Mercury Contamination Along the Mekong River, Cambodia 2006

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Abstract

The mean mercury content of livers in ten dolphins that died in the Mekong River (8.1 ±20 ppm) is one of the lowest reported. The mercury content of fish at Kratie was on average 103 ng/g (n=153) but in some species it was up to six fold higher. People located in the drainage basin with gold mines (Ratanakirri) had significantly more mercury in their hair (4.4 ppm) than those living along the northern portion of the Mekong River (3.4 ppm). Males had significantly more mercury than woman (5.2 vs 3.1 ppm, respectively). Individuals had as much as 23 ppm of mercury in their hair. The concentration of mercury in the hair of Khmers in NE Cambodia matches levels associated with the first phase of mercury toxicity in some studies. Gold mines in Cambodia are likely the major source of mercury but tree cores indicated a major flux of mercury associated with deforestation. Further analysis is required to determine what sources of mercury are manageable in Cambodia.

Dead Dolphin Calf

Introduction

Mercury is a toxic metal that, in low concentrations, can impair fertility, suppress the immune system or cause nerve damage that can create symptoms such as irritability in people or reduced ability to hunt in animals. Studies have reported a decreased visual field in people associated with mercury levels in hair of 7 µg/g in Canada and between 10 µg/g and 20 µg/g in Brazil (Barbeau et al. 1976 and Lebel et al. 1996, respectively). In Hong Kong, small increases in mercury in the hair of fertile males from 3.33 µg/g to 4.23 µg/g in subfertile males was associated with eating sea fish with high mercury (Dickman and Leung 1998). Presumably, beyond a critical threshold, humans are not able to excrete enough mercury and toxicity restricts sperm production. Male and female mink that were fed fish from the Great Lakes with 0.10 µg/g to 0.18 µg/g mercury exhibited reduced numbers whelping, reduced kit weight, and/or reduced kit survival (Aulerich et al. 1974). Children are often considered to be most at risk. Recent data suggest that even moderate levels of maternally delivered CH_3Hg may critically impact loon embryonic development (Nacci et al. 2005). In Cambodia, many young dolphins are dying shortly after birth (Cambodia 2005); there may be a linkage to disease and an impaired immune system. Mercury concentrations of 38.8 ppm were found in the livers of harbour porpoises dying in the North and Baltic Seas (Siebert et al. 1999). The authors suspected that mercury impaired the immune system and the animals died of a respiratory disease.

Ecotourism is developing around the town of Kratie on the Mekong River. The main attraction is the Irrawaddy dolphins. This fledging industry is stimulating hotels, restaurants, boat operators, taxis and many vendors. However in 2004, 17 of 80 dolphins died. They are genetically distinct, but it is yet unknown if these animals are a separate subspecies or species (Beasley, 2007). Without resolution of the rapid killing of the dolphins, they and the associated ecotourism will be gone within 10 years.

The first documented problem with mercury in Cambodia occurred when mercury wastes were brought into Cambodia illegally and stored poorly near Sihanoukville. Hess and Frumkin (2000) reported that at least six human deaths and hundreds of injuries have been associated with this incident. This site is isolated from the Mekong River and is unlikely having any effect on dolphins or other wildlife in the Mekong River. Furthermore, recently Agusa et al. (2005) reported that residents of this mercury spill area do not have high concentrations of mercury in their hair. However, these same authors report mercury concentrations in about 10% of their hair samples in Phnom Penh that would indicate at least developmental problems in children and Minamata disease in the worst cases

The largest documented source of mercury in Cambodia is from simple gold mines that use mercury amalgamation to extract gold (Sotham 2004). Because of limited resources, isolated sites and a concern over safety, the Sotham report has no measurement of mercury contamination. Globally the Amazon basin has the worst record of mercury contamination from such simple gold mines and is a model to be considered for Cambodia. Veiga et al. (1994) estimates that mercury losses from deforestation in Brazil are about half that escaping from crude gold mines and that the estimates of mercury loss from deforestation could be underrepresented by 6 fold. Deforestation is also proceeding quickly in Cambodia as peasants seek to grow rice and companies establish plantations for cashews or palm oil.

Mercury discharged from goldmines is inorganic but typically is converted to methylmercury downstream. Methylmercury is 100 to 1000 times more toxic to people than inorganic mercury. Furthermore, methylmercury readily bioaccumulates. Most mercury in fish, dolphins or people occurs as methylmercury. In the future, more mercury may be converted to methylmercury. The construction of dams is usually associated with enhanced methylation of mercury. Many dams are being built on the Mekong Basin in Laos, Vietnam and Yunnan (Oxfam 2006). Development pressures for hydroelectric dams in Cambodia are strong (Mori 2000).

Methods

Sampling

December 9 - 10, 2004: hair and mine tailings were collected at the O Tron gold mines 45 km N.E. of Kratie (12°48’ N, 106°16’ E). Samples were shipped to Canada, freeze dried and homogenized with a mortar and pestle prior to analysis. All samples for mercury analysis were processed in the DMA 80 Direct Mercury Analyser in triplicate.

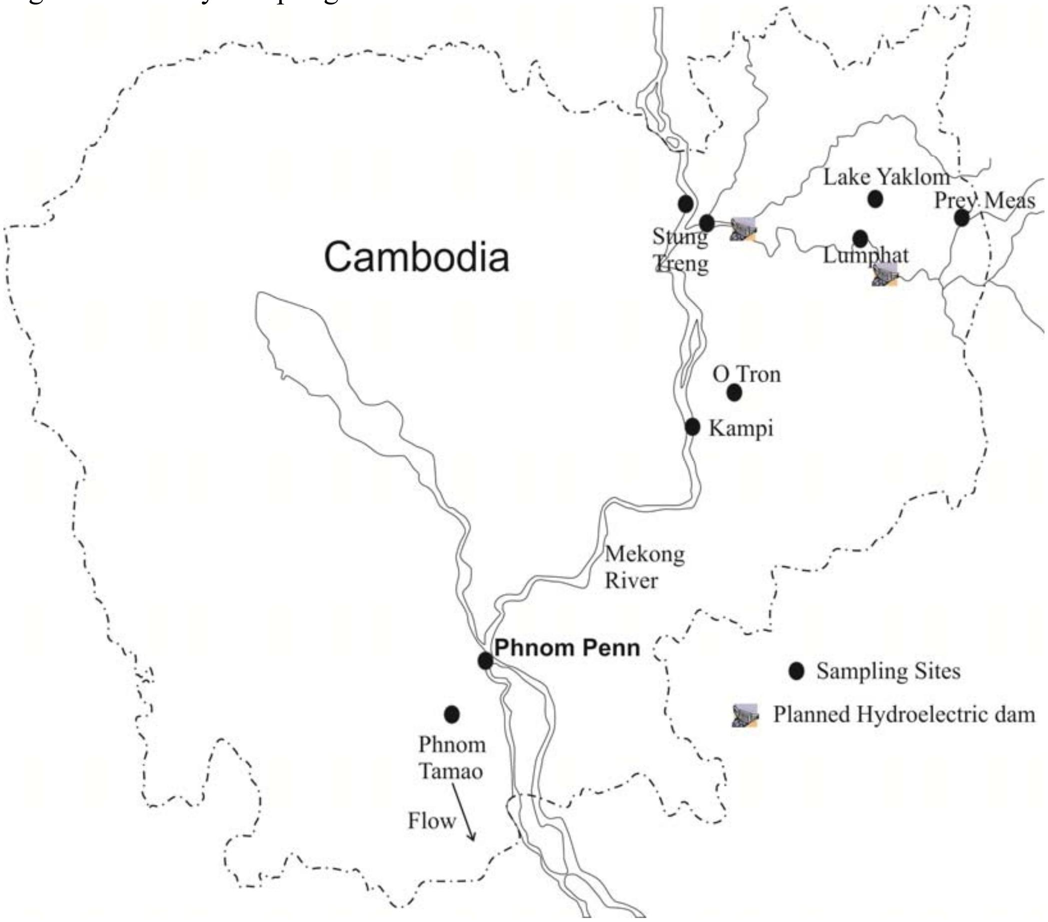
Jan 19-20, 2005, sediment samples were collected at the Kampi pool near Kratie (12°36’22” N, 106 01’19” E) with an Ekman dredge sampler. Samples were shipped to Canada, freeze dried and homogenized with a mortar and pestle prior to analysis. All samples for mercury analysis were processed in the DMA 80 Direct Mercury Analyser in triplicate. The Kampi pool is the major site where most dolphins now live and is very close to the O Tron mines.

April 1-3, 2005: hair samples were collected from the Tonle Srepok River near Lumphat, Ratanakirri (13°28’26” N, 106 59’43” E); on the Tonle Kong River 2 km upstream of Stung Treng (13°32’34” N, 105°59’32” E); on the Mekong River 2 km upstream of Stung Treng (13°34’01” N, 105 58’14” E) and on the Mekong River 2 km upstream of Kratie (12°36’22” N, 106 01’19” E). The Tonle Srepok and Tonle Kong are likely impacted by the gold mines using mercury near Prey Meas (Figure 1). June 27 to June 30, 2005: hair samples were collected at the same locations as in April 2005.

Fish samples were collected at three sites near Kratie (Kampi pool, 3 km up the tributary entering at the Kampi pool, and 3 km upstream on the tributary 8 km north of the Kampi pool) June 29-30, 2005. Samples of muscle, kidney and liver tissues from necropsies of 10 calves and 7 adults Irrawaddy dolphins (*Orcaella brevirostris*) were sent to Environment Canada, Burlington, Ontario by the Wildlife Conservation Society, Phnom Penh office in 2004. Samples were shipped with dry ice which was replaced at each airport en route to Canada. Once in Canada, samples were stored at minus 60°C. Analysis of mercury and other metals in dolphin tissues used Canada’s National Laboratory for Environmental Testing (NLET), a certified laboratory and Environment Canada’s main analytical laboratory.

