TOXIC HOT SPOTS IN THAILAND

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Toxic Hot Spots in Thailand

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Research reports based on sampling conducted in 2015–2017

Toxic Hot Spots in Thailand
Results of sampling conducted in 2015 – 2017

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Content

1. General introduction

1.1 INTRODUCTION

Thailand has undergone a major industrial and social transformation amid rapid economic growth and development for over half a century. It has successfully shifted its economy from agriculture to export-oriented manufacturing, while integrating key production, particularly automobiles and electronics, into regional value chains. Toxic pollution, as the other side of the industrialization, has also emerged in this second-largest economy in South-east Asia. Many fence line communities – nearly always marginalized and poor people – live in the vicinity of industrial factories and suffer from toxic pollution. This environmental justice problem has become an elephant in the room. Toxic pollution in the vicinity of industrial sites in Thailand is an obvious problem that no one in charge wants to discuss and effectively solve.

This series of six studies arose from the necessity to ignite a discussion about toxic pollution on several toxic hotspot areas in Thailand. Four studies are focused on the presentation and discussion of the data related to the contamination of soils and sediments, as well as the pollution of free-range chicken eggs, fish and other edible aquatic animals, such as molluscs and crustaceans. The first study concerns the contamination of various persistent organic pollutants in the environment in the four biggest hotspot areas. The second study is focused on the persistent organic pollutant contamination in free-range chicken eggs that were identified as the riskiest matrix in the inquired hotspot. The third study evaluates the impact of heavy metals on inhabitants and the environment on eight pollution hotspot areas. The fourth study is focused on mercury contamination of fish in the hotspot areas. Two additional studies are focused on air pollution by dioxins, dioxin-like PCBs and volatile organic compounds. Altogether, the studies cover important results of the toxic pollution measurement on various industrial sites in Thailand.

The data presented in the studies was obtained during sampling campaigns conducted in Thailand in February 2015, February and March 2016, and February 2017. The sampling campaigns represent an important part of the project "Increasing Transparency in Industrial Pollution Management through Citizen Science." This is a joint project of the Czech non-governmental organization, Arnika Association, and the Thai partner, Ecological Alert and Recovery – Thailand (EARTH). The main goals of the project are to increase the negotiating power of communities affected by industrial pollution in their demands for corporate and government accountability, and to increase transparency in industrial pollution management policies and processes in Thailand.

A selection of 10 hotspot areas was based on preliminary analyses, reports in literature, and personal experiences of members of the team from Ecological Alert and Recovery – Thailand (EARTH). There were hotspot areas with the metallurgical industry (Samut Sakhon and Khao Hin Sorn), gold mining (Loei), pulp and paper industry (Khon Kaen), petrochemical industry (Map Ta Phut and Rayong IRPC industrial zone), power generating (Tha Tum), cement kilns (Saraburi), waste incineration (Koh Samui) and a potentially contaminated site due to a landfill fire (Praeksa). Some hotspot areas like Map Ta Phut

or Tha Tum include more types of industries. Three sampling sites (Klong Dan, Chanthaburi, and Thap Lan National Park) were chosen as sites for sampling in order to find background levels of pollutants. Detailed descriptions of the sites are below.

The results presented in following reports are based on the analyses of 110 inorganic samples (sediments, soils, and ashes) and 65 organic samples (fish, eggs, molluscs, and crustaceans). The samples are described in Tables 1 and 2. Samples were analyzed for organochlorine pesticides and their metabolites (DDT, aldrin, chlordane, dieldrin, endosulfan, and many others); chlorobenzenes; 7 PCBs congeners; PAHs, PCDD/Fs and DL PCBs for both bioassay analysis and congener specific analysis; brominated flame retardants (including PBDEs), mercury and methylmercury; and other heavy metals (lead, cadmium, copper, chromium, zinc, and arsenic). Descriptions of the analytical methods are included in specific reports.

We hope that the work presented in the following reports will help to the fence-line communities that live in the hotspot areas not to become sacrificed zones for industrial development in Thailand.

1.2 SAMPLING

The samples were collected at the hotspot areas during three sampling campaigns. The majority of sampling was conducted from February 11 to February 22, 2016. The field campaign served for the inspection of the hotspot areas and collecting most of the organic (fish, mollusc, shellfish, and chicken eggs) and inorganic samples (soil, sediment, and ash). Additional samples were taken in February 2015 and February 2017. In February 2017, the background fish samples were taken in the Thap Lan National Park – – representing an unpolluted area of Thailand – in February 2017. The background egg sample was bought in a supermarket in Bangkok in February 2016.

Samples of soils and sediments were usually taken as mixed samples formed by several partial samples taken in various places of the given locality. Soil samples were taken by means of a shovel into polyethylene containers (V = 500 ml) with screw lids or into polyethylene bags. Sediment samples were taken by a core sampler into polyethylene containers (V = 500 ml). Mixed samples were homogenized in a steel bowl, some of them quartered after homogenization. During soil sampling, the sampling shovel and core sampler were washed with tap water, or with available river or lake water. Samples were stored in a cold and dark storage space before analysis. Fish samples were obtained from local fishermen and kept in a freezer wrapped in two polyethylene bags until analyzed.

1.3 SAMPLING AREAS

1.3.1 MAP TA PHUT

The Map Ta Phut industrial complex is a pollution hotspot located on the coast of the Gulf of Thailand, approximately 200 kilometers east of Bangkok. The industrial complex is situated in the vicinity of the town Map Ta Phut in Mueang Rayong District (Rayong Province, Eastern Thailand). The district has a total land area of 514.5 km^2 and a registered population of 263,524 (as of 2014). An additional unregistered population of at least 90,185 (as of 2009) are mostly workers and their children from northeast Thailand and neighboring countries. Population density is 687 persons per square kilometer, including the unregistered population.

The Map Ta Phut industrial complex is the country's largest industrial park and the world's eighth largest petrochemical industrial hub. Industrialization of Map Ta Phut has been carried out based on the policy to promote the Eastern Seaboard Development Plan since the early 1980s. It was founded in 1990 and the booming of the petrochemical industry led to the expansion of the industrial complex. The expansion was done partly by changing parts of assigned buffer zones into industrial zones, and by land reclamation. It is managed by the Industrial Estate Authority of Thailand, a government agency under the Ministry of Industry. The industrial zone was touted as the most modern in the making. Locals were promised that there would be no pollution problems with its high standard of management and control. However, over three decades of industrial development have turned the

area into the number-one toxic hotspot in Thailand. The Thai court declared Map Ta Phut and its surrounding areas as "Pollution Control Zones" in 2009, requiring pollution reduction. However factories continue to expand.

The Map Ta Phut industrial complex consists of five industrial estates in a total area of approximately 30 square kilometers: Map Ta Phut Industrial Estate (16 km^2), Eastern Hemaraj Industrial Estate (5 km^2), Asia Industrial Estate (5 km^2), RIL Industrial Estate (3 km^2), and Pa Daeng Industrial Estate (1 km^2). According to the Department of Industrial Works, there are a total of 756 registered factories in the Mueang Rayong District and 189 of them are in the town Map Ta Phut. The list of registered factories in the town of Map Ta Phut comprises eight power plants, seventy-five chemical plants, eleven gas production plants or gas refineries, four oil refineries, nine steel production plants, and three plastic pellet production plants. Four of the eight power plants are coal-fired power plants: BLCP Power Co. (2 units with total capacity of 1,400 MW), Gheco-One Co. (2 units with a total capacity of 1,400 MW), Glow Energy Public Co. (natural gas unit with a total capacity of 478 MW and coal unit with a total capacity of capacity 120 MW), and Glow SPP 3 Co. (with a total capacity of 240 MW). Moreover, there are twelve industrial ports – storage and transfer of crude oil, natural gas, LPG, coal, and pesticides. In addition, there are also over 500 unregistered factories outside industrial estates in the Mueang Rayong district.

There are four chlor-alkali production plants in the Map Ta Phut urban municipality, two of them in the Hemaraj Eastern Industrial Estate and two of them in the Map Ta Phut Industrial Estate. The chlor-alkali production plant of Aditya Birla Chemicals Co. is in the Eastern Hemaraj Industrial Estate producing liquid chlorine (74,520 tons per year) and epichlorohydrin. The factory area is 66,992 square meters. The chlor-alkali production plant of AGC Chemicals Co. is situated in the Eastern Hemaraj Industrial Estate and uses the electrolysis method at three production units. The factory area is 128,000 square meters. Vinythai Public Co. operates the third chlor-alkali production plant and a vinyl chloride plant, and a PVC plastic powder production plant in the Map Ta Phut Industrial Estate. There are four factories located in one area of 400,000 square meters. The Thai Plastic and Chemicals Co. established the last chlor-alkali production plant, a vinyl chloride monomer plant, and a polyvinyl-chloride plant.

There are several water streams flowing through and around the industrial complex. The main water streams are the Chak Mak Canal, Bang Berd Canal, Huay Yai Canal, Lord Canal, and Ta Kuan Canal. These water streams received discharged waste water from many facilities within the estates and were ultimately discharged into the Gulf of Thailand at the estates' southern edge. [1]

1.3.2 SAMUT SAKHON

Samut Sakhon is located in central Thailand with a total area of 872.3 km^2 and belongs to the one of the smallest provinces. It is part of the Bangkok Metropolitan Region. Neighboring provinces are (from the southwest clockwise) Samut Songkhram, Ratchaburi, Nakhon Pathom, and Bangkok. Its total population is nearly 545,400 registered inhabitants, and the province is divided into three districts. The districts are further subdivided into 40 communes and 288 villages. It is a coastal province with a network of more than 170 canals flowing into the Tha Chin River and the Gulf of Thailand. The local economy relies on industry, fishing, seafood processing, agriculture, and is a leading province for sea salt production. Industrial activities in the studied area are represented mostly with a high concentration of small-scale smelting and recycling factories, and informal recycling of metal scrap and open burning that are located in Mueang Samut Sakhon district. This is a dense area of industrial growth and lax pollution control, with an emerging impact on local workers and children, many of whom are found to have dangerously high levels of lead in their blood.

