a hazard to health because they accumulate and concentrate toxins by continuously filter-feeding minute particles from water. In other words, the high metal concentrations in seawater, sediments, and oysters apparently reflect a local anthropogenic input of pollutants, especially cadmium and arsenic. Similarly, intake of high cadmium and arsenic concentrations through consumption of oysters collected from the Machu Islands could be dangerous, especially for some high-risk Machu residents. Mercury and lead concentrations in oysters from different areas are generally low (range ND–0.810 and 0.100–0.178 μg/g dry wt, respectively).

## *Estimation of Potential Health Risks*

Compared with other foods, oysters have the highest concentrations of Cu, Zn, and As in Taiwan. We think these calculated data of copper, zinc, and arsenic concentrations of Taiwanese diets to be the first information related to health risk for the inhabitants of Taiwan. Metal concentrations detected in seafood from Taiwan (especially for the Hsiangshan area and the Machu Islands) were evaluated to investigate potential carcinogenic (inorganic arsenic) and noncarcinogenic (copper, zinc, cadmium, and organic mercury) risk to the public from ingestion of the seafood. Table 3 shows data for the main categories of seafood (fish, molluscs, and crustaceans) that contribute to the human diet. In the questionnaire, seafood consumption was registered in three categories such as fish, oysters, and shrimps. Frequency of consumption was categorized into four groups, from less than two to more than 15 different seafood meals during 1 week. In other words, the seafood consumers were divided into four groups: a slight intake group ($<$2 meals/week), a moderate intake group (2–6 meals/week), a high intake group (7–14 meals/week) and the highest intake group ($>$15 meals/week) (Table 3). Typical seafood consumption values vary from $<$8.6 to 30 g/d, whereas ‘‘extreme’’ values (for high consumers such as subsistence fishermen group) range to 139 g/d.

In general, three sources of uncertainty have been incorporated into health risk assessment: (1) contaminant uptake by commercially harvested seafood; (2) annual variability in the landing of commercial fisheries; and (3) seafood consumption rate (Lipton and Gillett 1991). Two types of hypothetical seafood consumption scenarios were identified and evaluated in this assessment (Cooper *et al.* 1991). The first was to represent the maximum exposed individual (MEI), assumed to consume 75, 139, and 64 g/day of fish, oysters, and shrimps, respectively. The second type of consumption scenarios was for typically general consumers (TGC), whom we assumed to consume 8.6–30 g/day of seafood.

According to the report of US EPA (1996), the dose calculations were made using the standard assumption for an integrated US EPA risk analysis, including exposure over an entire 70-year lifetime and to a 65-kg body weight for an average Taiwanese adult. In addition, it was assumed in accordance with the US EPA (1989) guideline that the ingested dose is equal to the absorbed contaminant dose and that cooking has no effect on the contaminants (Cooper *et al.* 1991).

Table 4 shows the results of estimated average metal intake doses (μg/kg/day) and target hazard quotients (THQs) caused by consuming different seafood. Because oysters are one of the popular seafoods in Taiwan and the Hsiangshan area is one of the major oyster-producing areas, we assume that all of the oysters consumed by some high-risk groups were cultured in the Hsiangshan area. The oysters have had an average GM of

**Table 3.** Estimated seafood consumption among respondents from Taipei City of Taiwan. Assumes 35, 65, and 30 g serving per meal of fish, oysters, and shrimps, respectively

| | Fish | | | Oyster | | | Shrimp | | |
|---|---|---|---|---|---|---|---|---|---|
| Meals/Week | No. of Respondents | Percent of Respondents (%) | Consumption Rates (g/day) | No. of Respondents | Percent of Respondents (%) | Consumption Rates (g/day) | No. of Respondents | Percent of Respondents (%) | Consumption Rates (g/day) |
| <2 | 136 | 21.7 | <10 | 602 | 90.9 | <18.6 | 603 | 91.2 | <8.6 |
| 2–6 | 314 | 50.1 | 10 ~ 30 | 54 | 8.2 | 18.6 ~ 56 | 51 | 7.7 | 8.6 ~ 26 |
| 7–14 | 112 | 17.8 | 35 ~ 70 | 5 | 0.7 | 65 ~ 130 | 6 | 0.9 | 30 ~ 60 |
| >15 | 63 | 10.4 | >75 | 1 | 0.2 | >139 | 1 | 0.2 | >64 |