On June 27 and March 6, 2006, tree core samples were collected at Lake Yaklom Volcanic Lake, near Banlung, Ratanakirri province (13° 43’ 52” N, 107° 01' 01.5” E). September 6, 2005: tree core samples were collected near the temple at Phnom Tamao (11° 18' 04" N, 104° 48'1 8" E), approximately 40 km south of Phnom Penh. Ratanakirri is part of a sacred park. Until very recently the land around Lake Yaklom was used only for swidden agriculture, i.e. slash and burn of small plots of land by natives (Maxwell 2001). The trees that were sampled at Phnom Tamao were also within a park but the history here is quite different. Phnom Tamao is 30 km from Phnom Penh. Most records were destroyed but anecdotal reports say the Khmer Rouge logged Phnom Tamao before it fell to the invading Vietnamese in 1979. Direct observation confirms this idea. The only large trees we could find were on temple property. The proximity to Phnom Penh with both domestic and export needs makes it highly likely to have been logged more commercially, intensively and frequently than Lake Yaklom which is very isolated (Figure 1).

Figure 1 Mercury Sampling Sites



Since mercury is often used as a catalyst to make methylamphetamine (yaba, French patent, 1964), 28 hair samples were collected October, 2005 from yaba users by Mith Samlanh Friends, Cambodia, shipped to Canada by RDI and measured for total mercury by Environment Canada.

Mercury Analysis

For most mercury analysis, a DMA80 Direct Mercury Analyzer from Milestone was used. The process is detailed in EPA Method 7473: Mercury in Solids and Solution by Thermal Decomposition, Amalgamation and Atomic Absorption Spectrophotometry. This process is designated for the determination of total Hg in solids, aqueous samples and digested solutions. Solid and aqueous samples are dried and then thermally and chemically decomposed by controlled heating in an oxygenated decomposition furnace to liberate mercury. The decomposition products are carried by flowing oxygen to the catalytic section of the furnace where oxidation is completed and halogens and nitrogen/sulfur oxides are trapped. The remaining decomposition products are then carried to an amalgamator that selectively traps mercury. After the system is purged with oxygen to remove any remaining residual by-products, the amalgamator is rapidly heated to release mercury vapour. The vapour flows through an atomic absorption spectrophotometer set at 253.7 nm to measure the concentration of mercury.

Certified reference materials (CRM) were used for each set of analysis. Results were always within the standard deviation of the CRM. Relative standard deviations were typically around 3%. Blanks were run for each set of analyses and always much less than 1% of samples. For the dolphin liver samples, analyses were done both on the DMA 80 and by Environment Canada's accredited National Laboratory for Environmental Testing (NLET). NLET uses a microwave digestion followed by ICP-SFMS analysis (NLET method 02-2705).

Table 1 Comparison of certified reference materials and actual measurements (µg/g)

Sample	Certified	Measured
Hair -example 1	4.64	4.81
Hair - example 2	4.64	4.39
Sediment	1.44	1.48
Fish 1- example 1	0.76	0.75
Fish 1- example 2	0.76	0.72
Fish 2 - example 1	4.64	4.72
Fish 2 - example 2	4.64	4.88

Stunted Tribal Girl

The tribal people of Ratanakirri province have no influence on the mining where they live and are heavily dependent upon fish for food and commerce.

Results

Mercury in dolphins

The results of mercury analysis in dolphin tissue was virtually identical in both laboratories (Table 2). One liver sample contained much more mercury than the rest and results were off-scale in the direct total analyzer (>50 ppm) and measured as 67 ppm in NLET. This one extreme sample with high mercury had a different composition of other trace metals too (Appendix 1). Of particular importance is the relatively lower selenium composition, relative to the mercury content.

Table 2 Comparison of Hg analysis DMA80 vs. NLET (µg/g)

Sample	DMA80	NLET
15 Calf Liver	1.16	1.04
9 Calf Liver	0.87	0.707
10 Calf Liver	1.33	1.16
14 Calf Liver	1.36	1.2
16 Calf Liver	1.49	1.15
11 Calf Liver	1.61	1.38
13 Adult liver	1.19	1.07
4 Adult Liver	>50	67.4
17 Adult Liver	2.84	2.39
8 Calf Liver	3.71	3.57

NLET is Environment Canada's accredited National Laboratory for Environmental Testing (NLET).

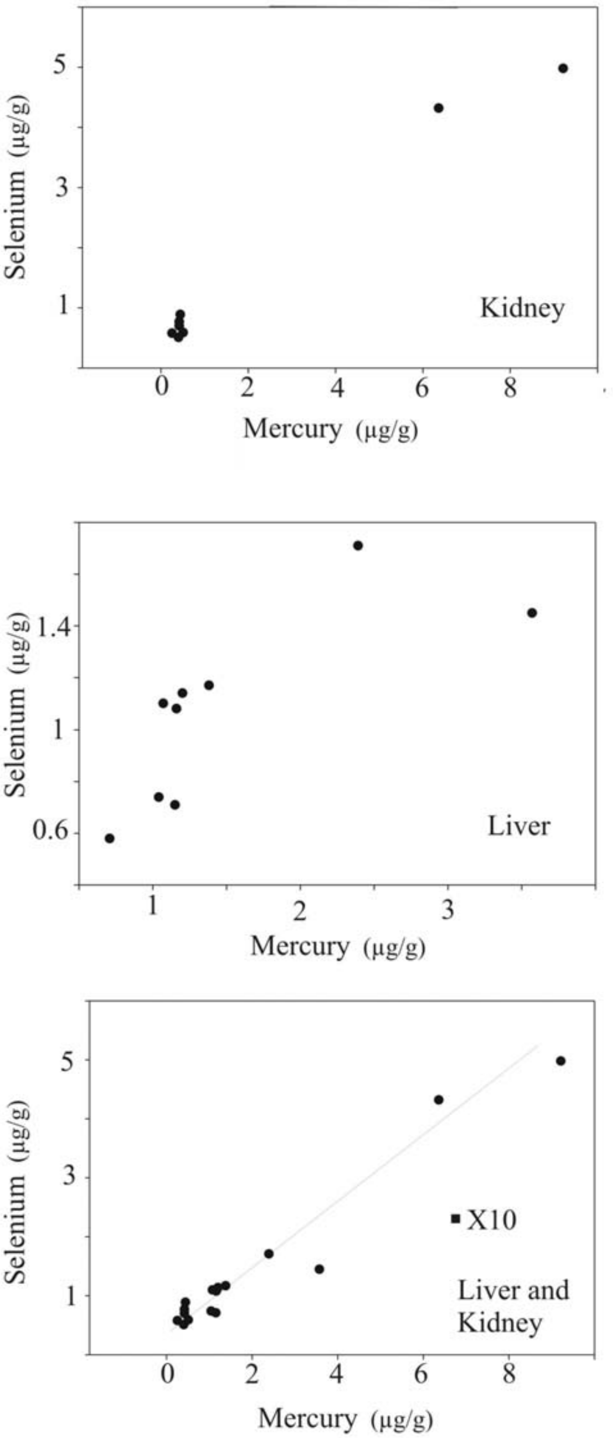
Selenium

The selenium content in kidney tissues was found to be closely correlated to mercury content (r^2 =.98, n=8). The molar ratio of selenium to mercury in the kidneys was 1.78 which is not much different than in liver tissue (1.80, without the extreme liver sample with high Se and Hg concentrations). The one liver sample with 67 µg/g of mercury had a molar ratio of selenium to mercury of 0.84, indicating a much higher proportion of mercury not complexed with selenium. The selenium and mercury contents of the livers were not so closely correlated (r^2= 0.58, n=8, again without the outlier). However when the data are plotted it becomes obvious that with the exception of the one outlier with high mercury, the mercury to selenium ratio is fairly constant (Figure 2).

Fish, Kratie

The mercury content of fish at Kratie was on average 103 ng/g (n=153) but in some species it was up to six fold higher (Appendix 2). The differences between the three sampling sites is too modest to be significant and any analysis is compromised by different species at different sites. The fish in the tributary entering at the Kampi pool had a mean of 128 ng/g Hg (n=29). The fish in the tributary 8 km N. of the Kampi pool had a mean of 90 ng/g Hg (n=60) and the fish in the main river had a mean of 105 ng/g Hg (n=64). The mean of the larger fish (>10 g) was 107 ng/g which is no different from the total population. At times, there was considerable variability in the mercury content of fish within triplicates. In two days, 82 species of fish were collected from two tributaries and the main river at Kratie. However, only one species was collected in triplicate from each of the three sites.

Figure 2. Mercury and Selenium in Dolphin Tissues



■X10 is the dolphin with 67 µg/g Hg

Mine Tailings O Tron

Table 3 O Tron Mine Samples ng/g Hg (ppb)

Site	Average	StDev	RSD	Sample Description
Mine-1	67.9	2.0	0.4	Grey-brown, fine tailings
Mine-1	95.9	4.4	0.4	Brown, fine tailings, some organic matter
Mine-1	609.1	14.2	0.4	Brown, fine tailings
Mine-2	1.4	0.3	0.4	Sandy, unsorted, gully draining trench
Mine-2	46.0	1.3	0.4	Light brown, excavation trench
Mine-2	5.8	0.1	0.4	Light brown, discharge from trench
Mine-2	207.5	6.3	0.4	Sluice box, sandy with fine grey powder
Mine-2	323.9	6.8	0.4	Larger pond, some organic matter
Mine-2	1378.7	17.4	0.4	Small pond grey brown, homogenous, fine particles
Mine-2	73.5	0.4	0.4	Brown, fine particles, some organic matter
Mine-2	55.1	2.3	0.4	Brown, fine particles
Blank	1.3	0.2	0.4	Deionized water
CRM	1483.3	22.2	0.4	
The description is an observation not based on particle analysis.				

CRM is certified reference material.