The area is drained by several water streams, including the Ekkachai canal and the Bang Nam Chued canal. They are tributaries of the Tha Chin River. The river is a distributary of the Chao Phraya River. It splits near the province of Chai Nat and then flows west from the Chao Phraya through the central plains, until it empties into the Gulf of Thailand. The Tha Chin drains a total area of 13,681 square kilometers. The Tha Chin Basin is part of the Chao Phraya Watershed. The water quality of rivers flowing into the upper Gulf of Thailand has seriously deteriorated in the past decade. [2] Fish and cockle farming ponds on the coast are connected by a network of canals flowing into Tha Chin River and the Gulf of Thailand.

1.3.3 THA TUM

Tha Tum industrial complex is a pollution hotspot situated in the vicinity of the town of Tha Tum, 140 kilometers east of Bangkok. The industrial complex and the town Tha Tum are located in the sub district of Tha Tum, which is part of the Si Maha Phot District (Prachinburi Province, Eastern Thailand). The Tha Tum sub district consists of 10 villages within a radius of 5 kilometers of the industrial area, with a registered population of 16,647 (as of December 2014).

Tha Tum industrial complex is the largest industrial park in Prachinburi Province. The industrial complex consists of 304 industrial parks and factories in its surroundings. There are several power plants, pulp and paper industries, and many other factories. According to the Department of Industrial Works, there are a total of 163 registered factories in the Tha Tum sub district (as of September 2015). There are five power plants belonging to the National Power Supply Plc., with a total capacity of 658 MW. The first of them, with a capacity of 328 MW, uses a mix of bituminous coal and biomass (coal 85-90 % and biomass 10-15 %). The second one uses black liquor from a craft process in the pulp industry with a capacity of 32.9 MW. The other tree power plants use biomasses as pieces of wood, bark and rice husk with a capacity of 297 MW in total. The pulp and paper industrial area of company Double a Plc. covers over 1.6 square kilometers. The pulp industry area consists of five paper mills with a total capacity 1,419,000 tons per year, a chlorine dioxide-producing plant, a white liquor-producing plant, lime kilns, and two waste water plants (total capacity of 46,000 cubic meters per day). The 304 industrial parks and surroundings include other industries, such as production of ethanol from cassava, production of corrugated cardboard, metal coating and machinery manufacturing, production of car engine parts, production of carbon copy paper, hard disk drive manufacturers, motorcycle parts manufacturing, and many others.

The area of the Tha Tum sub district is drained by a few water streams (Bang Pakong Canal, Hat Nang Kaeo Canal) to the Prachinburi River, laying 5.5 kilometers north from the industrial complex.

1.3.4 KHON KAEN

One of biggest pulp and paper industrial areas in Thailand is located 30 kilometers north of the city of Khon Kaen. The city is the administrative center of Khon Kaen Province (northeast Thailand) and is situated 450 kilometers northeast of Bangkok. The pulp and paper industrial area is surrounded by 11 villages in a radius of five kilometers. These villages belong to two sub districts: Kut Nam Sai (part of the Nam Phong District) and Khok Sung (Ubolratana District) and consist of 1,397 households. The pulp and paper industrial area alone is positioned in Kut Nam Sai sub district.

The pulp and paper industrial area established by Phoenix Pulp and Paper Plc. covers 1.9 square kilometers. Aside from factory space, there is also a waste landfill and eucalyptus forest of 6.6 square kilometers. The industrial area has two pulp and paper production lines with a total production capacity of 240,000 tons per year. Within the area, there are chemical plants, including a chlor-alkali production plant (20 tons of sodium hydroxide per day), a chlorine dioxide production plant (12 tons of chlorine dioxide per day), a sulphur dioxide production plant (0.6 tons of sulphur dioxide per day), and an oxygen production plant (13 tons of oxygen per day). There are also two power plants, a lime kiln, a waste incinerator (15.6 tons of ash per day), and a wastewater treatment plant (8 tons of sludge per day) in the industrial area.

The area is drained by the water stream Chot flowing through the eucalyptus forest. The water stream is a tributary of the Phong River (Nam Phong) passing north of the area. The river is an important water resource in the northeast of Thailand, with an average width of about 70-80 meters and an average depth of 6-7 meters. The river water is used not only for community and municipal water supply, industry, agriculture and aquaculture, but also the river itself is also a recipient of wastewaters from communities, industries, and run-off from agriculture. [3] The Phong River suffers from low dissolved oxygen levels due to wastewater influx.

The Thai state, under the auspices of its development planning agencies, identified Khon Kaen as the center of development growth of the northeast of Thailand in the 1970s. [4] Thus, the sitting of the Phoenix plant along the

Phong River was clearly part of the state's broader program of regional development. The plant was established in 1982 and received privileges, such as reductions in business and corporate income taxes for a set period and expenditures on electricity, water supplies, and other infrastructure as a form of state support. [5] Throughout the 1990s, the pulp and paper plant was repeatedly charged with polluting the Phong River and was ordered to halt production by the provincial governor, the Department of Industrial Works, the Pollution Control Department, or a combination of state agencies. [6]

1.3.5 LOEI

Loei is one of the most sparsely populated provinces of Thailand. It lies in the north east of the country in a fertile basin and is covered with mountains. The Loei River that flows through the province is a tributary of the Mekong, which forms part of the northern boundary of the province with neighboring Laos. The province has a total area of almost 11,425 km^2 with over 638,800 registered inhabitants and is divided into 14 districts. Its economy is driven mostly by agriculture and gold ore mining.

Villagers in the Na Nong Bong community in Loei province live less than one kilometer from the mine. Since it was open in 2006 they have filed numerous complaints against the mine's license in attempts to mitigate the contamination of nearby villages. The gold mining company was accused of poisoning villagers' land and water supplies and causing serious health problems. A government study of contamination in this area reported dangerous levels of contaminants in local rivers and creeks. They found cyanide, arsenic and mercury levels that exceeded safety standards in the blood of people living in its surrounding areas. Moreover, the mining operations have been accused of major environmental damage of that area too [7]. Samples analyzed in this study were taken in the industrial vicinity of this gold mine.

1.3.6 PRAEKSA

Praeksa belongs to the Samut Prakan Province that lies at the mouth of the Chao Phraya River on the Gulf of Thailand. The total area of this province is 1,004 kilometers squared with a total population of 1,279,300 registered inhabitants and the province is ranked as third highest population density in the country. Samut Prakan is further divided into six districts and Praeksa is a part of Mueang district with a population of 56,400 people.

There are over 6,576 factories in the area that produce motor vehicles, car parts and equipment, metal products, electronics, textiles, food products, chemicals, plastics, etc. There is also a dumping site of 0.24 km^2 and depth of 50 meters that accumulates municipal solid waste and, illegally, some industrial waste for over 20 years. In 2014, there was a massive fire that lasted for almost a week, in which about a ton of the dumped waste uncontrollably burned [8]. Our research was focused mainly on the surrounding of that landfill.

1.3.7 KHAO HIN SORN

Khao Hin Sorn is a part of Chachoengsao Province that lies in the eastern part of Thailand. The total area of the province is 5,351 km^2 and has a total population of almost 701,000 registered inhabitants. Chachoengsao is further divided into 11 districts, and one of them is Phanom Sarakham, where Khao Hin Sorn sub district is located. Its total population counts 15,600 inhabitants and is the second most populated in the district [9]. In the studied area there are different sources of pollution, e.g. a number of small industrial facilities, like an ash disposal site in a nearby eucalyptus plantation or an aluminium smelting plant.

1.3.8 KOH SAMUI

Koh Samui is one of the most famous of Thailand's numerous islands. However, there is a large municipal waste landfill hidden in a mountainous forest terrain in the south-eastern part of the island, approximately 1.6 km from the sea shoreline. Additionally, a large municipal waste incinerator was built in 1997 for 501 million Baht ($13.5 million USD) through a joint Thai-Japanese venture [10]. The incinerator was never used to its full capacity of burning 140 tons of garbage per day. The operation ceased due to problems, including the corrosion of the boiler tank in 2012, which caused the incinerator to run at half of its capacity [11]. The waste incinerator was left abandoned in the middle of a growing waste landfill. We have chosen an area 0.5 km downstream from both the waste landfill and abandoned waste incinerator for sampling. The ash sample from the waste incinerator was analyzed for heavy metals and

other contaminants by Greenpeace in 1999 [12]. The waste incinerator was also suspected to be a source of the soil contamination by mercury downwind from the facility [13].

1.3.9 SARABURI

Saraburi is the area with a big concentration of cement kilns owned by three major companies: Siam City Cement Public Co., Ltd., Siam Cement Group (SCG) – The Siam Cement Public Co., Ltd.; and TPI Polene Public Co., Ltd. It is located in three different districts: Kaeng Khoi (94,555 inhabitants), Ban Mo (total population 42,409 inhabitants) and Phra Phutthabat (total population 63,611 inhabitants); [14]. Saraburi belongs to the cities with the most severe pollution by $PM_{2.5}$ [15].

1.3.10 RAYONG IRPC INDUSTRIAL ZONE

The IRPC industrial zone belongs to Rayong province that was described above and is a part of Mueang Rayong district. If pollution occurs, then the possible source is most likely a petrochemical plant, a compounding plastics plant, or one of several refineries that operate in the area.

