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Mercury Contamination along the Mekong River, Cambodia

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Abstract: Sampling and analysis of mercury was conducted along the Mekong River from central to northern Cambodia. One of 10 Irrawaddy Dolphin livers analyzed had a high concentration of mercury (67 µg/g). The mercury content of fish at Kratie was on average 99 ng/g (n=160) but in some species it was up to six-fold higher. People located in a sample drainage basin with gold mines, on average, had more mercury in their hair (4.4 µg/g) than those living along the northern portion of the Mekong River (3.4 µg/g). Males, on average, exhibited higher mercury in their hair than women (5.2 vs 3.1 µg/g, respectively). Individuals had as much as 23 µg/g of mercury in their hair. While mercury levels in hair and fish were elevated and gold mines were one source, there are other unknown sources and further analysis is required to determine what sources of mercury are manageable in Cambodia.

Key words: Mercury, hair, fish, gold mining, hydropower, Mekong River, Cambodia.

Introduction

The Mekong River is one of the major rivers of the world, stretching somewhere between 4,000 and 4,800 km (depending on the reference used) from its headwaters in the Tibetan Plateau to the South China Sea (Baran, 2005; Mekong River Commission (MRC), 2005). Providing habitat for up to 1200 fish species, the river ranks third (behind the Amazon and Zaire rivers) in terms of species richness and is home to 57 globally threatened fish species, including the endangered *Tenualosa thibaudeaui* (freshwater herring), *Pangasius gigas* (Mekong giant catfish, which can reach lengths of 3 m), and *Orcaella brevirostris* (Irrawaddy dolphin) (Dudgeon, 2000; Tarr, 2003; Beasley et al., 2007). Tarr (2003) noted that Cambodia ranked fourth among the world's top freshwater capture fisheries, with fish providing up to 75% of all animal protein for rural Cambodians, much on the strength of the Mekong River and its tributaries (including the Tonle Sap Lake). Baran et al. (2007) reported the estimated value of the inland fisheries for the Lower Mekong Basin countries of Cambodia, Lao PDR, Thailand, and Vietnam, as being in the range of $1478 to $2000 million per year, but the inland fisheries sector remains poorly represented in national plans and priorities. Although the Mekong River is a central component of life for millions of people, Osborne (2000) suggested that surprisingly little is known about the river as compared to other great rivers, such as the Nile or Amazon.

The MRC (2003) indicated that until recently, the Mekong Basin's waters and related resources have been largely undeveloped, but with increasing population and goals to reduce poverty, the pace of development is increasing. Economic growth in Asia has been strong in

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recent years. For 2006, the Asian Development Bank reported economic growth of 7.1% and in September, 2007, revised growth projections to 8.3% for 2007 (e.g. http://www.adb.org/Media/Articles/2007/12156-asian-developments-outlooks/default.asp). An important element in this economic growth is the increasing demand for electricity and as such there has been a great deal of interest in developing hydropower capacity on the Mekong River and its tributaries (Yu, 2003; MRC, 2003; Sangha and Bunnarith, 2007; Greacen and Paletta, 2007; Mehtonen, 2008). The MRC (2003) estimated a potential of 30,000 mW of hydro capacity feasible for the Lower Mekong Basin, 13,000 mW of which are on the mainstream of the Mekong River and the remainder on tributaries. Furthermore, the MRC (2003) estimated that there is an additional 23,000 mW of potential in the Upper Mekong Basin (Yunnan Province, China). Already, China has completed two of six planned dams as part of a so-called "cascading system" with the two projects having an installed capacity of 2850 mW.