Both mine sites at O Tron were quite small. It is unlikely that the volume of mine tailings at the larger mine (site 1) were much larger than 200 m^3. The total volume of mine tailings at the smaller mine were about 1 m^3. The volume of the most contaminated tailings pond at the sediment mine could not have exceeded 0.1 m^3. There is some mercury in the mines near Kratie, but no samples approached an industrial standard for mercury contamination (Table 3). A typical industrial soil definition of contaminated soil with an industrial standard is 10 ppm. [http://wlapwww.gov.bc.ca/epd/epdpa/contam_sites/legal_decisions/orders/CanOxy/os16 149_reasons.html]. Areas which used mercury commercially such as chlor-alkali plants typically have tens of thousands of tonnes of soil exceeding this standard. The authors of the government report state that the miners at O Tron did not use mercury to extract gold (Sotham 2004) but the tailings contain some mercury and possibly small amounts of mercury were used. Also it is quite likely that much of the mercury had washed away in tropical rains. The presence of domestic animals and children around these mine spoils is worrisome, but likely the site has many more serious health issues than mercury.

Sediments at Kratie

The mercury content of sediment samples collected around the Kampi pool contained very low levels of mercury (< 64 ng/g) and most metals (Appendix 3 and 4). The dilution by sand must override any mine effluent. Any attempt to use sediment to trace sources of mercury would likely work better if they were screened to isolate the finer materials for analysis. The coarser sediments had very little mercury.

Mercury in Human Hair

There is a significant pattern indicating that the gold mines in Ratanakirri are a source of mercury impacting people (Table 4, Appendix 5). An exploratory investigation of the Hg data from the hair samples was conducted using a difference of means approach. The variance between variable pairs first was evaluated using an F-test to determine the appropriate form of the Student t-test to be applied. Based on the results of the F-test either a pooled or non-pooled form of the Student t-test was applied.

Results of this analysis showed that the mean level of Hg in hair from men (n=32) was significantly greater (alpha=0.05) than women (n=46), with all ages pooled together. When the women's sample was sorted according to area of sample, it was found that women living in Ratanakirri province, near mine-impacted areas (n=23) had a significantly greater (alpha=0.05) level of Hg in their hair than a control group (n=23) and again all ages were pooled together. Finally, when the women's control group was sorted into three groups by age (<12; 17-30; >50), we were surprised to find that the >50 age group had significantly lower Hg in their hair than the <12 or 17-30 age groups. The difference might be stronger than suggested by the data. The boat drivers were hesitant to approach within 20 km of the Laos border and it is possible that we did not go far enough up the Mekong north of the Sekong River to have a stronger control.

The limited hair analysis done at the O Tron gold mines did not find mercury concentrations which indicates little if any use of mercury amalgamation. It supports the analysis of the tailings done at O Tron. The limited sampling of goldsmiths in Phnom Penh found one person with elevated mercury in hair (12 ppm) confirming that mercury is used for gold purification and suggesting that some goldsmiths are being exposed to toxic levels of mercury. Other goldsmiths either had better ventilation or did not use mercury.

Some individuals have as much as 22 ppm Hg in their hair. Extrapolations of the Hong Kong mercury studies would suggest male sterility could occur in Cambodia (Dickman et al.1999). The studies done in Brazil (Lebel et al. 1996) and Quebec, Canada (Barbeau et al. 1976) also suggest that a small percentage of Cambodians could suffer nerve damage from mercury.

Methylamphetamine (Yaba)

The mean of total mercury in hair samples from 28 yaba users was 1.93 μg/g (Appendix 5). The samples were all collected from young male adults in Phnom Penh. This mercury concentration is less than what was found in samples we collected from northern Cambodia. Although mercury is often used as a catalyst to make yaba (French Patent 1964), the assimilation of mercury in yaba users is not substantial.

Atmospheric Mercury

Tree cores can provide an historical record of mercury deposition. The immediate area around the volcanic lake in Ratanakirri is a park with little interference with nature. It is considered a sacred site. Historically the surrounding land was used for swiddle agriculture. However, now much of the surrounding land is now being cleared for agriculture. The trees that were sampled at Phnom Tamao were also within a park but the history here is quite different. Phnom Tamao is close to Phnom Penh, was completely logged in 1979 and logging has gone on for centuries.

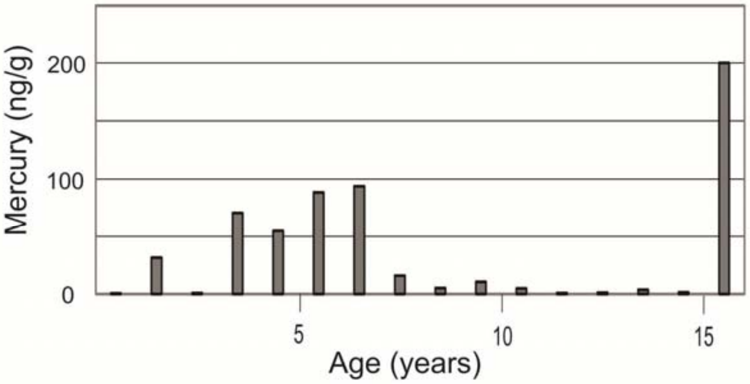
There were peaks of mercury associated with the recent deforestation in Ratanakirri but similar peaks were not found in association with the logging in 1979 at Phnom Tamao (Fig. 3, Appendix 6). Peaks of mercury in much older wood at Phnom Tamao and extrapolated growth rates from visible tree rings into the resin rich interior, probably indicate logging about 1905 and 1840. Presumably, the mercury that accumulated in the forest soils was lost during repeated harvests. This idea is supported by much smaller growth rings in Phnom Tamao (<1 mm) compared to Ratanakirri (5 mm). The longer cores that were collected in Ratanakirri in March 2006 changes the interpretation of earlier short cores very little. The surface of two tree species was very similar but one species was very different from the shorter core. Tree cores can provide an historical record of atmospheric mercury deposition from local emissions and subsequent bioaccumulation but the tree core record is only qualitative.

Table 4 Mercury in Human Hair

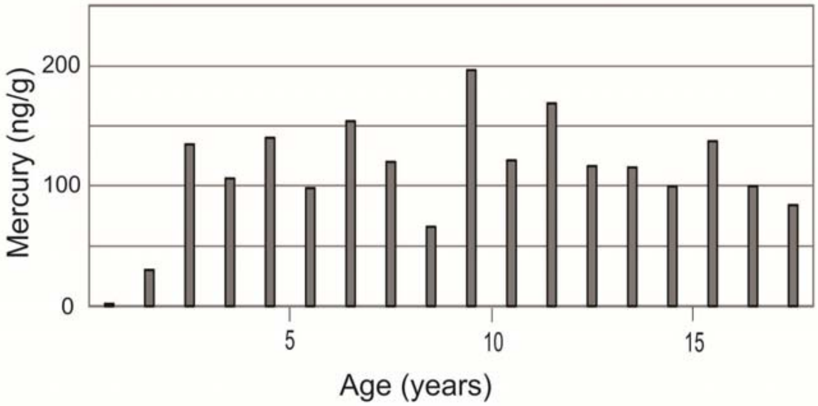
Site	Mean Hg ppm	SD	N	Comment
Mekong River				
Tonle Srepok	4.54	0.81	25	
Tonle Kong	4.22	0.39	17	
Mekong N. Stung Treng	3.36	0.28	16	
Mekong Kratie	3.47	0.40	20	
All Males	5.21	0.64	32	
All females	3.08	0.16	46	
All adults	4.01	0.36	59	
All children	3.38	0.27	19	Age <13 yr
Women Ratannakiri	3.47	1.12	23	
Women Mekong	2.70	0.87	23	
Other Khmers				
Goldsmiths	4.99	2.42	4	Phnom Penh
Yaba users	1.93	0.19	28	Phnom Penh
O Tron mine workers	2.93	1.1	3	
Prey Meas mine workers	2.33	0.43	13	Using Hg
Amer. Women	0.47		1726	McDowell et al.
Amer. Children	0.22		838	Age <5 yr
Hong Kong fertile men	3.9		42	Dickman and Leung 1998
Hong Kong subfertile men	4.5		117	Dickman and Leung 1998
Hong Kong Vegans	0.38		16	5 year no fish or meat
Philippine Gold mine all adults	0.99	1.6	163	Health impaired Akagi et al.
Threshold for Minamata disease	50			Harada 1995
Abnormal infantile	10			Proposed Barbosa et al.

Figure 3a Mercury in Tree Cores Lake Yaklom, Ratanakirri, longer set of cores

Lagerstoemia sp.