1.3.11 KLONG DAN

As mentioned above, Samut Prakan Province lies at the mouth of the Chao Phraya River on the Gulf of Thailand. The total area of this province 1,004 kilometers squared and has a total population of 1,279,300 registered inhabitants, and is therefore ranked as having the third highest population density in the country. Samut Prakan is further divided into 6 districts. The part of the province on the west side of the Chao Phraya River consists mostly of rice paddies and shrimp farms, as well as mangrove forests, while the eastern part is the urban center, including industrial factories.

Klong Dan belongs to the Bang Bo district and, with its almost 30,000 inhabitants, is the biggest sub district in the area. It is also a site with a never completed wastewater treatment plant financed partly by the Asian Development Bank. The 24 billion baht project was not completed due to opposition from local residents and charges of malfeasance levelled against those responsible for the project [16, 17]. Samples collected for purposes of this study originated from a small fishing town without any significant source of pollution apart from fishing facilities and accumulation of all kinds of ships and boats.

1.3.12 CHANTHABURI

Chanthaburi is a province in the east of Thailand. Its total area is 6,338 km^2 and its population is 531,000 inhabitants. The province is further divided into 10 districts [18]. While the southern part of Chanthaburi lies on the shore of the Gulf of Thailand and mostly consists of coastal alluvial plains, the hinterlands in the north of the province are mountainous. Samples for this study were collected in the northwestern part of the province in the Kaeng Hang Maeo District. There is no significant source of pollution in this area; therefore, amounts of risk elements in collected samples were expected to be relatively low.

1.3.13 THAP LAN NATIONAL PARK AND KLONG YANG CANAL

The areas of interest (Thap Lan National Park and Klong Yang Canal) are parts of Na Di District, which lies in the northeastern part of the province and has a total of 51,600 inhabitants. The park consists of rare fan palm forests. It is also a source of many river streams and has many natural attractions, such as cliffs and waterfalls. This 2,236 km^2 area was declared as the 40^{th} national park of Thailand on December 23, 1981 and is kept as an industry-free zone [19].

1.4 LIST OF SAMPLES

An inventory of **inorganic** and **organic** samples collected in the hotspot are as is listed in Tables 1 and 2, respectively. **Air samples** are described in the chapters evaluating them (see **chapters 4. and 5.**).

Table 1: *List of inorganic samples*

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
Map Ta Phut			
MTP 1-1	Sediment	12°40'34.37"N 101°10'29.66"E	Huai Yai Canal; Waters from petrochemical industry Black sandy sediment with clay layer on the surface; Anaerobic odour Relevancy to fish sample MTP-2017-8
MTP 1-2	Ash	12°40'26.39"N 101°10'26.58"E	Ash from a blue tank, BLCP power plant
MTP 1-6	Sediment	12°40'10.98"N 101°10'46.70"E	Ta Kuan Canal Black clay thin grey layer on the surface; Slightly anaerobic odour Relevancy to fish sample MTP 1-4
MTP 1-7	Sediment	12°41'30.89"N 101° 9'4.17"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Coke plant
MTP 1-8	Sediment	12°40'10.95"N 101° 9'29.18"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Coke plant Black mud mixed with sand; Small oil spots; Anaerobic oily odour Relevancy to fish samples: MTP 1-10/1; MTP 1-10/2
MTP 1-12	Sediment	12°40'40.75"N 101° 6'49.86"E	Sea; Sai Thong Beach
MTP 1-13	Sediment	12°40'44.52"N 101° 6'33.32"E	Bang Kraphrun Canal
MTP 1-14	Sediment	12°40'12.42"N 101° 9'37.71"E	Sea; 120-150 m away from eastern canal; Chlor-alkali plant; Chemical plant; Coke plant; Government survey 300,000 t of this black mud in the bay Black mud; Anaerobic H2S odour Relevancy to fish samples: MTP-2017-2; MTP-2017-3; MTP-2017-5
MTP 1-15	Sediment	12°41'26.22"N 101° 7'10.62"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
MTP 1-16	Sediment	12°41'23.50"N 101° 7'12.05"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
MTP 1-17	Sediment	12°40'43.67"N 101° 7'12.01"E	Bang Boet Canal; Chlor-alkali plant; Chemical plant
MTP 2-2	Sediment	12°45'32.06"N 101° 9'46.65"E	Canal Huai Phrao; upstream from RIL industrial estate Brown, very wet sediment Relevancy to fish samples: MTP 2-1/1; MTP 2-1/2

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
MTP 2-3	Sediment	12°44'3.23"N 101°10'7.09"E	Canal Huai Phrao; downstream from RIL industrial estate
MTP 2-5	Sediment	12°40'59.83"N 101° 9'46.08"E	East from Chak Mak Canal; Chlor-alkali plant; Chemical plant
MTP 2-6	Sediment	12°40'32.51"N 101° 9'27.05"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Petrochemical and Refinery plant Grey brown clay sediment; Slight anaerobic odour Relevancy to fish samples: MTP 2-8; MTP 2-9
MTP 2-6 (1)	Sediment	12°40'32.51"N 101° 9'27.05"E	Chak Mak Canal; Chlor-alkali plant; Chemical plant; Petrochemical and Refinery plant
MTP 2-14	Sediment	12°43'56.62"N 101° 6'1.24"E	Upstream Bang Kraphrun Canal
MTP 2-15	Sediment	12°43'17.11"N 101° 6'37.07"E	Upstream Chak Mak Canal
Samut Sakhon			
SMS 1-1	Sediment	13°30'46.21"N 100°16'48.07"E	Tha Chin River mouth
SMS 1-3	Sediment	13°30'45.08"N 100°16'43.54"E	Tha Chin river; Close to sea; Small industrial facilities; Metal smelting Grey sediment with a lot of trash; Orange coloured water and oil layers near Relevancy to fish sample SMS 1-2
SMS 1-5	Sediment	13°29'18.25"N 100°19'48.06"E	Luang Sahakon Canal
SMS 1-6	Sediment	13°29'14.99"N 100°20'2.39"E	Sea; 400 meters east from Luang Sahakon Canal
SMS 1-8	Sediment	13°29'24.40"N 100°21'21.01"E	Fish farm
SMS 1-9	Sediment	13°29'44.68"N 100°21'21.22"E	Pond close to farm; Small industry facilities; Open burning of waste; Metal smelting Grey clay Relevancy to fish samples: SMS 1-12/1; SMS 1-12/2; SMS 1-12/3
SMS 1-10	Sediment	13°30'6.65"N 100°16'22.96"E	Tha Chin River mouth
SMS 1-11	Sediment	13°33'31.16"N 100°18'46.55"E	Luang Sahakon Canal

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
SMS 1-14	Sediment	13°37'33.61"N 100°21'36.54"E	Residential area; Metal smelting factory
SMS 2-1	soil	13°37'34.8"N 100°21'51.1"E	Drained coverage of former dam/wetland (metal smelting; small industrial facilities; open burning of waste)
SMS 2-2	Sediment	13°37'37.26"N 100°21'48.36"E	Residential area; (Metal smelting facilities)
SMS 2-4	Ash	13°36'21.78"N 100°21'06.30"E	Sahamit factory, aluminium, lead and other metals smelter
SMS 2-6	Sediment	13°36'23.2"N 100°21'00.4"E	Soi Kong Phanan Phon Alley; (metal smelting; small industrial facilities; open burning of waste)
SMS 2-7	Sediment	13°36'29.16"N 100°20'48.24"E	Soi Kong Phanan Phon Alley; (metal smelting; small industrial facilities; open burning of waste)
SMS 2-10	Sediment	13°37'8.28"N 100°20'37.38"E	Soi Talab Thong 3 Alley; (metal smelting; small industrial facilities; open burning of waste)
SMS 2-11	Sediment	13°36'36.60"N 100°20'35.64"E	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste) Potential faecal pollution, Mud with visible oil pollution on the top; Petrol odour Relevancy to fish samples: SMS 1F; SMS 2F
SMS 2-12	Sediment	13°36'25.56"N 100°21'31.26"E	Bang Nam Chued Canal; (Metal smelting; Small industrial facilities; Open burning of waste)
A1	Ash	13°37'59.5"N 100°21'09.3"E	Soi Choed Mahachai 1 Alley; (small-scale brass smelting facility)
A2	Soil	13°36'21.8"N 100°20'49.1"E	Soi Kong Phanan Phon Alley, Taweesup Recycling company; (metal smelting; small industrial facilities; open burning of waste)
A3	Soil	13°36'21.8"N 100°20'49.1"E	Soi Kong Phanan Phon Alley, Taweesup Recycling company; (metal smelting; small industrial facilities; open burning of waste)
Tha Tum			
TT 1-1	Sediment	13°57'2.74"N 101°35'52.07"E	Effluent pond; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-2	Sediment	13°57'3.16"N 101°35'50.34"E	Klong Tha Fuek Canal; (Chemical plant; Pulp and paper industry; Coal power plant)