Although it is generally believed that dams negatively impact fisheries and biodiversity, there still is a great deal of uncertainty about the extent of the potential impacts on the Mekong system (Dudgeon, 2000; Koponen et al., 2005; Kummu and Varis, 2007; Lamberts, 2008; Xi Xi et al., 2008). One issue that has not been well addressed with respect to dam construction in the Mekong Basin is the possibility of increased mercury levels in fish. It has been well-documented that reservoir construction can elevate levels of mercury in fish through the release of natural and anthropogenic-sourced inorganic mercury from flooded vegetation and soils (e.g. Montgomery et al., 2000; Schetagne et al., 2000; Mailman et al., 2006).

The impetus for this study came in relation to the recent high mortality of the endangered Irrawaddy Dolphin in the Kratie area of the Mekong River. Recent surveys indicate about 127 dolphins remaining in the Cambodian Mekong system with a habitat range from approximately Kratie, Cambodia, north to the Khone Falls near the Lao PDR and Cambodia border (Beasley et al., 2007). Between 2001 and 2005, 48 dolphin carcasses were recovered and between 2005 and 2006 an additional 18 dolphins were found dead; 16 of these being dolphin calves. There was some concern that environmental contaminants, particularly mercury, may be playing a role in the calf mortality (Beasley et al., 2007). As part of the subsequent investigation, it was decided to conduct an exploratory examination of mercury along the Cambodian section of the Mekong River, particularly given the ongoing construction and potential for new construction of hydropower dams as well as the possibility that mercury contamination may be sourced at remote mines using mercury amalgamation to extract gold (Sotham, 2004).

Given the high level of fish consumption by Cambodians (Baran et al., 2007), bioaccumulation issues, potential for reservoir construction, and concern about mining activites, the objective of this study was to provide an exploratory assessment of mercury levels in humans, fish, river sediment, and mine tailings from selected areas, principally northward from Kratie along the Mekong River and tributaries. We are aware of only one other study that systematically examined mercury levels in humans and fish in Cambodia and this study focussed on the Phnom Penh and Kampong Som (Sihanoukville) areas (Agusa et al., 2005). The Sihanoukville samples were collected in response to the 1998 international incident in which waste industrial ash from Taiwan, having mercury concentrations in the range of 600 to 10,970 µg/g, were disposed off improperly with resulting health impacts (Hess and Frumkin, 2000).

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. In higher concentrations, mercury can delay speech and walking in young children and produce a syndrome resembling cerebral palsy. Higher concentrations in adults may produce tremors, deafness, and even death. 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, there was a small difference in mercury level in the hair of fertile males (3.9 µg/g) compared to subfertile males (4.5 µg/g) which was associated with eating sea fish high in mercury (Dickman et al., 1998; Dickman and Leung, 1998). Minamata disease associated with the consumption of mercury-contaminated fish and other seafood in Minamata, Japan, is probably the most thoroughly documented health situation (Harada, 1995).

Methods

Sampling

Samples of liver tissue from 10 calf and adult dolphins 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 –60°C. Subsequently, a sampling campaign was conducted between December, 2004 and June, 2005, primarily from Kratie (Kampi Pool, an important habitat area for the dolphins) north and eastward into Ratanakirri Province (Figure 1).

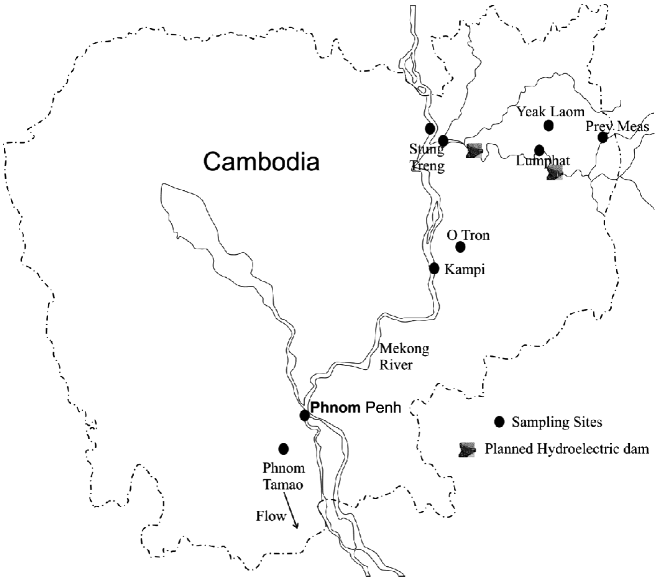

Figure 1: Mercury sampling sites.