Vitex pubescens



Eugenia multibracteolata

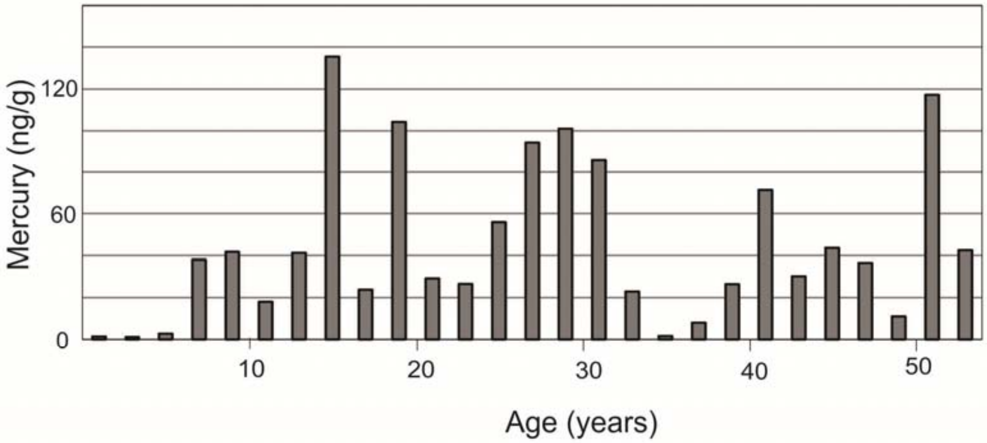
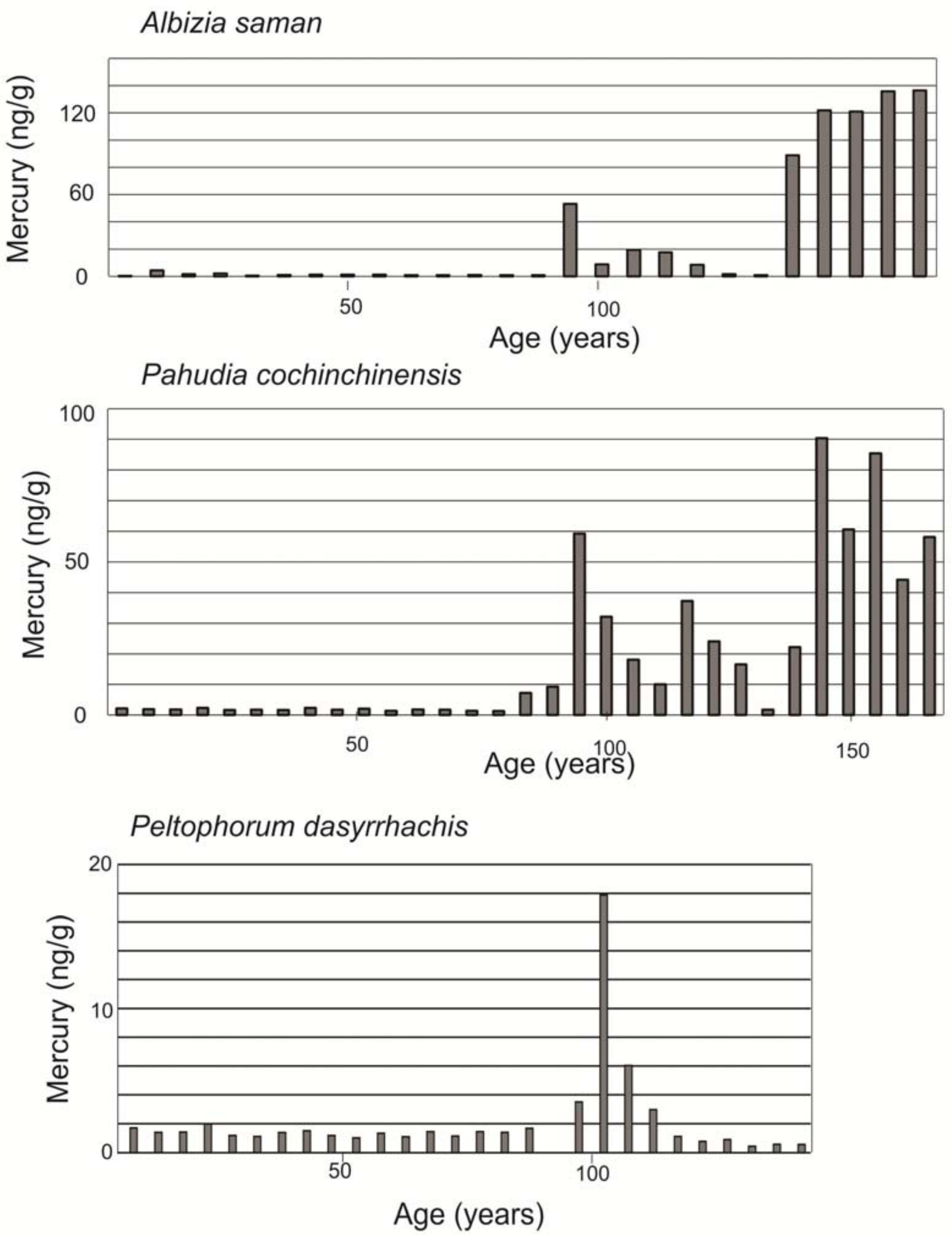


Figure 3b Mercury in Tree Cores Phnom Tamao


Albizia saman

Pahudia cochinchinensis

Peltophorum dasyrrhachis

Discussion

Fish/Dolphins

The risks presented by the mercury concentrations in fish at Kratie are uncertain. The mean mercury concentration of 103 ng/g would not require any restriction of fish consumption in Canada [http://www.ene.gov.on.ca/cons/590b12_intro.pdf] but 14 (of 152) fish at Kratie did exceed Canadian advisories of 200 ng/g in subsistence settings where people consume a lot of fish (Health Canada 1978, 1984). Some of the more popular fish are predators with more mercury. Health Canada's advisories suggest that 1.56 kg of the average fish in Kratie could be eaten safely in a week (Health and Welfare 1984). Some people would exceed this amount of fish. The mercury content in human hair must reflect significant assimilation of mercury from fish consumption. Since fish are the most likely vector for mercury assimilation by people and dolphins, fish analysis is important. However, our first sampling effort for fish at Kratie was awkward. Forty-eight fish species were collected and the fish found at three sites were usually different.

One dolphin was clearly exposed to much more mercury than the other carcasses that were sampled. It is not possible to prove it was killed by mercury, and where it assimilated the mercury is not clear. Perhaps it was feeding in an area closer to the gold mines using mercury amalgamation. The Prey Meas mine in Ratanakirri uses mercury amalgamation (Figure 1, Sotham 2004). Dolphins are rare but at times are found in the Tonle San where we observed higher mercury in human hair. It is unlikely that nine of the 10 carcasses that were processed reflected acute mercury toxicity.

The concentration of mercury in the livers from the Mekong River are amoung the lowest reported (Table 5). Lahaye et al. (2006) reviews 17 publications on mercury in dolphins that like Table 5 shows the Mekong dolphins have less mercury than is usually found. The same can be said for several publications on mercury in dolphins reviewed by Wagemann and Muir (1984) who stated that "the limit of Hg tolerance for the mammal's liver to be in the range of 100-400 µg/g wet weight", (page 1). The Mekong dolphins had <10% of the mercury in this inferred range of tolerance. Once mercury is inactivated by selenium it is mostly stored in the liver and not excreted (LaHaye et al., 2006; Wagemann et al., 2000). This inactivation results in much more mercury in the livers of dolphins than flesh of dolphins or of fish. But when the Mekong dolphins are compared to dolphins elsewhere their mercury concentration is low. Although there are widespread concerns about declining numbers of Mekong River dolphins (Beasley, 2007), it is not possible to prove that mercury resulted in the sampled Mekong dolphin mortality. .

The biggest problem with dolphin mortality in the Mekong River is occurring with newborns; they quickly die. It is not possible to do bioassays to prove cause and effect with dolphins. At first, Aulerich et al. (1971) attributed the suppression of reproduction in mink by Lake Michigan fish to mercury at similar concentrations as found in the Mekong River. But a later publication by Aulerich et al. (1974) suggests that PCBs, not mercury was responsible for inferior reproduction in mink. It was difficult to make simple conclusions in controlled experiments in Michigan. With an endangered animal in the wild in Cambodia, conclusions will be evasive.

Table 5 Dolphin Mercury Content

Location	Lead Author	Liver mean	Liver Max	Kidney mean	Number
Japan[#]	Endo et al., 2002	370 ±525	1980	43±44	22L, 15K
Texas[##]	Meador at al., 1999	212±313	1404	33±65	30L, 29K
Mekong [##]	This study	8.1 ±20	67	2.2±3.3	11L 8K

#These dolphins were captured alive. ## Stranded on shores

L is liver, K is kidney, all concentrations as wet weight μg/g (ppm), ND no data.

Selenium

Marine mammals are known for their low susceptibility to mercury toxicity, and selenium may play a role in this protection against mercury (Koeman et al. 1973, Wang et al. 2001). It has been reported that Brazil has high concentrations of selenium that may provide some natural protection against mercury contamination there (De Compos et al. 2002). In people without extremes of mercury, the molar ratio of selenium to mercury in hair is close to one. De Campos et al. (2002) report that a Hg-Se-Seleprotein decreases the bioavailability of mercury. The molar ratio of selenium and mercury in the Irrawaddy dolphins is about 1.8 and certainly not one. Naganuma and Imura, (1980) reported a molar ratio of selenium to mercury of two and identified bis(methylmercuric) selenide $(CH_3Hg)_2Se$ in extracts. However, in a site with varying exposures to selenium and mercury, the ratio of selenium to mercury changed with the dose (Chen et al. 2001) and this is likely the response expected when defense mechanism are overcome or is the product of more than one defense reaction. The lower ratio of selenium to mercury in the one extreme case of mercury bioaccumulation in a dolphin liver likely indicates saturation of defense reactions. One difficulty in making inferences about selenium inactivation is the lack of selenium data in many reports.

Atmospheric Mercury Loading

The first set of data from trees from Ratanakirri could have been interpreted as representing atmospheric contamination from coal burning in China or natural gas combustion in Thailand. However, the data from trees in Phnom Tamao do not support this hypothesis. The recent wood in trees in Phnom Tamao shows no mercury contamination. Relative to the distance to either China or Thailand, the two Cambodian sites are quite close. Furthermore, the deeper peaks in trees at Phnom Tamao probably represent earlier logging. The tree rings in the recent growth at Phnom Tamao are slightly less than 1 mm a year but in the mature forest of Ratanakirri the growth rate is about 5 mm a year. Logging of tropical forests typically results in loss of nutrients. Mercury that took many centuries to accumulate is also released. The potential that mercury contamination is coming from industrial areas in Asia is still possible, but sources in Cambodia appear to be more important.