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
TT 1-3	Sediment	13°57'7.47"N 101°36'0.10"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-4	Sediment	13°56'57.71"N 101°36'2.81"E	Supply water pond
TT 1-5	Sediment	13°55'11.60"N 101°34'59.99"E	Discharge water near wood chip plant; Black mud Relevancy to fish samples: TT2-6, TT2-7
TT 1-6	Sediment	13°55'28.26"N 101°35'17.08"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)
TT 1-7	Sediment	13°56'17.25"N 101°35'42.39"E	Downstream of Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant) Dark grey muddy clay; Muddy odour Relevancy to fish sample TT 1-1F
TT 1-8	Sediment	13°55'19.76"N 101°36'32.05"E	Nong Kla Canal
TT 1-9	Sediment	13°57'50.48"N 101°36'2.96"E	Water stream in cattle pasture; (Chemical plant; Pulp and paper industry; Coal power plant) Dark grey-black clay with brown top layer; Anaerobic odour Relevancy to fish samples: TT-2017-1; TT 2-8
TT 1-10	Sediment	13°57'44.11"N 101°36'46.99"E	Upstream Bang Pakong River
TT 1-11	Sediment	13°58'5.63"N 101°35'8.64"E	Downstream Bang Pakong River
TT 2-1	Sediment	13°54'1.34"N 101°34'48.15"E	Upstream Chalongwang Canal
S1	Sediment	13°57'52.0"N 101°36'02.9"E	near TT 1-9
S2	Sediment	13°55'28.4"N 101°35'17.0"E	near TT 1-6
S3	Sediment	13°55'55.6"N 101°35'34.6"E	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant; Coal stock pile)
S4	Sediment	13°55'45.1"N 101°36'19.1"E	Canal; South from supply water pond for industry

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
S5	Ash	13°45'23.6"N 101°36'40.5"E	Eucalyptus field
Khon Kaen			
KK 3	Sediment	16°40'44.9"N 102°43'58.1"E	Chot canal; upstream from Paper and pulp industry; Coal power plant
KK 4	Sediment	16°42'6.04"N 102°44'18.61"E	Paper and pulp industry; Coal power plant; Taken from outflow (30 m) of wasted water reservoir; Water red- coloured probably caused by soil particles Soil sand; Top layer – red-brown; Underneath grey; Odour anaerobic Relevancy to fish sample KK-2017-2
KK 5	Ash	16°42'55.6"N 102°44'39.8"E	
KK 7	Sediment	16°43'46.1"N 102°43'21.7"E	Phong river upstream from industry; (Paper and pulp industry; Coal power plant)
KK 8	Sediment	16°43'23.5"N 102°44'52.3"E	Chot canal downstream from industry; (Paper and pulp industry; Coal power plant)
KK 9	Sediment	16°43'23.33"N 102°44'52.70"E	Pond; (Paper and pulp industry; Coal power plant) Black mud with brown top layer; Contains a lot of small stones; Odour slightly anaerobic Relevancy to fish samples: KK-2017-5; KK-2017-6; KK 12; KK 14-1; KK 14-2
KK 10	Sediment	16°43'39.6"N 102°45'04.7"E	Chot reservoir before enter Phong river; (Paper and pulp industry; Coal power plant)
KK 11	Sediment	16°43'37.3"N 102°45'01.3"E	Rice paddy near Chot reservoir
KK 13	Sediment	16°43'56.02"N 102°45'38.12"E	Phong river; (Paper and pulp industry; Coal power plant)
Loei			
LOE 1	Sediment	17°22'02.1"N 101°40'20.3"E	Lakes in the middle of gold mine
LOE 2	Sediment	17°21'6.1"N 101°38'44.6"E	Pond, upstream the gold mine, Lek Creek
LOE 3	Sediment	17°21'5.0"N 101°38'51.0"E	Lek Creek, Little water stream in the fields (gold mine)

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
LOE 4	Sediment	17°21'13.8"N 101°39'4.3"E	Lek Creek with standing water in the abandoned rise fields (gold mine)
LOE 5	Sediment	17°21'14.6"N 101°39'7.99"E	Lek Creek, Wetland under dam (gold mine)
LOE 6	Sediment	17°21'14.1"N 101°39'8.3"E	Lek Creek (gold mine)
LOE 7	Sediment	17°21'13.3"N 101°39'14.8"E	Lek Creek, Wetland (gold mine)
LOE 8	Sediment	17°21'14.0"N 101°39'14.3"E	Lek Creek
LOE 9	Sediment	17°21'7.8"N 101°39'26.2"E	Pond (gold mine), TK1/1
LOE 11	Sediment	17°21'1.2"N 101°39'45.1"E	Pond for irrigation (gold mine)
LOE 12	Sediment	17°20' 57.0"N 101°39' 34.3"E	Lek Creek, Wetland on the edge of the field with soya beans (gold mine) Soil sand; Brown-grey; Water pH 5.05 Relevancy to fish samples: LOE 14; LOE 15
LOE 20	Sediment	17°20'24.9"N 101°40'2.6"E	Huai River, upstream the gold mine
LOE 21	Sediment	17°21'10.5"N 101°40'14.1"E	Huai River, Weir (gold mine)
LOE 22	Sediment	17°21'29.99"N 101°40'31.9"E	Downstream Huai River (gold mine)
LOE 23	Sediment	17°21'44.7"N 101°40'6.7"E	Small creek in the middle of field (gold mine)
LOE 24	Sediment	17°21' 31.8" N 101°38'40.1"E	Creek in the bamboo forest, upstream the gold mine
LOE 25	Sediment	17°21'05.9" N 101°38'22.7"E	Little stream upstream Ronghang Lin (gold mine)

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
LOE 26	Sediment	17°21'22.7" N 101°38'29.1"E	Spring upstream Lek creek in the rubber tree field (gold mine)
LOE 27	Sediment	17°22'52.5"N 101°38' 27.1"E	Upstream Puk Creek lake (gold mine) Muddy clay; Black-brown-grey colour Relevancy to fish samples: LOE 19; LOE 29
LOE 28	Sediment	17°21'48.2"N 101°39'47.6"E	Puk Creek in soya fields (gold mine)
LOE 1 C	White crystals	17°22'02.1"N 101°40'20.3"E	Bank of gold mine lake
LOE 1 D	Yellow crystals	17°22'02.1"N 101°40'20.3"E	Bank of gold mine lake
Praeksa			
PKS 1	Sediment	13°33'34.98"N 100°38'36.38"E	Outflow from the waste landfill into the channel
PKS 2	Sediment	13°33'38.64"N 100°38'34.82"E	Similar location to later sample PR 2
PRE 1-1	Sediment	13°33'25.4"N 100°35'49.9"E	Fishing pond next to the waste landfill
PR 1	Sediment	13°33'34.79"N 100°38'36.1"E	Outflow from the waste landfill into the channel
PR 2	Sediment	13°33'38.35"N 100°38'34.66" E	North stream with standing water (waste landfill) Surface clay layer Relevancy to fish sample PR 3
PR 4	Sediment	13°33'15.89"N 100°38'23.07"E	Fish and vegetable (morning glory) pond on the West from the waste landfill. Water comes from channel which flows around the waste landfill.
PR 5	Sediment	13°33'20.28" N 100°38'25.31" E	Channel flowing around the waste landfill and long the people houses Black mud with parts of brown clay; No odour Relevancy to fish sample PR 7
PR 8	Sediment	13°33'19.04"N 100°38'48.76"E	East stream located at corner of the waste landfill wall

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
Khao Hin Sorn			
KHS 1	Sediment	13°41'19.9"N 101°27'4.1"E	Downstream Rabom channel, in the channel meander behind the bridge, near waste water discharge (metal smelting, illegal dumping of waste, Khao Hin Sorn) Light brown; No odour Relevancy to fish sample KHS 10
KHS 2	Sediment	13°41'17.3" N 101°28'32.09" E	Wetland used for agricultural purposes, next to eucalyptus fields and cassava plantation (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 3	Sediment	13°41'34.0"N 101°27'56.3"E	Creek with leachate from power plant ash, "304 industry" and house waste water (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 4	Sediment	13°46'1.6" N 101°36'22.39" E	Wastewater aeration pond, outflow black water with strong smell, rocky channel with green algae (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 4a	White gel	13°46'1.6" N 101°36'22.39" E	Wastewater aeration pond, outflow black water with strong smell, rocky channel with green algae (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 5	Sediment	13°43'41.9"N 101°36'39.8"E	Creek going through a farm (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 7	Sediment	13°41'13.2"N 101°35'59.79" E	Downstream of a creek where wastewaters are released, close before entering Rabom channel overgrowing pool (metal smelting, illegal dumping of waste, Khao Hin Sorn) Black mud; No odour Relevancy to fish sample KHS 6
KHS 8	Sediment	13°40'50.0" N 101°36'4.39"E	Rabom channel with water plants (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 9	Sediment	13°40'50.9" N 101°35'48.9"E	Rabom channel after receiving wastewater, along banana and gum-tree plantation (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 2-2	Sediment	13°47'44.96"N 101°29'3.75"E	Stream near aluminium plant (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 2-5	Sediment	13°47'44.96"N 101°29'3.75"E	Pond near the aluminium plant (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 2-7	Sediment	13°47'30.25"N 101°28'33.56" E	Water flow with low water level near aluminium factory (metal smelting, illegal dumping of waste, Khao Hin Sorn)
KHS 2-8	Sediment	13°46'49.8"N 101°30'2.27"E	Canal going from the recycling plant and dump site (metal smelting, illegal dumping of waste, Khao Hin Sorn)

NAME	MATRIX	COORDINATES	SAMPLING SPOT DESCRIPTION
Rayong IRPC industrial zone			
IRPC 2	Sediment	12°39′08.3″N 101°18′4.0″E	Channel (IRPC industrial zone, petrochemistry, chemical and plastic industry, Rayong)
IRPC 3	Sediment	12°39′16.3″N 101°17′19.0″E	River (IRPC industrial zone, petrochemistry, chemical and plastic industry, Rayong)
IRPC 6	Sediment	12°39′22.6″N 101°16′54.09″ E	Mangrove (IRPC industrial zone, petrochemistry, chemical and plastic industry, Rayong) Sandy with little pieces of black mud; Anaerobic odour Relevancy to fish sample IRPC 7
Klong Dan			
KLO 1-4	Sediment	13°28´44.68″N 100°48´09.76″E	Sediment from a dam Dark grey, odourless sediment Relevancy to fish samples: KLO 1-3/1-3; KLO 1-3/4-6
Chanthanburi			
CHA 1	Sediment	12°58′11.73″N 101°45′07.82″ E	Upstream creek in the middle of forest above waterfall. Rocky creek with wood and plants across it. Sandy sediment with decomposed organic matter; Grey colour; no odour Relevancy to fish samples: CHA3; CHA4