Hair samples were collected from randomly selected participants, representing a range of ages, and immediately placed in individually-marked, clean polyethylene bags. The hair sampling focussed on populations around the O Tron gold mines (including mine workers) 45 km northeast of Kratie; mine workers in the Prey Meas area; rural populations living on the Srepok River near Lumphat; rural populations living on the Kong River, 2 km upstream of Stung Treng; rural populations living on the Mekong River, 2 km upstream of Stung Treng; and on the Mekong River, 2 km upstream of Kratie. The hair of goldsmiths (*n*=9) working in a Phnom Penh market also was sampled. The hair was kept dry and delivered to the Environment Canada Laboratories in Burlington.

Fish samples were collected through on-site purchase from local fishermen at the Kampi Pool near Kratie; 3 km up the tributary entering the Kampi Pool; and 3 km upstream on a small tributary 8 km north of the Kampi Pool. Pieces of muscle tissue were cut from the fish in the field and stored in 20 ml scintillation vials. The fish were kept on ice and couriered from Phnom Penh to the Environment Canada Laboratories in Burlington. Fish also were collected at the Srepok, Kong, and Mekong River sites near Stung Treng, but were spoiled because of shipping difficulties, an issue that always presents a challenge when working in remote sites.

Mine tailing samples were collected from the O Tron gold mines at the same time that hair samples were collected. Surface sediment samples were collected from the Kampi Pool using an Ekman dredge. In both cases, the samples were placed in clean, polyethylene bags and couriered from Phnom Penh to the Environment Canada Laboratories in Burlington. At the Environment Canada Laboratories, the samples were freeze dried and homogenized with mortar and pestle prior to analysis.

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.

Two types of certified reference materials (CRM) were used for each set of analyses: (i) DORM-1 (Dogfish), used for fish, dolphin, and snail (animal tissue type of samples) from Institute for Environmental Chemistry, Ottawa, for bio samples and (ii) River Sediment 1645, US Dept. of Commerce, National Bureau of Standards, Washington DC. 20234, used for sediment and gold mine tailings. Results always were within the standard deviation of the CRM (Table 1). Relative standard deviations typically were around 3%. Blanks were run for each set of analyses and were less than 1% of samples. All sediment and fish samples analyzed using the DMA 80 system were done in triplicate. 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 used a microwave digestion followed by ICP-SFMS analysis (NLET method 02-2705).

Table 1: Certified reference materials (μg/g)

	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

Results

The results of mercury analysis in dolphin tissue were similar for the DMA 80 system and from the NLET Laboratory (Table 2). One liver sample contained much more mercury than the rest and results were off-scale in the direct total analyzer (>50 μg/g) and measured as 67 μg/g by NLET.

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

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

NLET is Environment Canada's National Laboratory for Environmental Testing

A total of 82 species of fish were collected from the two tributaries and the main river at Kratie and unfortunately only one specie was collected in triplicate from each of the three sites, which does not facilitate between site or between species comparisons. The mercury content of fish (*n*=160) for all three sites combined in the Kratie area on average was 99 ng/g, with a standard deviation of 86 ng/g and a range of 8 to 642 ng/g. The differences between the three sampling sites was modest and any quantitative analysis was compromised by different species at the different sites. The fish in the tributary entering at the Kampi Pool had a mean of 120 ng/g (*n*=31). The fish in the tributary 8 km north of the Kampi Pool had a mean of 91 ng/g (*n*=60) and the fish in the main river had a mean of 98 ng/g (*n*=69). One possible way of assessing mercury levels is according to the size of the fish and as such fish from the three sites were grouped according to "small size" (<10 g; *n*=109) and "large size" (>10 g; *n*=51). Recognizing the complications introduced by mixing species, a non-pooled Student t-test was nonetheless applied, and the mean mercury concentration of the "large size" fish (128 ng/g) was significantly greater than the mean of the "small size" fish (86 ng/g).