For three reasons the mercury contamination in Ratanakirri is recent: 1) The mines are new. 2) Extensive deforestation is recent. 3) Children have similar mercury contamination in their hair as adults. The last situation is unusual. In general, older people have more mercury and the age difference is believed to reflect the long-term accumulation of mercury and not lifestyle. In the USA, adult woman have 470 ng/g Hg on average and children have 220 ng/g in hair (McDowell et al. 2004). Compared to the American study, our data set is small, but we do not see as large a difference between adults and children in Cambodia. Adimado and Baah (2002) also failed to see a correlation between mercury in hair and age near gold mines in Ghana. The lack of an age response with Hg in northern Cambodia hair could indicate a recent significant source of mercury, i.e. mines and deforestation. Ideally, a baseline of mercury contamination would be established so that future monitoring could distinguish if the contamination is getting worse or if control strategies such as a change in gold mining procedures are having an effect.

Sources of Mercury in Cambodia - relative scale

There is too little data to accurately calculate the fluxes of mercury from mining, deforestation or the urban source in Phnom Penh. However, it is possible to make simple inferences and estimate the relative scale.

Mining

We can take the following variables on gold processing from the report on gold mining in Cambodia (Sotham 2004) and then calculate an estimated a flux of mercury from mining of-10.8 tonnes a year.

1) On average each team member extracts around 34 g of gold per month (Sotham, page 28)
2) One kg of mercury extracts 37.5g of gold (Sotham, page 31)]
3) Adjust the "between 5000 and 6000 miners a month at peak" to assume that 1000 miners use mercury year round.

The ratio of mercury to gold extracted in Cambodia of 26:1 is much higher than the 1:1 ratio reported in Brazil by Veiga (1997) where more advanced amalgamation procedures such as gravity concentration are used prior to mercury amalgamation. However, the Cambodian ratio is slightly more efficient than that reported in a large UNIDO project on artisanal goldmines using simple technology in Sulawesi, Indonesia where the ratio of mercury used to gold extracted was 40-60:1 (Filho et al. 2004).

Deforestation

Veiga et al. (1994) estimated mercury emissions from deforestation in the Amazon of 17.6 g/ha (1.76 kg/km^2). If we assume the same areal flux in Cambodia, we can estimate the amount of deforestation to match the mercury from mines. It is equivalent to the mercury released by deforesting 6000 km^2 a year. It cannot be this high. These estimates are too rough to justify much comparison between mining and deforestation. It is enough to say that both mining and deforestation are both major sources of mercury.

Phnom Penh Mercury Source

Agusa et al. (2005) published that there was significant mercury contamination in Phnom Penh. Tanabe (personal communication) believes mercury is in a food supply more concentrated than fish he measured in the market in Phnom Penh. We can use a few known variables to estimate the impact of mercury contamination in diet effecting people upon the total flux of mercury.

The data from Agusa et al. (2005) indicate about 10% of people in Phnom Penh have over 10 ppm of mercury in their hair and are getting too much mercury in their diet. With this study, we can estimate that 100,000 people in Phnom Penh are contaminated with mercury.

Use the mercury data from Veiga of a maximum concentration of mercury in urine of 840 ppb. The normal level is less than 20 ppb. Assume 1000 ppb for a worst case (and some loss via feces).

Use an approximation of 1000 ml of urine production a day (range 750 to 1500 ml/d)

It can be estimated that from these contaminated people there would be 3 kg/month or 36 kg a year of mercury in their urine. It is a rough estimate but is more than 10 fold less than the major mercury sources. It is important that people be protected, but if the Hg problem in Phnom Penh were dietary, it would not impact the dolphins - at least not relative to either mining or deforestation.

There are a number of weak variables in these calculations, but with this approach, deforestation and mining are more important. It would be nice to sharpen the variables. It would at least be nice to estimate the yearly deforestation perhaps with satellite images. Also it would be useful to measure the mercury content of the surface organic layers in the forests. Likely both mining and deforestation processes are important to the biota in the Mekong River.

Suggested Analyses

1) Source of Mercury in Phnom Penh

It is important to identify the source of mercury contamination in Phnom Penh discovered by Agusa et al. (2005). It is not yaba. Moreover, the yaba users were not exposed to the source of mercury detected by Agusa's team.

2) Mines along the Mekong

It is important to quantify mercury releases at one typical mine using amalgamation but it is not possible to visit each mine and too many rumors exist about the location of the mines. Researchers were not welcome at one mine and the opinion of the Sotham (2004) that safety is a concern when visiting these mine sites seems valid. A suite of different approaches could be used to trace use of mercury in mines and minimize risks.

3) Fish Sampling

Since fish are most likely the vector for mercury assimilation by people and dolphins, more fish analysis is important. It is important to compare fish of similar size, habitat (i.e. predator) and ideally non-migratory species. Sessile aquatic animals like mollusks or prawns that could be collected. Monirith et al. (2000) were able to collect green mussels for organochlorine analysis in parts of Cambodia. Placing caged animals at sites for known periods of exposure to mercury is another option, but such experimentation in a remote area with limited transportation would be awkward. Shipping of tissues is also a concern.

4) Hair Sampling

People are much easier to sample than fish. Woman are more likely to be home than men and they represent the immediate environment better. Men might have worked in a mine or have been exposed to mercury sources while traveling. Hair samples are easy to ship. Ideally selenium analysis would also be done on hair samples. It is possible that a threshold exists where natural defense mechanisms are overcome and the ratio of Se to Hg may reflect this threshold.

5) Map Analysis
Aerial and satellite photography are capable of detecting mines. Once the image of a known mine is captured digitally, software can then find other similar images. Detailed satellite images would be capable of this task, safer and less expensive than searching by vehicle, but still expensive. Map analysis would provide guidance to land and river sampling.

6) More Deforestation Analysis
Ideally several samples of surface soil from both undisturbed forest and developed farmland in Ratanakirri will be analyzed for total mercury. Naturally occurring organic matter has often been shown to inactivate mercury (Driscoll et al. 1995, Mason et al. 2000), but when the trash from logging is burned much of this mercury is volatilized or lost in subsequent soil erosion. The history of fires in this area is complicated. Likely historic practices of slash and burn (Maxwell 2004) were not done at the current rates. Analysis of sediment cores in lakes as was done by Maxwell (2004) might produce interesting insights into the changes in mercury fluxes historically.

Wood in at least Phnom Tamao could be radiodated to determine when Hg spikes occurred and if subsequent tree growth was restricted by logging. For basic purposes, it would also be useful to determine the speciation of mercury in the trees. It would be useful to estimate the rate and extent of deforestation by analysis of historical aerial photography and satellite images. Collectively these measurements could allow better estimates of mercury release from deforestation.

7) Avian fish predators
The potential that some avian fish predators are being adversely impacted by mercury could also be evaluated, perhaps by sampling eggs or blood. Any initial attempt would likely be most appropriate in the mining district of Ratanakirri. Picking a control site would require input from wildlife managers.

Control Strategies

Deforestation impacts on many issues beyond mercury release. Because of economic incentives, deforestation is not likely to change. Further data is required to assess what proportion of mercury sources can be controlled. There is no doubt that deforestation results in mercury contamination. In addition to the Amazon and Cambodia, the concept that mercury is released in deforestation has been documented in Quebec, Canada (Garcia and Carignan 1999, Garcia and Carignan 2000).

The potential to retrofit simple gold mining is much better than chances to restrict mercury loses associated with deforestation. By recycling mercury in retorts, miners need to buy much less mercury and their health is protected. Some retorts are very simple to use (www.globalmercury.org) and only training and education are required.

Mercury and Disease

The ability of mercury to suppress the immune system has specific relevance to those people working in gold mines or living near hydroelectric dams. It has been estimated that gold workers in Brazil are four times more likely to have a malaria infection (Crompton et al. 2002). Mines in Cambodia are often in areas with endemic malaria (Sotham 2004). The Cambodian Daily (Sept. 2, 2005) reported that waterborne disease killed three people downstream from hydroelectric dam on the Sesan River. No details of the disease were reported, but since a change in water levels appeared to trigger the disease, it was likely associated with a mosquito hatch and either dengue fever or malaria was likely present. Dam construction often results in enhanced methylation of mercury, and a 100 to 1000 fold increase in mercury toxicity. In areas where mercury is used for gold mines, people rely upon fish for protein, malaria is endemic and dams are planned. It is critical to prepare for the expected problems.

Other Potential Immune System Suppressors

Globally there is heightened concern regarding immune defense suppression and regulated substances known to interfere with endocrine control of reproduction. The United States Geological Survey has many websites reviewing their increased concern over the effects of mercury and organochlorine chemicals on reproduction (i.e. http//www.best.usgs.gov/misover.htm). Limited analysis in Cambodia indicates the lowest level of organochlorine contamination in fish and mussels in Asia (Monirith et al. 2000).

Mercury concentrations in samples collected by this study in Cambodia are far from the extremes of Minamata disease (Harada 2000) but some exceed levels known to impair infantile development (Barbosa et al. 1995). Piotrowski and Inskip (1981) report that mercury in the hair of fish eating communities is often up to 5 mg/kg, which places Cambodia at the upper range of "natural" contamination. However, many recent publications stress that natural levels of mercury in fish are a concern to human health. The studies by Dickman et al. (1998, 1999) in Hong Kong clearly show that male fertility is impaired by less mercury than is found in the average Cambodian man in NE Cambodia. Mercury in Cambodian hair is typical of some reports of gold workers in Brazil (Lacerda and Salomons 1998) but less than reported in other Brazilian gold workers (Boischio and Cernichiari 1998). Cambodian hair exceeds that observed near gold mines in the Philippines where authors associated impaired human health with mercury (Akagi et al. 2000). The most alarming concern with mercury in human health is presented by Agusa et al. (2005). This study presents mercury contamination that indicates potentially ten of thousands of Cambodians in Phnom Penh are suffering neural damage.