**Table 4.** Estimated average metal intake doses (μg/kg/day) and target hazard quotients (THQs) caused by consuming different seafoods

| | | Maximally Exposed Individuals | | | | | | Typically Exposed Individuals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fish | | Oyster | | Shrimp | | Fish | | Oyster | | Shrimp | |
| Metal | Reference Dose (μg/kg/day) | Intake Dose | THQ | Intake Dose | THQ | Intake Dose | THQ | Intake Dose | THQ | Intake Dose | THQ | Intake Dose | THQ |
| Cu | 40 | 1.07 | 0.027 | 373 | 9.33 | 3.59 | 0.090 | 0.428 | 0.011 | 49.9 | 1.25 | 0.482 | 0.012 |
| Zn | 300 | 26.7 | 0.089 | 531 | 1.77 | 13.2 | 0.044 | 10.7 | 0.036 | 71.1 | 0.237 | 1.77 | 0.006 |
| Cd | 0.5 | 0.029 | 0.058 | 0.340 | 0.68 | 0.017 | 0.034 | 0.012 | 0.024 | 0.045 | 0.090 | 0.002 | 0.004 |
| Inorganic As | 0.3 | 0.102 | 0.340 | 0.484 | 1.61 | 0.015 | 0.049 | 0.041 | 0.136 | 0.065 | 0.203 | 0.002 | 0.007 |
| Organic Hg | 0.1 | 1.70 | 17.0 | 0.056 | 0.560 | 0.315 | 3.15 | 0.678 | 6.78 | 0.008 | 0.080 | 0.042 | 0.420 |

copper of 182 μg/g wet wt (909 μg/g dry wt) during the past 5 years (Table 2), and the average copper intake from oysters for an adult with 65 kg body weight was 373 μg/kg/day. The safety levels of dietary copper intake for adults suggested by the risk-based concentration table of US EPA are 40 μg/kg/day for adults (US EPA 1996). In other words, the highest average copper intake from oysters for individuals is 9.33 times (*i.e.*, THQ = 9.33) more than that of international limits. On the other hand, for calculating THQs of Hg and As, organic Hg, and inorganic As used were 75 and 10% of the total, respectively (Nakagawa *et al.* 1997). Organic mercury intakes varied from 0.056 μg/kg/day for oysters to 1.70 μg/kg/day for fish (Table 4). It is seen from Table 4 that a relatively higher THQ was reached from consuming fish (THQ = 17.0) than from consuming oysters (THQ = 0.560) and shrimps (THQ = 3.15). For various seafood containing zinc and cadmium, THQ values are generally below 1 in adults, and only slightly over 1.60 for inorganic arsenic from consumption of oysters. On the whole, it is interesting that consumption of contaminated oysters increases the total exposure to inorganic arsenic and copper considerably. The results of THQ showed that if only the maximally exposed individuals were considered, the value of 20%, 60%, and 40% for fish, oysters, and shrimps, respectively, were higher than 1 in comparison with reference dose.

Values of the THQ index for total exposure above 1.0 indicate that the estimated exposure is potentially of concern. However, the THQ does not define a dose-response relationship, and its numerical value should not be regarded as a direct estimate of risk (US EPA 1996). In other words, the reference dose is not a sharp division line between "safe" and "unsafe" intakes. It is by no means certain that intakes at or below the references are risk-free or that intakes above it pose undue risks (Rodricks and Jackson 1992).

Potential human health risks associated with inorganic arsenic uptake for various seafoods were evaluated. We assume inorganic arsenic accounts for 10% of all arsenic in seafood (Edmonds and Francesconi 1993; MacIntosh *et al.* 1996). Carcinogenic risks were estimated by multiplying the exposure estimate by the carcinogenic slope factor for ingested inorganic arsenic, *i.e.*, 1.50 $(mg/kg\text{-}day)^{-1}$ (US EPA 1996).