Both mine sites at O Tron were quite small; the volume of mine tailings at the larger mine was approximately 200 m^3 and at the smaller mine was about 1 m^3. There is some mercury at the O Tron mines, but no samples approached an industrial standard for mercury contamination (Table 3). A typical definition of contaminated soil with an industrial standard is 10 μg/g [http://wlapwww.gov.bc.ca/epd/epdpa/contam_sites/legal_decisions/orders/CanOxy/os16 149_reasons.html]. Sotham (2004) reported that the miners at O Tron did not use mercury to extract gold but the tailings contain some mercury and possibly small amounts of mercury were used in the past.

The mercury content of sediment samples collected around the Kampi Pool contained low levels of mercury (< 64 ng/g). Dilution by sand may override any mine effluent signal.

Levels of mercury in hair samples are summarized in Table 4 and there is a significant pattern suggesting that the gold mines in Ratanakirri are a source of mercury impacting people. An exploratory investigation of the mercury data from the hair samples was conducted using a difference of means approach. Based on the results of the F-test for variances, either a pooled or non-pooled form of the Student t-test was applied to the difference of means. Results of this analysis showed that the mean level of mercury in hair from men (*n*=32) was significantly greater (α=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 (α=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 mercury in their hair than the <12 or 17-30 age groups.

The hair analysis done at the O Tron gold mines did not find mercury concentrations indicating use of mercury amalgamation. It supports the analysis of the tailings done at O Tron and the findings of Sotham (2004). The

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

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	Buffalo River 2704 Actual = 1.44 μg/g +/– 0.07 μg/g

The description is an observation not based on particle analysis.
CRM is certified reference material.

Table 4: Mercury in human hair (μg/g)

Site	*Mean Hg*	*Std. Dev.*	*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 Ratanakirri	3.47	1.12	23	
Women Mekong	2.70	0.87	23	
Other Khmers				
Goldsmiths	5.02	1.34	9	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., 2004
Amer. Children	0.22		838	Age <5 yr, McDowell et al., 2004
Hong Kong fertile men	3.9		42	Dickman et al., 1998, 1999
Hong Kong subfertile men	4.5		117	Dickman et al., 1998, 1999
Hong Kong Vegans	0.38		16	5 year no fish or meat, Dickman et al., 1998, 1999
Philippine gold mine all adults	0.99	1.6	163	Health impaired Akagi et al., 2000
Threshold for Minamata disease	50			Harada, 1995
Abnormal infantile development	10			Proposed Barbosa et al., 1995

sampling of goldsmiths in Phnom Penh found one person with elevated mercury in hair (12 μg/g) suggesting that mercury may be used for gold purification and that some goldsmiths can be exposed to toxic levels of mercury. Hair sampling of the miners at Prey Meas was limited and should be expanded in future efforts.

Discussion

While mercury was present in the O Tron mine tailings, the levels did not approach a high level of contamination and tailing volume was not extensive. In western countries, soil and sediment contamination associated with chlor-alkali plants, for example, may have mercury concentrations in the range of 200-1500 µg/g, with volumes exceeding two million cubic metres of material (Neculita et al., 2005; Lizlovs, 2005; Ullrich et al., 2007).