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Mine tailings at O Tron

Appendix 1 Metal Content of Dolphin Livers (mg/kg)

element	10L	11L	13L	14L	15L	16L	17L	4L	8L	9L
AG	0.0262	0.0385	0.0214	0.0297	0.0223	0.019	0.0171	0.451	0.0663	0.0111
AL	2.94	3.96	1.03	1.7	4.01	5.62	81.2	4.46	6.22	0.88
AS	0.01	0.02	0.057	0.004	0.001	0.004	0.084	0.09	0.237	0.002
BA	0.0025	0.052	0.287	0.044	0.0025	0.181	0.554	0.024	0.015	0.0025
BE	0.00005	0.0001	0.00005	0.00005	0.00005	0.0001	0.0037	0.0008	0.0004	0.00005
BI	0.0013	0.0039	0.0021	0.0028	0.0025	0.0016	0.0035	0.0022	0.0023	0.0008
CD	0.0026	0.0281	0.0003	0.00005	0.0025	0.0016	0.114	0.913	0.356	0.0038
CO	0.0102	0.0182	0.0061	0.0049	0.0084	0.009	0.0685	0.0383	0.039	0.0051
CR	0.064	0.037	0.023	0.037	0.013	0.163	1.57	0.1	0.134	0.094
CS	0.0721	0.0581	0.037	0.0719	0.0362	0.0442	0.0734	0.116	0.064	0.0604
CU	76.7	67.2	36.3	30.4	54.4	33.5	7.81	4.26	8.38	24.3
FE	508	484	153	275	482	349	493	1170	747	357
GA	0.0008	0.0014	0.0008	0.0006	0.0006	0.002	0.0319	0.0026	0.0032	0.001
LA	0.0012	0.0012	0.00005	0.00005	0.00005	0.0022	0.0779	0.0689	0.0142	0.00005
LI	0.01	0.01	0.005	0.01	0.005	0.005	0.07	0.01	0.01	0.005
MN	1.16	1.49	5.81	2.04	1	3.44	4.73	3.56	2.84	1.85
MO	0.034	0.052	0.024	0.034	0.04	0.047	0.554	1.39	1.31	0.046
NI	0.116	0.039	0.053	0.019	0.021	0.053	0.795	0.041	0.051	0.034
PB	0.083	0.032	0.086	0.006	0.01	0.025	0.181	0.241	0.126	0.086
PT	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
RB	8.67	6.93	3.88	7.34	5.65	5.4	7.38	8.12	6.38	7.85
SB	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.007	0.005	0.002	0.0005
SE	1.08	1.17	1.1	1.14	0.74	0.71	1.71	22.3	1.45	0.58
SN	0.17	0.02	0.06	0.01	0.02	0.02	0.07	0.08	0.03	0.06
SR	0.021	0.177	0.729	0.46	0.015	0.136	0.179	0.108	0.055	0.017
TL	0.0407	0.0852	0.0427	0.034	0.0198	0.0253	0.0029	0.0056	0.0058	0.0273
U	0.00005	0.00005	0.0121	0.00005	0.00005	0.0009	0.0047	0.0003	0.0001	0.00005
V	0.004	0.006	0.004	0.002	0.001	0.008	0.207	0.055	0.04	0.002
ZN	28.2	63.5	40.5	31.1	42	83.1	61	56.3	70.8	72.5
PD	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
K	2390	2600	1200	2710	2220	2050	2580	2620	2640	2580
HG	1.16	1.38	1.07	1.2	1.04	1.15	2.39	67.4	3.57	0.707

Appendix 1 Metal Content of Dolphin Kidneys (k) and Muscle (m) (mg/kg)

element	10K	11K	13K	14K	15K	6K	8K	9K	15M	16M
AG	0.0005	0.0028	0.0037	0.0019	0.0003	0.0233	0.0131	0.0029	0.0012	0.0002
AL	4.93	13.9	2.07	0.37	1.37	8.06	14.5	1.26	3.83	1.25
AS	0.012	0.019	0.076	0.006	0.002	0.105	0.172	0.006	0.023	0.003
BA	0.027	0.179	0.307	0.041	0.0025	0.026	0.158	0.0025	0.023	0.0025
BE	0.00005	0.0002	0.00005	0.00005	0.00005	0.0001	0.0009	0.00005	0.0023	0.00005
BI	0.0003	0.0015	0.0011	0.0007	0.0006	0.0047	0.0068	0.0005	0.00005	0.00005
CD	0.0092	0.0114	0.0016	0.00005	0.00005	2.69	4.56	0.0085	0.0005	0.0027
CO	0.0072	0.0184	0.0066	0.0035	0.0068	0.105	0.142	0.0061	0.0025	0.0034
CR	0.035	0.035	0.024	0.05	0.031	0.057	0.089	0.067	0.094	0.034
CS	0.109	0.0672	0.0313	0.0914	0.054	0.05	0.0813	0.0883	0.0221	0.0962
CU	3.49	6.32	3.79	3.07	3.59	5.38	8.82	8.98	0.59	2.31
FE	224	245	130	118	150	255	201	176	67.7	102
GA	0.0012	0.0033	0.0006	0.0003	0.0003	0.0017	0.0084	0.0008	0.0006	0.0008
LA	0.0035	0.0051	0.0002	0.00005	0.00005	0.0015	0.0316	0.00005	0.0014	0.00005
LI	0.005	0.01	0.005	0.01	0.005	0.01	0.02	0.005	0.005	0.005
MN	0.869	1.46	5.41	0.801	0.702	1.41	2.42	0.658	0.184	0.33
MO	0.027	0.039	0.025	0.024	0.024	0.091	0.14	0.031	0.013	0.004
NI	0.131	0.097	0.011	0.018	0.048	0.02	0.078	0.259	0.055	0.04
PB	0.042	0.04	0.015	0.003	0.004	0.044	0.052	0.025	0.015	0.002
PT	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
RB	10.4	7.37	2.74	7.68	7.01	7.05	7.21	8.98	2.55	7.4
SB	0.001	0.0005	0.002	0.0005	0.0005	0.001	0.002	0.003	0.0005	0.0005
SE	0.7	0.89	0.59	0.77	0.58	4.32	4.98	0.51	0.1	0.3
SN	0.04	0.02	0.01	0.005	0.02	0.03	0.1	0.03	0.02	0.01
SR	0.022	0.484	0.592	0.485	0.03	0.316	0.176	0.034	0.055	0.009
TL	0.0574	0.0893	0.109	0.0745	0.0213	0.028	0.0174	0.0591	0.0066	0.0458
U	0.00005	0.0004	0.0101	0.00005	0.00005	0.0001	0.0021	0.0002	0.00005	0.00005
V	0.007	0.023	0.004	0.001	0.001	0.02	0.067	0.002	0.011	0.001
ZN	24.9	46	32.9	27.2	24.1	35.9	69	28.7	8.66	47.4
PD	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
K	2720	2760	926	2960	2650	2310	3120	3060	1070	3170
HG	0.417	0.441	0.508	0.417	0.253	6.36	9.21	0.4	0.343	0.515

Appendix 2 Mercury in Fish, Kratie Area

Mean Hg (ng/g)	length (cm)	Weight (g)	Khmer Name
	Trib. 8 km N. of Kampi		
200	41.5	3480	Keschumrov
156	36.9	2355	Keschumrov
69	33.5	402	Knrak
91	6.8	<10	Kombutchrormos
36	6.8	<10	Kombutchrormos
39	6.9	<10	Kombutchrormos
88	4.5	<10	Kaeth
111	4	<10	Kaeth
120	3	<10	Kaeth
35	2.5	<10	Kaeth kmao
55	2.6	<10	Kaeth kmao
26	2.7	<10	Kaeth kmao
63	4.5	<10	Chorngva ampov
79	4.5	<10	Chorngva ampov
105	4.3	<10	Chorngva ampov
120	4.5	<10	Kagnchagn chras
102	4.5	<10	Kagnchagn chras
55	5	<10	Kagnchagn chras
40	4.8	<10	Srokakdam kontuyloeung
59	4	<10	Srokakdam kontuyloeung
48	3.6	<10	Srokakdam kontuyloeung
37	4	<10	Changva phleng
46	4.2	<10	Changva phleng
45	4	<10	Changva phleng
189	7	<10	Trey khmang
147	5	<10	Trey khmang
176	4	<10	Trey khmang
56	6.5	<10	Srorka kdam
72	6.5	<10	Srorka kdam
80	6	<10	Srorka kdam
23	14	<10	Koun proum
51	13	<10	Koun proum
23	14	<10	Koun proum
62	6.6	<10	Trey kontrorb
103	6.5	<10	Trey kontrorb
91	6.4	<10	Trey kontrorb
73	13.4	<10	Bondoul chek
62	13.2	<10	Bondoul chek
123	12.5	<10	Bondoul chek
247	17	<10	Phtoung
261	17.2	<10	Unknown
37	15	<10	Kachoeng
39	15.5	<10	Kachoeng
49	17	<10	Kachoeng

Average Hg (ng/g)	length (cm)	Weight (g)	Khmer Name
144	9.5	<10	Chhkegn
84	8	<10	Chhkegn
80	16	<10	Chhlougn
84	17	<10	Chhlougn
49	17	<10	Chhlougn
85	9.2	<10	Ach kok
97	25.5	223	Trey kaek
177	26	182	Chhlang
109	40	600	Khaya
72	32	260	Khaya
65	26	155	Khaya
250	5.8	<10	Changva pleng
41	7	<10	Kombutchrormos
67	7.8	<10	Kombutchrormos
61	8.8	<10	Kombutchrormos
188	16	110	Trey kompot
	Main River at Kampi		
39	15/6	<10	Koun proum
46	12 or 6	<10	Koun proum
17	13/6	<10	Koun proum
62	4.5	<10	Kognchagnchras
196	4.5	<10	Kognchagnchras
60	4	<10	Kognchagnchras
44	6.3	<10	Trey kragn
54	6.8	<10	Trey kragn
75	5.8	<10	Trey kragn
129	6.6	<10	Unknown
92	12	<10	Bondoul chek
85	11.9	<10	Bondoul chek
92	11.3	<10	Bondoul chek
104	8.8	<10	Changva moul
173	7.4	<10	Changva moul
327	5	<10	Changva moul
121	9.9	<10	Achkok
52	9.3	<10	Achkok
155	10	<10	Achkok
8	7	<10	Kompliegnphloeung
57	8	<10	Kampliegn
73	6.8	<10	Kampliegn
44	6.8	<10	Kampliegn
175	17	<10	Trey kachoeng
27	11.5	<10	Trey kachoeng
28	7.6	<10	Trey kachoeng
244	17.4	<10	Trey phtoung
64	5	<10	Unknown
196	7	<10	Unknown