The theoretical and estimated lifetime cancer risks (target cancer risks; TR) of inorganic arsenic are summarized in Table 5 and Figure 3. The estimated lifetime cancer risk for inorganic arsenic was $1.26 \times 10^{-6}$–$3.11 \times 10^{-4}$ in 1995–1997, but this risk varied with seafood and consumption rate. The GM inorganic arsenic concentration of 0.236 μg/g wet wt (10% of total arsenic as inorganic arsenic) in oysters resulted in an estimated risk of $3.11 \times 10^{-4}$ (Table 5). In general, of the three exposure pathways—consumption of fish, oysters, and shrimps,—risks from consumption of oysters were highest, with TR = $3.11 \times 10^{-4}$ (based on 139 g oysters/day) and a minimum value occurring at $3.24 \times 10^{-5}$ (based on 18.6 g oysters/day). Population risks from consuming fish had TR = $2.62 \times 10^{-5}$ (based on 30 g fish/day) with minimum and maximum values occurring at $8.74 \times 10^{-6}$ (based on 10 g fish/day) and $6.56 \times 10^{-5}$ (based on 75 g fish/day), respectively; whereas risks from the shrimp compartment had TR = $1.26 \times 10^{-6}$ (based on 8.6 g shrimps/day) with a maximum value occurring at $9.39 \times 10^{-6}$ (based on 64 g shrimps/day) (Figure 3). All cancer risk estimates for consumption of inorganic arsenic in fish, oysters, and shrimps were higher than $10^{-6}$, which is the risk of cancer benchmark often used by EPA as the lower end of the range of acceptable risk (Yost and Schoof 1995).

Metal speciation is important in assessing hazard potential and in the risk assessment process. To derive risk values for arsenicals, consideration is given to physicochemical properties and toxicities of the arsenic compounds, as well as other chemical moieties (ATSDR 1991). In addition, exposure to inorganic arsenic may increase the risk of lung cancer by

**Table 5.** Estimated lifetime cancer risks for inorganic arsenic from consumption of various seafoods of Taiwan

| Seafood | Maximally Exposed Individuals | Typically Exposed Individuals |
|---|---|---|
| Fish | $6.56 \times 10^{-5}$ | $2.62 \times 10^{-5}$ |
| Oyster | $3.11 \times 10^{-4}$ | $3.24 \times 10^{-5}$ |
| Shrimp | $9.39 \times 10^{-6}$ | $1.26 \times 10^{-6}$ |

inhalation (Järup *et al.* 1989) and skin cancer by ingestion, but it is also associated with increased liver, bladder, and kidney cancer (Bates *et al.* 1992; Hsueh *et al.* 1995). Moreover, inorganic arsenic increases the formation of lipid peroxides and free radicals, and a decrease in selenium levels has been observed. Consequently, inorganic arsenic exposure has been linked to neurological and cardiovascular diseases (Maitani *et al.* 1987; Jensen *et al.* 1991; Chiou *et al.* 1997). In a review of potentially harmful substances in seafood, Friberg (1988) states that from the toxicological point of view there are two forms of arsenic in marine organisms that should be considered, namely, arsenobetaine, which is the dominant form in most seafood, and inorganic arsenic, which constitutes 2–10% of the total arsenic in seafood. It is known that inorganic arsenic is much more toxic than organic arsenic (Edmonds and Francesconi, 1993).