The risks presented by the mercury concentrations in fish at Kratie are uncertain. The mean mercury concentration of 99 ng/g would not require any restriction of fish consumption in Canada [http://www.ene.gov.on.ca/cons/590b12_intro.pdf] but 16 (of 160) 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). Health Canada's advisories suggest that 1.56 kg of the average fish in Kratie could be eaten safely in a week (Health Canada, 1984). Baran et al. (2007) reported the average weekly fish consumption in Cambodia to be approximately 1.26 kg. Those that eat more than the average amount of fish at the higher levels of mercury would be at greater risk of health impact. Although our sampling indicated that the larger fish generally have a higher mercury burden, similarly there is considerable variation between species, and size is not the only important variable. Some large fish species in the Mekong River are herbivores (Rainboth, 1996) but our larger fish were piscavores. More analysis is required before public notices could be prepared. Mercury levels in fish muscle from gold mining regions in Indonesia averaged 580 ng/g and 250 ng/g from the Tatelu and Galangan areas, respectively (Castilhos et al., 2006). The mining activity appears to be more intensive in this Indonesian example, as compared to the Cambodian study area. For example, there were 2000-3000 miners active in the Indonesian area of Galangan (Castilhos et al., 2006), while in the O Tron mine area of Cambodia about 330 miners were active and in the Prey Meas mine area the number of miners reached several hundred in peak season (Sotham, 2004).

The mercury content in human hair similarly reflects significant assimilation of mercury from fish consumption (e.g. Agusa et al., 2005). 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 compromised by the complexity of the fish communities. Forty-eight fish species were collected and the fish found at three sites usually were different. Mapping of the distribution of mercury in fish would be an exceptionally difficult task.

One dolphin was clearly exposed to more mercury than the other carcasses that were sampled. 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 area where we observed higher mercury in human hair. Ultimately, in examining all available data, Beasley et al. (2007) concluded that it was unlikely that dolphin mortality resulted from mercury toxicity.

Some individuals had as much as 23 µg/g Hg in their hair and while these concentrations are far from the extremes of Minamata disease (Harada, 1995) some exceeded levels known to impair infantile development (Barbosa et al., 1995). Piotrowski and Inskip (1981) reported that mercury in the hair of fish eating communities often was up to 5 µg/g, 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 (5.21 µg/g) from this survey (Table 4).

Mercury in our Cambodian hair sample was 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). Mercury levels in the Cambodian hair sample exceeded those observed near gold mines in the Philippines where authors associated impaired human health with mercury (Akagi et al., 2000). Dumont et al. (1998) reported that mercury levels in the hair of the Cree population that were impacted by eating contaminated fish from hydropower reservoirs in the James Bay region, Canada (constructed between the mid-1970's and mid-1980's), declined between 1988 and 1994. For example, in 1988, 38% of the sampled population had hair concentrations of ≤2.5 µg/g and 24% of the population was in the 2.6-5.9 µg/g range. Subsequent sampling showed 73% of the population had hair concentrations of ≤2.5 µg/g and 16% of the population was in the 2.6-5.9 µg/g range. This decrease was not attributed to declining concentrations in fish alone, but also the likelihood that there had been a shift in consumption patterns. The results from our Cambodian sample appear to be in the range of the arguably marginalized Cree population in northern Canada that has had a well-known problem with mercury contamination of fish.

Often, mercury levels are found to increase with population age (e.g. Dumont et al., 1998; McDowell et al., 2004) although Agusa et al. (2005) found the correlation to be weak in their Cambodian study. Interestingly, in our sample the oldest women's age group

(>50) in the control population had significantly lower levels of mercury in their hair than younger age groups. The reason for this result is unclear. It is conceivable that there has been a shift in diet over the past 30 years, but this would have to be confirmed by a more detailed study.