Table 2: *List of organic samples*

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name, Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age/ Fat Content
Map Ta Phut						
MTP 1-10/1	Fish	12°40′09.6″N 101°09′29.1″E	Belonidae n=1	Tek Lang – Needle Fish Carnivore	Sea coast; (Chlor-alki plant; Chemical plant; Coal Power plant)	94.5 cm; 86.5 cm; 1349 g; -
MTP 1-10/2	Fish	12°40′09.6″N 101°09′29.1″E	Belonidae n=1	Tek Lang – Needle Fish Carnivore	Sea coast; (Chlor-alki plant; Chemical plant; Coal Power plant)	38.5 cm; 33 cm; 733 g; -
MTP 2-1/1	Fish	12°45′32.06″N 101° 9′46.65″E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Canal Kvai Phrao; (Chlor-alkali plant; Chemical plant; Coal Power plant; Open burning of waste)	30 cm; 24.5 cm; 265 g; 1 year
MTP 2-1/2	Fish	12°45′32.06″N 101° 9′46.65″E	Trichogaster pectoralis n=1	Pla Salid – Snakeskin Gourami Omnivore	Canal Kvai Phrao; (Chlor-alkali plant; Chemical plant; Coal Power plant)	18.5 cm; 15.5 cm; 124 g; 1 year
MTP 2-8	Fish	12°40′58.76″N 101° 9′17.79″E	Clarias batrachus n=3	Pla Dook – Walking Catfish Omnivore	(Chlor-alkali plant; Chemical plant; Coal Power plant)	31/27.5/32.8 cm; 29/25/29.5 m; 249/192/232 g; -
MTP 2-9	Fish	12°40′58.76″N 101° 9′17.79″E	Clarias batrachus n=3	Pla Dook – Walking Catfish Omnivore	(Chlor-alkali plant; Chemical plant; Coal Power plant)	34.7/32.5/36 m; 31.5/29.5/31.5 m; 257/247/423 g; -
MTP-2017-1A+1B	Fish	12°39′02.2″N 101°10′40.0″E	Lutjanus johnii n=2	Pla Kapong - John's snapper	Sea coast; (Coal power plant, Chemical industry)	41/34 cm; 34/29 cm; 857/654 g; 1/1 year
MTP-2017-2	Fish	12°39′02.2″N 101°10′40.0″E	Dasyatis pastinaca n=1	Pla Kraben – Stingray Carnivore	Sea coast; (Coal power plant, Chemical industry)	51 cm; 175 cm; 4065 g; 1 year
MTP-2017-3	Fish	12°38′23.0″N 101°09′24.0″E	Acanthopagrus berda n=1	Pla E-klud – Goldsilk Seabream	Sea coast; (Coal power plant, Chemical industry)	43 cm; 38 cm; 1315 g; 1 year
MTP-2017-5	Fish	12°38′08.5″N 101°07′23.8″E	Pomadasys kaakan n=1	Pla Kapong Samea – Javelin Grunter Carnivore	Sea coast; (Coal power plant, Chemical industry)	43 cm; 38 cm; 1140 g; 1 year
MTP-2017-8	Fish	12°40′30.5″N 101°10′29.5″E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Sea coast; (Coal power plant, Chemical industry)	35 cm; 29 cm; 465 g; 1 year

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name, Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age/ Fat Content
MTP 1-4	Mollusc	12°40′11.0″N 101°10′46.7″E	Perna viridis	Asian green mussel	Sea coast; (Chlor-alkali plant; Chemical plant; Coal Power plant)	
MTP 1-3	Crustacean	12°40′11.0″N 101°10′46.7″E	Scylla serrata n=3	Mud Crab/ Black Crab	Sea coast; (Chlor-alkali plant; Chemical plant; Coal Power plant)	
MTP 1-5	Crustacean	12°40′11.0″N 101°10′46.7″E	Thalamita crenata n=3	Spiny Rock Crab	Sea coast; (Chlor-alkali plant; Chemical plant; Coal Power plant)	
MTP 1-9	Crustacean	12°40′9.85″N 101° 9′28.90″E	Scylla serrata n=3	Mud Crab/ Mangrove Crab/ Black Crab	Sea coast; (Chlor-alkali plant; Chemical plant; Coal Power plant)	
MTP 2-18	Egg	12°41′11.44″N 101° 6′56.74″E	n=3		Habitat; (Chlor-alkali plant; Chemical plant; Coal Power plant)	Fat content: 14.1 %
MTP 2-19	Egg	12°41′9.64″N 101° 6′54.22″E	n=3		Habitat; (Chlor-alkali plant; Chemical plant; Coal Power plant)	Fat content: 14.1 %
MTP 1-11	Egg	12°40′45.2″N 101°6′32.9″E	n=4			Fat content: 17.6 %
MAP-1	Egg	12°44′32.93″ N 101°9′43.90″ E	n=2			Fat content: 17 %
Samut Sakhon						
SMS1-12/1,2	Fish					
SMS 1-12/1-(1-2)	Fish	13°29′44.68″N 100°21′21.22″E	Polynemidae n=2	Pla Kulao - Threadfins	Fish and Cockle farming ponds	33.8/31 cm;28.7/26 cm; 307/285 cm; -
SMS 1-12/2-(1-2)	Fish	13°29′44.68″N 100°21′21.22″E	Ambassidae n=2	Pla Kao Mao - Asiatic glassfish	Fish and Cockle farming ponds	16/17 cm; 13.8/14 cm;88/117 g; -
SMS 1-12/3	Fish	13°29′44.68″N 100°21′21.22″E	Sillago sihana n=1	Pla Sai - Silver Sillago	Fish and Cockle farming ponds	18 cm; 16 cm;
SMS 1-2/1-3	Fish	13°30′48.19″N 100°16′39.27″E	Mugilidae n=3	Pla Kra Bok - Mullets or Grey Mullets	Tha Chin river	24/25/23.5 cm; 20/21.5/20.5 cm; 180/190/160 g; 1/1/1 year

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name, Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age/ Fat Content
SMS 1F	Fish	13°36´38.66"N 100°20´37.39"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)	33 cm; 28 cm; 274 g; -
SMS 2F	Fish	13°35'42.82"N 100°19'55.17"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Ekkachai canal; (Metal smelting; Small industrial facilities; Open burning of waste)	28 cm; 24 cm; 178 g; -
SMS 2-13	Egg	13°36'29.16"N 100°20'46.07"E	n=3		Residential area; (Metal smelting; Small industrial facilities; Open burning of waste)	Fat content: 15.6%
Samut Sakhon	Egg	13°37'33.5"N 100°21'36.1"E	n=3		Residential area; (informal metal-scrap recycling and open burning)	Fat content: 11.6 %
Tha Tum						
TT 2-8	Fish	13°57'51.0"N 101°36'03.2"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)	29 cm; 25.5 cm; 211 g; 0-1 year
TT 2-6	Fish	13°55'17.57"N 101°35'10.12"E	Oreochromis niloticus n=3	Pla Nil – Nile Tilapia Omnivore	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)	17.5/17/20 cm; 13.5/13.8/16.2 cm; 114/101/151 g; 0-1/0-1/0-1 year
TT-2017-1	Fish	13°57´36.85"N 101°36´06.99"E	Channa striata n=1	Pla Chorn - Snakehead Omnivore	Chalongweang Canal; (Pulp and paper industry; Thermal power plant)	51 cm; 44 cm; 1166 g; 2 years
TT1-1F	Fish	13°56´13.88"N 101°35´36.84"E	Channa striata n=1	Pla Chorn - Snakehead Omnivore	Industrial park wastewater pond; (Chemical plant; Pulp and paper industry; Coal power plant)	37 cm; 32 cm; 448 g; -
TT 2-9	Mollusc	13°55'27.78"N 101°35'16.59"E	Phylloda foliacea	Hoi Karb - Clam	Chalongwang Canal; (Chemical plant; Pulp and paper industry; Coal power plant)	
TT2-7	Mollusc	13°55´17.56"N E101°35´10.11"E	Bivalve		Discharge water; (Chemical plant; Pulp and paper industry; Coal power plant)	
Tha Thum	Egg	13°56'01.9"N 101°35'45.2"E	n=4		Residential area; (Chemical plant; Pulp and paper industry; Coal power plant)	Fat content: 12.5 %