Results of iterative simulations of population risks indicate the following order of exposure pathways: oysters ($3.11 \times 10^{-4}$) $>$ fish ($6.56 \times 10^{-5}$) $>$ shrimps ($9.39 \times 10^{-6}$). The mean oyster MEI risk for inorganic arsenic was 4.74 and 33.1 times greater than the MEI risk for consumers of fish and shrimps, respectively. One of the primary causes of the risk differentials is a relatively small proportion of shrimps landed in the Taiwan region. The dominance of the oysters exposure route suggests that individuals consuming oysters might be at greater risk than those who consume shrimps. Although the risks from the three seafood may be additive (total risks $= 3.86 \times 10^{-4}$), the consumption of these three seafood may not be independent. In addition, exposure assumptions consistent with US EPA guidelines were selected to be able to predict the reasonable maximum exposure level (US EPA 1989). For example, different methods of preparing and cooking seafood can result in a differential loss of contaminant residues (Skea *et al.* 1979). This seafood body-burden loss factor includes losses from both preparation (skinning, gutting, filleting) and cooking. For the purposes of this analysis, however, it was assumed that the loss factor = 0 (Lipton and Gillett 1991).

As such, these assumptions are likely to overestimate exposure for many individuals. The MEI risk will exceed the highest risk threshold of $10^{-4}$ when oyster consumption is greater than 139 g/day. The risk ($10^{-6}$) is slightly higher than that of consumption levels in excess of 18.6 g/day. These results suggest that ‘‘average’’ consumers and ‘‘extreme’’ consumers have different likelihoods of exceeding risk levels, an outcome that must be considered when evaluating the equitability of any proposed regulatory action (Lipton and Gillett 1991).

Table 6 shows various estimated THQs for copper, zinc, cadmium, and inorganic arsenic caused by consuming oysters collected from different culture areas. A THQ of 9.33 (based on 139 g oysters/day) for copper caused by consuming oysters from the Hsiangshan area is higher than that from other areas (range 0.124–5.95). However, the maximum THQ values for cadmium and arsenic caused by consuming oysters collected from the Machu Islands had THQs of 5.57 and 2.63 for cadmium and arsenic, respectively. Table 6 also shows that for maximally exposed individuals, 50% (12 out of 24 THQ) of THQs exceeded 1. In other words, one who has long-term exposure to four metals through consumption of oysters will have potential health risks, especially for Machu Islands area. Gorell *et al.* (1997) reported and suggested that chronic exposures to copper, mercury, zinc, and lead, etc., were associated with Parkinson’s disease and that they might act alone or together over time to help produce the disease.

Table 7 shows the various lifetime cancer risks for inorganic arsenic (MEI risk range from $1.28 \times 10^{-4}$ to $5.10 \times 10^{-4}$) caused by consuming oysters collected from different culture areas. The highest risk estimate for inorganic arsenic was $5.10 \times 10^{-4}$ for consumption of oysters by Machu Islands residents. Hung *et al.* (1998) indicated that total arsenic levels in both sediments and oysters from the Machu Islands were consistently two to six times higher than those from the Hsiangshan coastal area of Taiwan. There is reason to believe that these sediments are a major source of exposure to the contaminants, but the sediments sampled are not the only source of exposure. It is interesting to understand the relationship between high cancer risk of the BFD patients and high lifetime cancer risk caused by consumption of oysters from the Putai (BFD) area. Chiou *et al.* (1995) reported that a high inorganic arsenic intake from the wellwater of Putai had been associated with increased risks for cancer. In Taiwan, epidemiological studies of residents from fishing communities of the BFD area have shown multiple risk factors associated with arsenic-induced skin cancer (Hsueh *et al.* 1995). Therefore, the Machu Islands residents might be a suitable study base for epidemiologic studies on the mortality and cancer mobility associated with dietary exposure to arsenic and other metals.

Figure 3 also illustrates a sensitivity analysis of the calculated upperbound increased cancer risks from this study as a function of seafood consumption rate. Based on the present results, there is a likelihood that some Taiwan residents consuming certain amount of locally caught seafood (especially oysters) may run the risk in between the amount used as maximum and typical in the calculation. Principal conclusions are as follows.

1) The great majority of the estimated increase cancer risk was attributed to inorganic arsenic in the Taiwan oysters for any long-term consumers of even a small amount of this item.
2) The cancer risks estimated to be greater than $10^{-4}$ in this study were associated with the assumed long-term maximum consumption of very large quantities of oysters from the Machu Islands, on the order of more than 139 g/day.
3) With the exception of risk due to consumption of shrimps, the estimated risks to the prototype typical local consumers of Taiwanese seafood were relatively small.