Average Hg (ng/g)	length (cm)	Weight (g)	Khmer Name
47	4.5	<10	Kroem tonsay
103	13	<10	Phtouk
50	15	<10	Chhlougn
46	14	<10	Chhlougn
67	14	<10	Chhlougn
65	19	95	Trey trorsok
38	19.2	97	Trey trorsok
146	15.6	95	Trey kontrorb
148	11.2	20	Trey kontrorb
164	9.2	10	Trey kontrorb
24	20.5	105	Trey chhkork
115	16	43	Unknown
78	5.6	<10	Unknown
58	21	140	Sombork srorlao
53	19	85	Sombork srorlao
245	24.5	362	Trey kmann
62	27	102	Trey khey
52	26	102	Trey khey
82	23	65	Trey khey
306	13.8	105	Trey kompot
259	12	<10	Khtes dangkhteng
66	12.5	<10	Trey komphlav
26	10.5	<10	Trey ka he
36	14.5	<10	Trey chvat
74	13.5	<10	Kogn chus kdorng
94	18	65	Trey chektoum
229	26.5	95	Trey kes prak
116	19.7	63	Kognchus tmor
34	20	63	Trey brorma
28	25	225	Trey chhpen
77	18.7	88	Trey legn
39	20.5	105	Trey chektoum
83	20	160	Unknown
8	20/52	180	Lobster
13	19/46	182	Lobster
193	34	495	Trey ptuk
110	42	1160	Trey pour
69	55	1640	Trey ker
254	58	1555	Trey nel
153	40	663	Trey krorbey

Average Hg (ng/g)	length (cm)	Weight (g)	Khmer Name
	Tributary entering at Kampi		
83	13.3	<10	Trey ta on
83	9	<10	Sloek rousey
24p	8.5	<10	Trey chveat
60	6.8	<10	Trey kontrorb
113	12.8	<10	Trey korgn chus chor
642	19.3	60	Unknown
86	12.8	<10	Unknown
59	13.1	<10	Trey kruos
59	11	<10	Unknown
51	10.5	<10	Unknown
32	18.5	62	Unknown
214	15	40	Trey rieltouch
153	26	65	Trey kachoeng
60	24.5	120	Trey brakondor
59	27	60	Unknown
487	18.7	225	Trey kompot
338	19.8	155	Trey chhkegn
49	24	258	Sombork srorlao
42	27	303	Trey kaek
130	31	462	Trey kaya
110	17.5	43	Unknown
24	12.9	<10	Riel
29	13	<10	Riel
55	10	<10	Sloek rousey
140	10	<10	Sloek rousey
229	9.8	<10	Sloek rousey
17	14.8	46	Unknown
19	8.2	<10	Kombutchrormus
117	8	<10	Chorngva moul
91	8	<10	Bondoul chek
67	13	<10	Unknown

Appendix 3 Mekong River Kratie Region Sediment Samples (ng/g)

Kratie Region	Mercury ng/g (ppb)			
Site	Average	StDev	Sample Description	GPS
KDP1-6m (ponar)	12.1	0.98	Sandy, heterogeneous	12º 36.348N, 106º 01.213E
KDP2-4.5m (core)	14.1	0.45	Sandy, heterogeneous	12º 36.398N, 106º 01.281E
KDP3-2cm (core)	49.5	0.43	Brown, fine particles. Low density.	12º 36.978N, 106º 01.253E
KDP3-4cm (core)	53.3	0.47	Brown, fine particles. Low density.	12º 36.978N, 106º 01.253E
KDP3-6cm (core)	44.5	0.15	Brown, fine particles. Low density.	12º 36.978N, 106º 01.253E
KDP3-14cm (core)	2.0	0.12	Sandy, fine particles	12º 36.978N, 106º 01.253E
KDP3-8cm (core)	153.1	5.40	Brown, fine particles. Low density.	12º 36.978N, 106º 01.253E
KDP3-10cm (core)	174.6	1.98	Brown, fine particles. Low density.	12º 36.978N, 106º 01.253E
KDP3-12cm (core)	131.5	1.59	Brown, fine particles. Low density.	12º 36.978N, 106º 01.253E
Trib1 (grab)	65.2	2.57	Reddish sand with some pebbles	12º 50.195N, 106º 10.765E
Trib2 (grab)	134.6	3.27	Fine, grey brown with organics	12º 50.251N, 106º 10.721E
Trib3-2cm (core)	52.6	4.83	Reddish fine with coarse pebbles	12º 50.251N, 106º 10.721E
2Trib (grab)	144.7	2.82	Pale brown, fine with some organics	12º 45.447N, 106º 09.519E
Kopla 18m (ponar)	15.5	0.95	Fine, sandy particles	12º 49.743N, 105º 56.489E
Achen 4 cm (core)	96.3	0.95	Mostly fine, red-brown + organics	12º 52.608N, 105º 56.310E
Achen 2 cm (core)	109.6	0.26	Mostly fine, red-brown + organics	12º 52.608N, 105º 56.310E
Sambo 2m (ponar)	1.2	0.10	Coarse pebbles	12º 46.649N, 105º 57.433E
Buffalo River CRM	1480.7	19.91	Actual = 1.44 ug/g (+/- 0.07 ug/g)	
Dogfish CRM	4693.6	0.00	Actual = 4.64 ug/g (+/- 0.26 ug/g)	
Est. Sed CRM	72.1	0.00	Actual = 0.063 ug/g (+/- 0.012ug/g)	
Blank	0.88	0.00	Deionized water	

KDP = Kampi dolphin pool CRM - certified reference material
Est. Sed. CRM = Estuarine Sediment CRM, Trib = Tributary
All samples freeze dried and homogenized with mortar and pestle prior to analysis

Appendix 4 Metals in Sediments in Kratie Area (mg/kg)

Metal	KDP1-6M	KDP2-4.5M	KDP3-2CM	KDP3-4CM	KDP3-6CM	KDP3-14CM
As	6	7	9	9	7	1
Be	0.40	0.66	2.15	2.32	2.07	0.21
Bi	0.1	0.2	0.5	0.5	0.4	< 0.1
Cd	< 0.1	0.1	0.1	0.1	0.3	< 0.1
Co	6.0	7.9	24.5	23.2	21.4	2.1
Ga	2.82	4.45	19.4	19.3	17.0	1.76
La	28.3	23.8	39.5	40.0	40.8	3.99
I	9.6	14.5	40.7	40.9	33.6	1.9
Mo	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Ni	11.9	16.0	34.3	33.8	27.7	2.0
Pb	12.6	11.2	24.8	25.3	21.6	2.4
Rb	13.1	23.7	86.1	89.8	74.4	6.9
Sb	0.3	0.4	0.1	0.1	0.1	< 0.1
Tl	0.081	0.144	0.499	0.535	0.420	0.037
U	1.07	1.09	2.25	2.71	2.36	0.32
Al	8240	13700	77100	72600	63300	4950
Ba	40	62	309	300	264	20
Cr	19	23	58	58	49	7
Cu	6	8	40	38	34	2
Fe	15500	16900	49900	44800	39800	4510
Mn	170	219	1380	1190	980	97
Pb	221	245	620	582	494	49
Sr	16	18	58	58	61	20
V	25	27	101	94	85	13
Zn	28	38	93	86	74	6
Ca	1440	1890	5520	5180	5810	1270
Mg	2220	3290	7230	6930	6220	427
Na	< 500	< 500	< 500	544	< 500	< 500
K	1670	2900	9590	10700	8500	887
Hg	**0.020**	**0.026**	**0.065**	**0.068**	**0.056**	**0.024**

See Appendix 3 for GPS locations of these samples.

Appendix 5 Mercury in Human Hair

Sites impacted by Hg Amalgamation			Control Sites Removed from Hg Amalgamation		
Near Gold Mines - Tonle Srepok			Control 1 Mekong N Steung Treng		
Hg ppb	Sex	age	Hg ppb	Sex	Age
3290	male	12	5534	male	30
4436	male	14	2407	female	28
2807	male	17	2532	female	70
2516	female	48	3126	female	10
2016	female	45	3545	female	7
2992	male	5	2749	female	8
2911	female	14	3638	male	18
3888	female	13	4916	male	22
3665	female	45	4586	male	22
5224	male	23	2676	female	56
23195	male	22	1429	female	53
4211	male	15	2013	male	20
6180	female	12	2962	female	23
5158	female	4	3790	female	17
3170	female	25	3127	female	17
3128	male	39	4689	female	25
2619	female	25			
3776	female	30			
4096	male	8			
6416	male	35	Control 2 Mekong at Kampi		
3707	female	7	1577	male	34
3598	male	39	2003	female	28
5748	male	59	1817	female	10
1897	female	61	1775	female	7
2834	female	57	3510	female	7
			2384	female	12
Tributary of Gold Mines, Tonle San			2966	female	10
4242	male	12	1863	female	33
4091	female	5	1593	female	60
3524	female	33	1974	female	17
4218	female	35	3996	female	27
5178	female	25	1665	female	77
3538	male	32	3510	female	20
4783	male	36	4032	male	42
6038	male	25	4147	male	15
8476	male	40	5799	male	14
3041	male	22	6187	male	14
3877	female	20	5843	male	30
6209	male	35	5910	male	30
3089	female	8	6914	male	21
4407	female	6			
1579	female	12			
2626	female	12			
2812	female	70			