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name, Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age/ Fat Content
Khon Kaen						
KK 12/1	Fish	16°43′16.61″N 102°45′4.36″E	Barbonymus gonionotus n=1	Pla Thapian – Silver Barb Omnivore	Canal; (Pulp and paper and pulp industry; Coal power plant)	19.2cm; 16.2 cm; 142 g; -
KK 14/1	Fish	16°43′16.61″N 102°45′4.36″E	Hampala macrolepidota n=2	Pla Kasoop Kit – Hampala Barb Omnivore	Reservoir; (Pulp and paper industry; Coal power plant)	20.5/21 cm; 17.1/17; 121/127 g; 1 year
KK 14/2	Fish	16°43′16.61″N 102°45′4.36″E	Channa micropeltes n=1	Pla Chado – Giant snakehead Carnivore	Reservoir; (Pulp and paper industry; Coal power plant)	16.8 cm; 14.9 cm; 49 g; 1 year
KK-2017-2	Fish	16°41´49.45″N 102°44´07.05″E	Clarias batrachus n=1	Pla Dook – Walking Catfish Omnivore	Canal; (Pulp and paper industry; Coal power plant)	29 cm; 26.5 cm; 204 g; 4 months
KK-2017-5	Fish	16°43´23.39″N 102°44´52.44″E	Channa striata n=1	Pla Chorn - Snakehead Omnivore	Canal; (Pulp and paper industry; Coal power plant)	40 cm; 34 cm; 598 g; 0-1 year
KK-2017-6	Fish	16°43´18.63″N 102°45´04.93″E	Clarias batrachus n=1	Pla Dook – Walking Catfish Omnivore	Reservoir; (Pulp and paper industry; Coal power plant)	32 cm; 28 cm; 245 cm; 0-1 year
KK 1	Egg	16°41′38.61″N 102°44′14.66″E				Fat content: 13 %
KK 1/1	Egg		n=2			Fat content: 16.3 %
KK 1/2	Egg		n=3			Fat content: 14.1 %
Loei						
LOE 14	Fish	17°21´07.76″N 101°39´26.21″E	Barbonymus gonionotus n=2	Pla Thapian – Silver Barb Omnivore	Lek creek; (Gold mining)	29/30 cm; 22/23 cm; 370/380 g; -
LOE 15	Fish	17°21´07.76″N 101°39´26.21″E	Channa striata n=4	Pla Chorn - Snakehead Omnivore	Lek creek; (Gold mining)	25.5/36/18/19 cm; 21/29/15/15.5 cm; 170/800/100/105 g; -
LOE 19	Fish	17°26´09.89″N 101°37´48.60″E	Oxyeleotris marmorata n=2	Pla Boo – Marble Goby Carnivore	Huai river upstream; (Gold mining)	37/- cm; 31/- cm; 700/- g,; 2-3/0-1 year
LOE 29	Fish	17°22´52.50″N 101°37´27.10″E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	(Gold mining)	20.5 cm; 17.5 cm; 92 g; 0-1 year

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name, Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age/ Fat Content
Praeksa						
PR3	Fish	13°33´38.35"N 100°38´34.66"E	Channa striata n=2	Pla Chorn – Snakehead Omnivore	Canal; (Municipal waste landfill; Hazardous waste landfill)	43/39.5 cm; 37.4/33.5 cm; 795/616 g; -
PR7	Fish	13°33´24.45"N 100°38´25.64"E	Anabas testudineus n=2	Pla Mooh – Climbing Perch Omnivore	Fish pond; (Municipal waste landfill; Hazardous waste landfill)	19/17 cm; 16.6/13.8 cm; 142/110 g; 1-2/1-2 years
PKS-EGG1	Egg	13°33´55.31"N 100°38´41.59"E	n=4			Fat content: 18.1%
Khao Hin Sorn						
KHS 6	Fish	13°41´13.20"N 101°35´59.79"E	Oxyeleotris marmorata n=1	Pla Boo – Marble Goby Carnivore	Canal; (Illegal dumping of hazardous waste; Metal smelting)	28.5; 22.3; 340 g; 4 years
KHS 10	Fish	13°42´52.49"N 101°25´40.40"E	Channa striata n=1	Pla Chorn - Snakehead Carnivore	Canal; (Illegal dumping of hazardous waste; Metal smelting)	37.5 cm; 31.5 cm 431 g; 2 years
Koh Samui						
Samui 01	Egg	9°26'58.86"N 100°0'43.47"E	n = 4			Fat content: 12.8 %
Samui 02	Egg	9°26'59.65"N 100° 0'40.97"E	n = 4			Fat content: 14.7 %
Saraburi						
SAR 1	Egg	14°33'38.3"N 100°44'40.3"E	n = 5			Fat content: 11.1 %
Rayong IRPC industrial zone						
IRPC 7	Mollusc	12°39´22.60"N 101°16´54.09"E	Bivalve	Mussels	Port; (Petrochemical plant; Compounding plastics plant; Refineries)	

Sample code	Type of organic samples	Coordinates	Sampled Fish Latin Name, Number of Subjects (n)	Sampled Fish Common Name Feeding Habits	Sampling Spot Description (Potential Source of Contamination)	Length 1; Length 2; Weight; Age/ Fat Content
Klong Dan						
KLO1-3/1-3	Fish	13°28´44.68"N 100°48´09.76"E	Polynemidae n=3	Gulao – Threadfins Carnivore	River mouth	46/47/48.8 cm; 39/39/40.5 cm; 973/1087/1176 g; -
KLO1-3/4-6	Fish	13°28´44.68"N 100°48´09.76"E	Mugillidae n=3	Pla Krabok – Mullet Omnivore	River mouth	24.5/24.6/24.5 cm; 20.5/20.8/19.9 cm; 174/170/165 g; -
KLO1-2	Mollusc	13°28´19.20"N 100°48´51.00"E	Bivalvia	Mussels	Sea	
Chanthaburi						
CHA 3	Fish	12°58´12.50"N 101°45´09.67"E	Neolissochillus stracheyi n=1	Pla Puang – Mahseer Barb Omnivore	Jungle waterfall	23 cm; 18.5 cm; 131 g; 1-2 years
CHA 4	Fish	12°58´11.73"N 101°45´07.81"E	Neolissochillus stracheyi n=1	Pla Puang – Mahseer Barb Omnivore	Jungle waterfall	36 cm; 29.2 cm; 558 g; 3 years
Thap Lan National Park and Klong Yang Canal						
PRN-2017-1	Fish	14°12'19.4"N 101°55'15.2"E	Channa striata n=1	Pla Chorn – Snakehead Omnivore	Water reservoir, Thap Lan National Park	44 cm; 38 cm; 586 g; 0-1 year
PRN-2017-2	Fish	14°14'24.9"N 101°53'02.8"E	Oxyeleotris marmorata n=2	Pla Boo – Marble Goby Carnivore	Klong Yang Canal	23/22 cm; 20/18 cm; 156/127 g; 0-1/0-1 year
PRN-2017-3A+3B	Fish	14°12'19.4"N 101°55'15.2"E	Oreochromis niloticus n=2	Pla Nil – Nile Tilapia Omnivore	Water reservoir, Thap Lan National Park	41/37 cm; 34/29 cm; 1349/1238 g; 1/1 year
Bangkok						
Control group, supermarket	Egg		n=6			Fat content: 12.3 %

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1.6 ABBREVIATIONS

BDS – BioDetection Systems (laboratory in Netherlands)
BEQ – bioanalytical toxic equivalent
BFRs - brominated flame retardants
CALUX – chemically activated luciferase gene expression
CAS – chemical abstracts service registry number (a unique numerical identifier assigned to every chemical substance described in open scientific literature)
BTBPE – 1, 2-bis (2,4,6-tribromo-fenoxy) ethane
CDI – chronic daily intake
DDD – dichlorodiphenyldichloroethane (a metabolite of DDT)
DDE – dichlorodiphenyldichloroethylene (a chemical compound formed by the loss of hydrogen chloride from DDT)
DDT – dichlorodiphenyltricholoroethane (pesticide)
DI – dietary intake
DL PCBs – dioxin-like PCBs
d.w. – dry weight
EFSA – European Food Safety Agency
ELCR - excess lifetime cancer risk
EU – European Union
f.w. – fresh weight
GC – gas chromatography
GEF – Global Environment Facility
GMP – Global Monitoring Plan
GPC - gel permeation chromatography
GPS - global positioning system
HBB - hexabromobenzene
HBCD - hexabromocyclododecane
HCB – hexachlorobenzene
HCBD - hexachlorobutadiene
HCHs – hexachlorocyclohexanes (pesticides and their metabolites)
HpCDD – heptachlorodibenzo-p-dioxin
HpCDF – heptachlorodibenzo-p-furan
HRGC-HRMS – high resolution gas chromatography – high resolution mass spectroscopy
HxCDD – hexachlorodibenzo-p-dioxin
HxCDF – hexachlorodibenzo-p-furan
IPEN – International POPs Elimination Network
IARC - International Agency for Research on Cancer
INC – Intergovernmental Negotiating Committee (normally set up for negotiations of new international convention)
I-TEQ - international toxic equivalent (usually used before introduction of WHO-TEQ as international standard)
LOAEL - lowest observed adverse effect level
LOD – limit of detection
LOQ – limit of quantification
MAC – maximum acceptable (allowable) concentration
ML – maximum level
MONET – Monitoring Network
MRL – maximum residue level
NA – not analyzed
NGO – non-governmental organization (civil society organization)
NIP – National Implementation Plan of the Stockholm Convention
NOAEL - no observed adverse effect level
OBIND – octabromotrimethylfenylindane
OCPs – organochlorinated pesticides

OCDD – octachlorodibenzo-p-dioxin
OCDF – octachlorodibenzo-p-furan
PAHs - polycyclic aromatic hydrocarbons
PAS – Passive air sampler
PBDD/Fs – polyfrominated dibenzo-p-dioxins and furans
PBDEs - polybrominated diphenyl ethers
PBEB – pentabromoethylbenzene
PBT – pentabromotoluen
PCBs – polychlorinated biphenyls
PCDD/Fs – polychlorinated dibenzo-p-dioxins and furans
PCDDs – polychlorinated dibenzo-p-dioxins
PCDFs – polychlorinated furans
PeCB - pentachlorobenzene
PeCDD – pentachlorodibenzo-p-dioxin
PeCDF – pentachlorodibenzo-p-furan
POPs – persistent organic pollutants
PUF – Polyurethane foam
RISC - risk-integrated software for cleanups
RSL - regional screening levels
SC – Stockholm Convention on Persistent Organic Pollutants
TEQ – toxic equivalent
TCDD – tetrachlorodibenzo-p-dioxin
TCDF – tetrachlorodibenzo-p-furan
TDI – tolerable daily intake
TEF – Toxic equivalency factor
TEQ – toxic equivalent
TWI – tolerable week intake
UNDP – United Nations Development Programme
UNECE – United Nations Economic Commission for Europe
U-POPs – unintentionally produced persistent organic pollutants (e.g. dioxins)
US EPA – United States Environmental Protection Agency
VOCs - volatile organic compounds
WHO – World Health Organization
WHO-TEQ – toxic equivalent defined by WHO experts panel in 2005
w.w. – wet weight

2. POPs at five Thai hot spots: Map Ta Phut, Samut Sakhon, Tha Tum, Praeksa and Khon Kaen

Václav Mach, Ph.D.