The most alarming concern with mercury and potential human health impacts in Cambodia is presented by Agusa et al. (2005), although the high levels were not associated with the population around Sihanoukville, as might be anticipated. The arithmetic mean level of mercury in hair samples (n=22) from Sihanoukville was 3.2 µg/g, with a range of 1.1 to 7.5 µg/g. The arithmetic mean level of mercury in hair samples from Phnom Penh (n=40) was 11 µg/g with a range of 0.54 to 190 µg/g and in the nearby district of Kean Svay the arithmetic mean was 8.2 µg/g with a range of 0.54 to 70 µg/g. Agusa et al. (2005) concluded that the extreme levels of mercury in Phnom Penh and Kean Svay could not be explained by intake from fish consumption, but also could not identify an alternative source. The levels of mercury from the Agusa et al. (2005) study are high enough to be associated with health impact.

There is a number of emerging water quality issues in Cambodia ranging from basic sanitation, to arsenic contamination in drinking water wells, to improper pesticide practice, to mercury contamination (e.g. Environmental Justice Foundation, 2002; Polya et al., 2005; Irvine et al., 2006; Feldman et al., 2007). Unfortunately, a great deal is still unknown about the country's environment and there is a need to build capacity for environmental investigations. The Mekong River Commission, for example, samples at 99 sites throughout the Lower Mekong Basin (Campbell, 2007) but only analyzes for conventional parameters (e.g. nutrients, suspended sediment) and on a monthly basis. This type of coarse time step makes it difficult to assess system dynamics and trends, and toxic contaminants typically are not considered.

The levels of mercury in fish and human hair, particularly along the Mekong River corridor, were sufficiently high that a more detailed assessment of source is needed. One of the difficulties in assessing current gold mining impacts in Cambodia is that the mines generally are small and remote; Sotham's 2004 study was the first reconnaissance survey of the gold mining situation in Cambodia. Sotham noted that gold mining activity was increasing, although still small by international standards, with an estimated 5000-6000 miners being employed country-wide at peak mining season. Another difficulty in assessing mining activities is safety; as Sotham noted, security from local armed forces was hired at each survey site.

It would be worthwhile to study several test areas in more detail. Areas along the Srepok and Sesan rivers in Ratanakirri province might be one possibility since hydropower reservoirs already have been constructed in this area and more are planned. The study should include more detailed tailings sampling, water and suspended sediment sampling in the river, more controlled fish sampling (using standardized fish species), and an expanded effort in hair sampling. In addition to fish, sessile aquatic organisms such as mollusks or prawns might be tested using a controlled, caged approach to minimize variability due to fish migration. Monirith et al. (2000) collected green mussels for organochlorine analysis in parts of Cambodia. Other mercury sources that should be quantified include foodstuffs in addition to fish, long range atmospheric loadings from combustion activities (thermal electric power production, vehicles, waste incineration) (UNEP, 2002), and even emissions due to deforestation (e.g. Veiga et al., 1994).

Once mercury sources are better understood in Cambodia, it will be possible to develop appropriate management strategies. Murphy et al. (2006), for example, conducted a pilot study to introduce simple, locally-made retorts to a gold mining community in the Prey Meas area that would recover the mercury and reduce the miner's exposure. Furthermore, it is important to recognize that hydropower development and reservoir construction is planned for some of the watersheds in which the mining areas are located. Boudou et al. (2005) reported a synergistic effect related to gold mining and reservoirs in the Amazon basin and as such, future hydropower development in Cambodia could exacerbate mercury contamination, particularly for poor, rural communities dependent on fishing.

Conclusion

Environmental contamination and associated health impacts due to mercury are now a global concern (UNEP, 2002). One source of mercury that recently has gained attention in developing regions is gold mining (Boudou et al., 2005; Castilhos et al., 2006). This exploratory study focussed on assessing mercury levels in Irrawaddy dolphins, fish, sediment, and human hair as possibly related to gold mine activities along tributaries to the Mekong River in Cambodia. Mercury levels in human hair and fish were elevated, although not to the extent that severe health impacts would be observed and a separate study by Agusa et al. (2005) actually reported higher mercury levels from hair samples in the Phnom Penh area. Additional sampling is needed to fully resolve the sources of mercury contamination and develop appropriate management strategies.

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