Appendix 5 continued

Yaba users			Goldsmiths	
Average	Stdev		Average	Stdev
4656	560		1600	7
1248	5		4233	36
1048	2		2088	47
1892	60		12040	723
1004	19			
4547	5		O Tron miners	
1872	64		4890	56
1226	16		2790	207
1615	16		1110	13
1251	31			
2391	139		Canadian lab worker	
1981	67		208	
1577	58			
1611	64			
3066	44			
791	4			
2473	6			
1389	45			
3134	6			
2260	54			
1444	13			
1462	22			
3236	1			
1322	2			
1244	37			
1661	50			
1057	22			
1590	56			

Appendix 6 Trees cores Lake Yaklom, Ratanakirri, Collected July 25, 2005

Vitex pubescens		
hard, dry, 98 mm long		
cut into 10 mm sections (except Section 0=8 mm)		
Sample	Mass (g)	ng Hg /g
C3-0	0.0743	6.5
C3-1	0.2303	37.5
C3-2	0.2457	43.3
C3-3	0.2280	29.5
C3-4	0.2133	20.0
C3-5	0.2059	13.1
C3-6	0.2432	14.5
C3-7	0.1584	12.9
C3-8	0.1518	6.5
C3-9	0.2498	8.1
Blank Average		0.4
NIST 1571		146.0
Lagerstroemia sp.		
very hard, dry, 118 mm long		
cut into 15 mm sections (except Section 0=13 mm)		
Sample	Mass (g)	ng Hg /g
C4-0	0.1157	7.5
C4-1	0.2012	23.2
C4-2	0.2275	69.9
C4-3	0.2583	65.3
C4-4	0.2552	41.3
C4-5	0.2648	22.2
C4-6	0.3601	8.7
C4-7	0.1534	3.8
Blank		0.5
NIST 1571 Average		130.3

Appendix 6 continued, Tree cores from Lake Yaklom, Ratanakirri, July 25, 2005

Eugenia multibracteolata		
very hard, dry, 110 mm long		
Sample	Mass (g)	ng Hg /g
C5-0	0.1117	10.9
C5-1	0.1685	86.8
C5-2	0.1578	129.0
C5-3	0.2146	130.8
C5-4	0.2205	102.8
C5-5	0.2241	134.6
C5-6	0.1595	113.8
C5-7	0.1655	58.6
C5-8	0.1483	3.4
C5-9	0.1287	0.5
C5-10	0.2685	8.3
Blank Average		1.0
NIST 1571		141.2

Section 0 and sometimes Section 1 contains tree bark.
CRM: Orchard Leaves (NIST 1571, 0.155+/- 0.015 ug/g Hg)
Blank: Deionized water
All samples from outside to inside

Appendix 6 continued Tree Cores from Phnom Tamao, Collected September 6, 2005

Peltophorum dasyrrhachis				
Sample	mass (g)	Length (mm)	Accum. Length (cm)	Hg (ng/g)
Slice1	0.1204	5	0.5	1.7
Slice2	0.1303	5	1	1.4
Slice3	0.1152	5	1.5	1.41
Slice4	0.1032	4.5	1.95	1.97
Slice5	0.1035	4.5	2.4	1.18
Slice6	0.1147	4.5	2.85	1.11
Slice7	0.1193	4.5	3.3	1.39
Slice8	0.121	5	3.8	1.51
Slice9	0.1209	5	4.3	1.19
Slice10	0.1193	4.5	4.75	1.01
Slice11	0.1205	5	5.25	1.34
Slice12	0.1113	4.5	5.7	1.09
Slice13	0.1128	4.5	6.15	1.44
Slice14	0.1244	5	6.65	1.14
Slice15	0.1212	5	7.15	1.45
Slice16	0.1166	4.5	7.6	1.4
Slice17	0.1087	4	8	1.68
Slice18	0.1098	4.5	8.45	
Slice19	0.2193	7	9.15	3.5
Slice20	0.2036	7	9.85	17.88
Slice21	0.2375	7.5	10.6	6.03
Slice22	0.1991	6.5	11.25	2.97
Slice23	0.1909	6.5	11.9	1.11
Slice24	0.1896	6.5	12.55	0.78
Slice25	0.2173	7	13.25	0.89
Slice26	0.1931	6.5	13.9	0.44
Slice27	0.2024	7	14.6	0.58
Slice28	0.1589	6	15.2	0.56
Orchard leaf standard	0.0943			139.31
Blank average	0.26			0.26

Appendix 6 continued Tree Core from Phnom Tamao collected September 6, 2005

Pahudia cochinchinensis				
Sample	Mass (g)	Length (mm)	Accum. Length (cm)	Hg ng/g
Slice1	0.1063	4	0.4	2.16
Slice2	0.1216	4.5	0.8	1.88
Slice3	0.1131	4.5	1.25	1.84
Slice4	0.1053	4	1.7	2.35
Slice5	0.1033	4	2.1	1.61
Slice6	0.0946	4	2.5	1.76
Slice7	0.0893	4	2.9	1.63
Slice8	0.0813	3.5	3.3	2.37
Slice9	0.1064	4	3.65	1.77
Slice10	0.1328	5.5	4.05	2.04
Slice11	0.1199	5	4.6	1.38
Slice12	0.1406	6	5.1	1.78
Slice13	0.1322	5.5	5.7	1.73
Slice14	0.1031	4	6.25	1.42
Slice15	0.126	5.5	6.65	1.32
Slice16	0.2708	7.5	7.2	7.24
Slice17	0.2204	6.5	7.95	9.28
Slice18	0.2893	7.5	8.6	59.26
Slice19	0.2482	6.5	9.35	32.14
Slice20	0.2286	6.5	10	18.04
Slice21	0.2233	6.5	10.65	9.99
Slice22	0.2216	6.5	11.3	37.26
Slice23	0.221	6.5	11.95	24.03
Slice24	0.2122	6.5	12.6	16.54
Slice25	0.1818	6	13.25	1.7
Slice26	0.4232	15	13.85	22.22
Slice27	0.4152	15	15.35	90.38
Slice28	0.4022	14	16.85	60.61
Slice29	0.4227	15	18.25	85.44
Slice30	0.3778	13	19.75	44.14
Slice31	0.3173	10	21.05	58.12
Orchard Leaf standard	0.0922			142.92
Blank average	0.122			0.122

Appendix 6 continued Tree Core from Phnom Tamao collected September 6, 2005

Albizia saman				
Sample	Mass (g)	Length (mm)	Accum. Length (cm)	Hg (ng/g)
Slice1	0.0742	3.5	0.35	0.295
Slice2	0.0622	3.5	0.7	4.37
Slice3	0.1025	4	1.1	1.57
Slice4	0.0993	4	1.5	2.05
Slice5	0.0927	4	1.9	0.61
Slice6	0.1016	4	2.3	1.03
Slice7	0.1236	5	2.8	1.27
Slice8	0.105	4	3.2	1.24
Slice9	0.1115	4.5	3.65	1.17
Slice10	0.1233	5	4.15	0.84
Slice11	0.1274	5	4.65	0.81
Slice12	0.1039	4	5.05	0.99
Slice13	0.1206	5	5.55	0.91
Slice14	0.1266	5	6.05	0.81
Slice15	0.2867	8	6.85	53.15
Slice16	0.2514	7.5	7.6	8.87
Slice17	0.2498	7.5	8.35	19.39
Slice18	0.2436	7.5	9.1	17.62
Slice19	0.2276	7	9.8	8.51
Slice20	0.2145	7	10.5	1.67
Slice21	0.2193	7	11.2	0.8
Slice22	0.4292	16	12.8	88.86
Slice23	0.3988	16	14.4	121.82
Slice24	0.4138	16	16	120.86
Slice25	0.3972	16	17.6	135.82
Slice26	0.2481	7	18.3	136.56
Orchard leaf standard	0.0951			143.32
Blank average	0.18			0.18

Appendix 6 continued Long Cores, Lake Yaklom, collected March 6, 2006

Vitex pubescens	
Sample	ng Hg /g
C4-0	1.83
C4-1	29.99
C4-2	134.33
C4-3	105.93
C4-4	139.8
C4-5	97.81
C4-6	154.01
C4-7	119.6
C4-8	66.14
C4-9	196.69
C4-10	120.94
C4-11	168.78
C4-12	116.1
C4-13	115.08
C4-14	99.11
C4-15	137.01
C4-16	99.11
C4-17	137.01
C4-18	99.28
C4-19	83.65
Orchard Lead Standard	140.78
Blank Average	0.46

1 cm long sections

Appendix 6 continued, continued Long Cores, Lake Yaklom, collected March 6, 2006

Eugenia multibracteolata	
Sample	ng Hg /g
C5-0	1.33
C5-1	1.12
C5-2	2.69
C5-3	38.11
C5-4	41.67
C5-5	17.98
C5-6	41.25
C5-7	135.31
C5-8	23.76
C5-9	104.21
C5-10	29.21
C5-11	26.51
C5-12	55.9
C5-13	94.32
C5-14	100.96
C5-15	85.91
C5-16	22.94
C5-17	1.61
C5-18	7.94
C5-19	26.43
C5-20	71.3
C5-21	30.23
C5-22	43.61
C5-23	36.6
C5-24	11.02
C5-25	117.3
C5-26	42.45
Orchard Leave	151.45
Blank	0.12

1 cm long sections

Appendix 6 continued, continued Long Cores, Lake Yaklom, collected March 6, 2006

Lagerstroemia sp

Sample	ng Hg /g
C6-0	0.75
C6-1	31.67
C6-2	0.83
C6-3	70.5
C6-4	54.82
C6-5	88.4
C6-6	93.64
C6-7	15.99
C6-8	5.05
C6-9	10.51
C6-10	4.84
C6-11	0.94
C6-12	1.12
C6-13	3.89
C6-14	1.4
C6-15	200.12
Orchard leave standard	151.51
Blank	0.33

1 cm long sections