Figure 4 shows estimate of lifetime cancer risk vs. concentration of inorganic arsenic in Hsiangshan’s oysters at selected consumption rates. Where the risk level is low, such as $10^{-6}$ or lower, the exposure might be considered acceptable (US EPA 1996). However, where the risk is higher, various risk management decisions may have to be taken. (The limit depends heavily on data and assumptions concerning oyster consumption rates). At present, total arsenic residues in cultured oysters

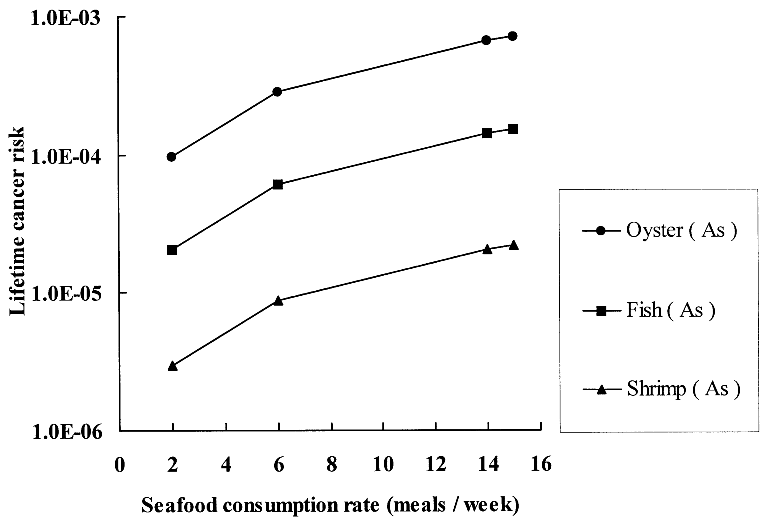


**Fig. 3.** Estimated lifetime cancer risk for inorganic As at different levels of consuming various seafoods

**Table 6.** Various estimated target hazard quotients (THQs) for metals caused by consuming oysters collected from different culture areas

| Metal | Reference Dose (μg/kg/day) | Maximally Exposed Individuals: Hsiangshan | Lukang | Putai | Anpin | Penghu | Machu Islands | Typically Exposed Individuals: Hsiangshan | Lukang | Putai | Anpin | Penghu | Machu Islands |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cu | 40 | 9.93 | 3.36 | 1.52 | 5.95 | 0.124 | 3.07 | 1.25 | 0.450 | 0.203 | 0.796 | 0.017 | 0.411 |
| Zn | 300 | 1.77 | 1.13 | 0.549 | 3.48 | 0.301 | 1.09 | 0.237 | 0.151 | 0.073 | 0.466 | 0.040 | 0.146 |
| Cd | 0.5 | 0.680 | 0.819 | 1.84 | 0.901 | 1.22 | 5.57 | 0.090 | 0.110 | 0.246 | 0.121 | 0.163 | 0.745 |
| Inorganic As | 0.3 | 1.61 | 1.80 | 0.663 | 1.34 | 0.866 | 2.63 | 0.203 | 0.241 | 0.089 | 0.179 | 0.116 | 0.352 |

**Table 7.** Various estimated lifetime cancer risks for inorganic As caused by consuming oysters collected from different culture areas

| Culture Area | Maximally Exposed Individuals | Typically Exposed Individuals |
|---|---|---|
| Hsiangshan | $3.11 \times 10^{-4}$ | $4.16 \times 10^{-5}$ |
| Lukang | $3.48 \times 10^{-4}$ | $4.67 \times 10^{-5}$ |
| Putai | $1.28 \times 10^{-4}$ | $1.71 \times 10^{-5}$ |
| Anpin | $2.58 \times 10^{-4}$ | $3.46 \times 10^{-5}$ |
| Penghu Islands | $1.68 \times 10^{-4}$ | $2.24 \times 10^{-5}$ |
| Machu Islands | $5.10 \times 10^{-4}$ | $6.81 \times 10^{-5}$ |