2.1 SUMMARY

Persistent organic pollutants (POPs) are toxic chemicals that persist over long periods of time in the environment. These chemicals are industrially synthesized organic chemicals (DDT, aldrin, chlordane, dieldrin, endosulfan, PCBs, and many others) or unintentional products of chemical and combustion processes (dioxins, hexachlorobutadiene, hexachlorobenzene, PCBs and other). The demand for agricultural productivity caused a rapid increase in the use of organochlorine pesticides in Thailand from 1950 to early 1970. Moreover, some other POPs and PCBs were imported to Thailand in various products. Environmental implications from historical use of organochlorine pesticides, PCBs, and other POPs remain. Furthermore, unintentional POPs are still synthesized and emitted into the environment from many industrial processes. This study is focused on the presentation of data related to contamination by POPs in four hotspot areas in Thailand. These hotspot areas are: The Map Ta Phut industrial complex, the Samut Sakhon hotspot area, the Tha Tum industrial complex, and the Pulp and Paper industrial area near Khon Kaen. The data was obtained from these hotspot areas during three sampling campaigns conducted in Thailand from February 2015 to March 2017. The field campaigns allowed for the inspection of the hotspot areas and collection of organic (fish, mollusc, shellfish, and chicken eggs) and inorganic samples (soil, sediment, and ash). The background fish samples were taken in the Thap Lan National Park – representing an unpolluted area of Thailand. The background egg sample was bought in a supermarket in Bangkok. Collected samples were analyzed for content of multiple POPs – dioxins (PCDD/Fs), PCBs, chlorobenzenes, organochlorine pesticides, polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers, hexabromocyclododecane, and brominated flame retardants. Our results show that organochlorine pesticide residue is still present in the environment of Thailand. The most common organochlorine pesticide is DDT and its residues, which is backed by literature and data on amounts of pesticides used. The most problematic POPs found in the hotspot areas are unintentionally produced chemicals, such as dioxins, hexachlorobenzene, pentachlorobenzene, PCBs, hexachlorobutadiene, and hexachlorocyclohexane. These contaminants can be created during industrial processes, such as paper bleaching, waste recycling operations, open burning of waste (e-waste in particular), chlor-alkali production, production of plastics, or waste incineration. The most contaminated matrix in the hotspot areas are eggs, because most of the egg samples exceed the maximum residue limits of hexachlorobenzene and hexachlorocyclohexane for Thailand or maximum levels of PCBs and PCDD/Fs for the European Union.

2.2. INTRODUCTION

Persistent organic pollutants are industrially synthesized organic chemicals or unintentional products of chemical and combustion processes that persist over long periods of time in the environment and are toxic for people and wildlife. [20] These contaminants accumulate in the tissues of living organisms and are often found in higher concentrations at the upper levels of food chains [21]. Persistent organic pollutants (POPs) can also be transported over long distances by natural processes that involve soil, water, and wind. [22] POPs may be divided into two broad groups: agricultural organochlorine pesticides and industrial chemicals; though, some POPs, for example hexachlorobenzene (HCB), were used as both pesticides and industrial chemicals. Some POPs, such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), are generated unintentionally as by-products of various industrial processes [23]. Problems associated with POPs are not only found in rural areas with historic or recent agricultural applications of organochlorine pesticides, but are also found in urban and industrial areas, where industrial manufacturing processes, solid waste landfills, pesticide stockpiles, waste incineration, and disease vector control programs induce the emission of large amounts of POPs. Many POPs were originally developed and synthesized for use during the 1930s and 1940s, and their applications became widespread around the world during the 1950s and 1960s. By the early 1970s, concerns over environmental persistence and the adverse effects on humans culminated in restricting the use of POPs in many countries. Subsequent restrictions and bans became worldwide by the late 1990s and early 2000s [24].

In Thailand, the demand for agricultural productivity caused a rapid increase in the use of pesticides. During the period from 1950 to early 1970, most of the imported pesticides were organochlorine pesticides. The first record of the use of POPs in Thailand was in 1949, when DDT was first introduced as a means of malaria control. [25] The Malaria epidemic in 1951 was very serious and killed over 40,000 Thai people; therefore, DDT has been widely applied. DDT has also been used in agriculture for pest control. Dieldrin, aldrin, and endrin were introduced to Thailand in 1955, and lindane (γ-hexachlorcyklohexane) and toxaphene followed in 1959. These organochlorine pesticides have been widely applied for the pest control of almost all crops including cassava, fruit, and vegetable crops. In 1971, toxaphene, DDT, and lindane formed the volume of 62; 1,968; and 17 metric tons respectively. In the same year, the volume of dieldrin, aldrin, endrin, chlordane, and heptachlor were less: 8, 6, 0.8, 3, and 1 metric ton respectively. In general, the importation of these organochlorine pesticides had increased until they were banned in specified years due to impacts on human health and the environment. Import of most organochlorine pesticides has been banned since the 1980s: endrin in 1981; toxaphene in 1983; DDT for agricultural use in 1983 and for malaria control in 1994; aldrin, dieldrin, and heptachlor in 1988; chlordane for public health use in 1995 and for agricultural use in 2000 (Table 1) [26]. According to the National Implementation Plan of Thailand [27], mirex and HCB have never been imported or used in Thailand. There is evidence that stockpiles of obsolete organochlorine pesticides might be found in the old pesticide storage at agricultural facilities.

According to the National Implementation Plan of Stockholm Convention [27], polychlorinated biphenyls (PCBs) have never been imported to Thailand for industrial use in the form of liquid. The main purpose for which they were used in a relatively large quantity was as a dielectric fluid for electric capacitors and transformers. Capacitors and transformers were imported into Thailand until 1975. Moreover, PCBs have been used in small amounts as industrial fluids for hydraulic systems and gas turbines, as lubricating oil, and as a plasticizer [25]. Imported volumes and the date for all these purposes have never been recorded. PCB importation has been controlled by the Toxic Act Committee in Thailand since 1975, and no importation permit was granted. In October 2004, PCBs were reclassified from a Type III chemical, that of which the production, import, export, or possession of must obtain a permit, to a Type IV chemical, that of which the production, import, export or possession of is prohibited. The PCB inventory carried out in 2005 indicated that there were 973 PCBs containing capacitors and transformers at a total weight of almost 1,912 tons being kept in safe storage. [27] Nevertheless, the actual amounts may be higher due to the lack of import data, identification technique and equipment, and information [28]. According to the Department of Industrial Works, data collected under the

Basel Convention showed that approximately 761 tons of PCBs wastes were exported from 1992 to 2002. Some of the used capacitors and transformers were sent to France, the United Kingdom, and Belgium for final disposal [26]. Besides the intentional production of PCBs, there is also unintentional formation of PCBs from cement, chlorine and steel industries.

Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) and some other POPs (PCBs, HCB, and HCHs) are unintentionally formed and released from thermal processes involving organic matter and chlorine as a result of incomplete combustion or chemical reactions [29]. Industrial source categories listed in Annex C, Part II and Part III of the Stockholm Convention on POPs have the potential for comparatively high formation and release of these chemicals into the environment. These industrial source categories also exist to some extent in Thailand. In 2005, PCDD/F inventory had been carried out and potential releases of PCDD/Fs emission to air, water, land, product, and residue were estimated from mass production multiplying with the default emission factor proposed by the UNEP's Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases. The maximum emission to residue was found at the amount of 773.30 g I-TEQ/a, followed by emission to air at the amount of 286.30 g I-TEQ/a. The amount of emission to product, land and water were 8.31, 6.64, and 1.33 g I-TEQ/a, respectively. Emission to residue was found to be the highest for production of chemicals and consumer goods at an amount of 384.16 g I-TEQ/a (49.68%), followed by the uncontrolled combustion process of 236.10 g I-TEQ/a (30.53%)), ferrous and non-ferrous metal production of 99.64 g I-TEQ/a (12.89%), waste incineration of 32.45 g I-TEQ/a (4.20%), and power generation and heating of 14.28 g I-TEQ/a (1.85%). Emission to air was found to be the highest for the uncontrolled combustion process at an amount of 144.24 g I-TEQ/a, followed by waste incineration of 42.37 g I-TEQ/a, power generation and heating of 33.33 g I-TEQ/a, miscellaneous of 21.81 g I-TEQ/a and ferrous and non-ferrous metal production of 20.20 g I-TEQ/a [27]. According to the National Implementation Plan of the Stockholm Convention from 2005, Best Available Techniques (BAT) and Best Environmental Practices (BEP) were not applied to any of the source categories of PCDD/Fs due to a limitation on financial and technical supports to these source categories.