in several areas of Taiwan contain arsenic in the range of 0.972 to 3.86 μg/g wet wt (Table 2). Clearly, imposition of a 0.057 μg/g wet wt (based on 139 g oysters/day) limit would mean the end of consuming many different cultured oysters in Taiwan until environmental levels of arsenic decline to sufficiently low levels (Figure 4). Absolute residue limits are difficult to derive because of the lack of direct evidence for critical levels in seafood. Risks to humans of consuming oysters have not been clearly proven, although there is some indirect evidence (such as green oysters have sometimes been found in Taiwan) (Han and Hung 1990; Han *et al.* 1994). These high consumption rates are likely to overestimate exposure for many consumers. For these reasons, a risk manager might weigh the risks associated with chemical contamination of fish and shellfish against the health benefits (*e.g.*, decrease risk of heart disease) associated with consumption of fish and shellfish in place of meat (US EPA 1989).

The potential variation of health risk in consuming seafood is that both population and individual risks may straddle commonly used regulatory thresholds of $10^{-6}$ and $10^{-5}$, as well as extending to $10^{-4}$ in certain circumstances. The relevance of this range lies in the fact that seafood consumption might thus be termed both "safe" and "unsafe." In general, risk managers should consider acceptable exceedence frequencies in addition to determining acceptable risk levels. This level of acceptable uncertainty should be based on both the severity of the adverse effect and the size of the affected population (Lipton and Gillett 1991).

The overall problem of metal contamination in seafood (especially oysters) was more serious than was thought to be in such an industrialized and densely populated area. Some chemicals suspected of playing a role in human carcinogenesis were likely present but not analyzed for in the oysters of Hsiangshan and the Machu Islands. For example, PCBs were not analyzed in this study but were detected in fish from the Erhjin Chi River at levels (Ling and Huang 1995) high enough to produce estimates of about $9 \times 10^{-3}$ and $1.5 \times 10^{-3}$ lifetime risk from consuming 65 g of *Megalops cyprinoides* and *Tilapia mossambica* per day, respectively. The other major risk of acute disease is associated with the consumption of raw shellfish, which was infected by microorganisms due to the polluted water (high in *E. coli*) and high metal contents in Taiwan. In addition, we also recommend limited consumption of oysters from polluted water because most current health risks associated with seafood safety originate in the environment, which should be dealt with by control of aquaculture sources or at the point of harvest.

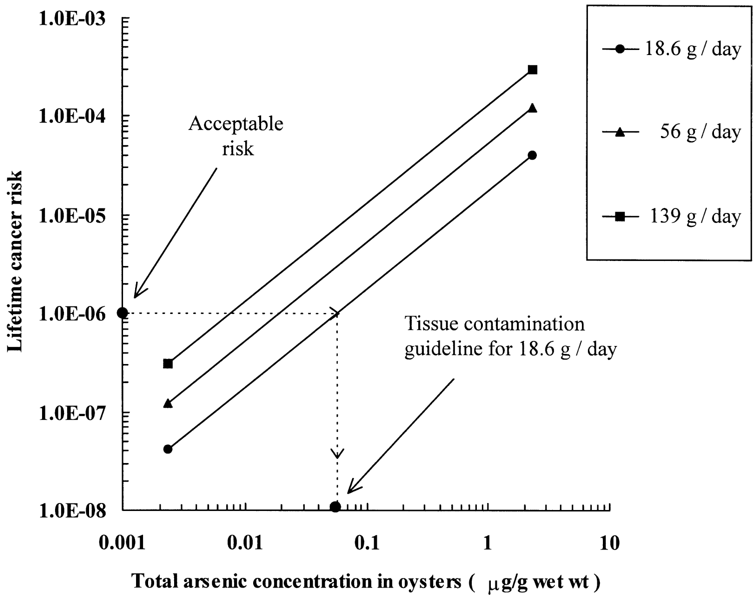


**Fig. 4.** Estimate of lifetime cancer risk vs. total concentration of As in Hsiangshan's oysters at selected consumption rates

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