Brominated flame retardants (BFRs) are a group of bromine-containing organic compounds, which are used to prevent or retard the spread of fires. They are present in a broad range of consumer and industrial products, such as electronic and electrical devices, printed circuit boards, furniture, construction materials, and automotive parts and plastics. Polybrominated diphenylethers (PBDEs) and hexabromocyclododecane (HBCD) are among the most widely used BFRs and have attracted significant interest during the last decade. Many BFRs are hydrophobic and persistent in the environment, leading to the contamination of humans, wildlife, and ecosystems. BFRs have been highlighted as a problem meriting serious and urgent attention. [30] BFRs pose a potential threat to human health and the environment. Due to a growing number of both human health and environmental concerns associated with BFRs, the tetrabromodiphenyl ether, pentabromodiphenyl ether, hexabromodiphenyl ether, heptabromodiphenyl ether, HBCD, and hexabrombifenyl have been regulated under the Stockholm Convention on POPs in 2009 and/or 2013. Despite this, BFRs may be present in a diverse array of goods and wastes, especially electronic waste. In 2003, the total electronic waste produced in Thailand was estimated at approximately 58,000 tons. Contamination by some BFRs (e.g. PBDEs) in electronic waste storage facilities was reported in Thailand recently. [31] The evidence of the cited study suggests that improper storage of e-waste may constitute a source of BFRs in the Thai environment.

Efforts have been made to regulate and phase out POPs through international environmental treaties, such as the Stockholm Convention on POPs. The Stockholm Convention, which came into effect in 2004, initially identified twelve chemicals or chemical groups for regulation and elimination of production and use. The number of chemicals added to the list of POPs under the Stockholm Convention has been increasing, with 28 chemicals or chemical groups presently listed for elimination. Thailand has signed and ratified the Stockholm Convention on POPs since May 22, 2002 and January 31, 2005, respectively. In accordance with the main provisions of the Stockholm Convention, each country that is a party to the Convention prohibits and/or takes legal and administrative actions required for the elimination and/or restriction of production and use of chemicals listed in Annexes A and B to the Convention, as well as on reduction or elimination of POP releases resulting from

intended or unintended production, as well as releases related to stocks and wastes containing POPs. The Stockholm Convention regulates the following pesticides: chlordecone, hexachlorocyclohexane (HCH), pentachlorobenzene (PeCB), DDT, aldrin, chlordane, dieldrin, endosulfan, endrin, heptachlor, hexachlorobenzene (HCB), mirex and toxaphene. Further, it regulates these industrial chemicals: PCBs, HCB, hexabromobiphenyl, hexabromodiphenyl ether, heptabromodiphenyl ether, PeCB, perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride, short chain chlorinated paraffin (SCCP), tetrabromodiphenyl ether, pentabromodiphenyl ether, and decabromodiphenyl ether. It also regulates unintentional by-products: polychlorinated dibenzofurans (PCDFs), polychlorinated dibenzo-p-dioxins (PCDDs), hexachlorobutadien (HCBD), HCH, PeCB, HCB, and PCBs. [32]

Environmental implications for human health from a historical use of organochlorine pesticides, PCBs, and other POPs remain. Unintentional POPs are still synthesized and emitted into the environment from many industrial processes [24]. Toxic burdens and emissions of POPs need to be assessed, as well as mitigated. This study is focused on the presentation of the data related to the contamination of organic and inorganic matrices by POPs in four hotspot areas. These hotspots areas are: The Map Ta Phut industrial complex, the Samut Sakhon hotspot area, the Tha Tum industrial complex, and the Pulp and Paper industrial area near Khon Kaen. The data presented in this report was obtained during a sampling campaign conducted in Thailand in February 2016. The sampling campaign represents an important part of the project "Increasing Transparency in Industrial Pollution Management through Citizen Science." This is a joint project of the Czech non-governmental organization Arnika Association and the Thai partner, Ecological Alert and Recovery – Thailand (EARTH). The main goals of the project are to increase the negotiating power of communities affected by industrial pollution in their demands for corporate and government accountability, and to increase transparency in industrial pollution management policies and processes in Thailand. These goals include: enabling communities affected by

Tab. 1: *Banned POPs in Thailand according to Department of Agriculture. "PH" means public health use, "AG" means agricultural use.*

Chemicals	Date of ban	Reasons
Aldrin	1988	Persistent, accumulate in living organisms
Chlordane	1995 (PH), 2000 (AG)	Possible carcinogen, persistent, high impact to environment, many alternatives
DDT	1983 (AG), 1994 (PH)	Persistent and accumulation in food chains, possible carcinogen in tested animals
Dieldrin	1988	Persistent, accumulate in living organisms, high acute poisoning, high risk for users
Endrin	1981	Persistent in agricultural products and in food chain, harm to non-target organisms
Heptachlor	1988	Persistent, accumulate in living organisms
Hexachlorobenzene	1980	Never imported
Mirex	1995	Never imported
PCBs	2004	Risk to human health and the environment
Toxaphene	1983	Possible carcinogen in tested animals, persistent

industrial pollution to generate scientific evidence, broadening awareness about environmental and health damages from industrial pollution, and promoting citizens' right-to-know in Thailand and raise awareness on good practices of right-to-know legislation from the European Union, as a participatory mechanism for pollution reduction and prevention.

2.3 SAMPLING AND ANALYTICAL METHODS

Inorganic and organic samples for this study were taken on four hot spot areas in several regions of Thailand. The sampling procedure and the detailed list of samples are presented in General Introduction.

Inorganic samples-- soil, sediment, and ash-- were analyzed for content of PCDD/Fs, dioxin-like PCBs (DL PCBs), seven indicate congeners of PCBs (∑ 7 PCBs), chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, QClB), organochlorine pesticides (HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, endrin, aldrin, octachlorstyrene, chlordan, oxychlordane, methoxychlor, mirex), and polycyclic aromatic hydrocarbons (PAHs). Organic samples-- fish, mollusc, shellfish, and chicken eggs-- were analyzed for content of PCDD/Fs, DL PCBs, ∑ 7 PCBs, chlorobenzenes (HCB, PeCB), hexachlorobutadiene (HCBD), organochlorine pesticides (HCH, DDT), polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), and other brominated flame retardants (BFRs).

To test for content of PCDD/Fs and DL PCBs, inorganic and organic samples were analyzed by the high-resolution gas chromatography/high-resolution mass spectrometry at the accredited laboratories of Axys-Varilab,s.r.o. in Vrané nad Vltavou and at the State Veterinary Institute, both located in Prague, Czech Republic. Some organic samples (fish and shellfish) were analyzed for PCDD/Fs and DL PCBs using the DR CALUX method. [33] These were sent to the Dutch ISO 17025 certified laboratory BioDetection Systems B.V. in Amsterdam, Netherlands. DR CALUX's analysis results comply with EU requirements, as indicated in the Commission Regulation (EC) No 252/2012. Analysis for the content of ∑ 7 PCBs in inorganic and organic samples was conducted by high-resolution gas chromatography/high-resolution mass spectrometry at the accredited laboratory, Axys-Varilab, s.r.o. in Vrané nad Vltavou, and by gas chromatography coupled with tandem mass spectrometry at the accredited laboratory at the University of Chemistry and Technology, Department of Food Chemistry and Analysis, both located in Prague, Czech Republic.

Inorganic and organic samples were analyzed for the content of chlorobenzenes (HCB and PeCB), HCBD, and organochlorine pesticides (HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin) by gas chromatography coupled with tandem mass spectrometry at the accredited laboratory of the University of Chemistry and Technology, Department of Food Chemistry and Analysis in Prague, Czech Republic. Some inorganic samples were analyzed for chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, and QClB) and organochlorine pesticides (HCH, DDT, aldrin, oktachlorstyren, chlordan, oxychlordan, metoxychlor, and mirex) by gas chromatography with an electron capture detector at the accredited laboratory of the State Veterinary Institute in Prague, Czech Republic.

In some organic samples (fish and chicken eggs), the content of PBDEs and other brominated flame retardants (BFRs) were analyzed by gas chromatography coupled with tandem mass spectrometry and the content of HBCD was analyzed by ultra-high-pressure liquid chromatography, coupled with tandem mass spectrometry, both at the accredited laboratory of the University of Chemistry and Technology, Department of Food Chemistry and Analysis in Prague, Czech Republic. The content of PAHs in inorganic and organic samples was analyzed by high-resolution gas chromatography/high- resolution mass spectrometry at the accredited laboratory of Axys-Varilab s.r.o. in Vrané nad Vltavou, Czech Republic. Some inorganic samples were analyzed for PAHs by the high-resolution liquid chromatography with fluorescence detection at the accredited laboratory of the University of Chemistry and Technology, Department of Food Chemistry and Analysis in Prague, Czech Republic. One chicken egg sample was also analyzed for the content of polybrominated dibenzo-p-dioxins and polybrominated dibenzofurans (PBDD/Fs) by the high-resolution gas chromatography/high-resolution mass spectrometry analysis at the Dutch ISO 17025 certified laboratory BioDetection Systems B.V. in Amsterdam, Netherlands.

Tab. 2: *Levels of detection in inorganic matrices (sediment, soil, and ash)*

Compounds	Level of detection
PCBs (each of 7 indicating congeners)	0.05 µg/kg
PAHs (each of 16 homologues)	0.5 µg/kg
Organochlorine pesticides and chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, QClB, HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, endrin, aldrin, oktachlorstyren, chlordan, oxychlordan, metoxychlor, mirex)	0.05 µg/kg

2.4 RESULTS

The results of chemical analyses of PCDD/Fs, PCBs, organochlorine pesticides (HCB, HCH, PeCB, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin), HBCDs, and naphthalene in sediment and ash samples from the Map Ta Phut hotspot are presented in Table 3. Levels of all the contaminants in inorganic matrices, except PCBs, HCBs, PeCB, DDTs, HBCDs, and naphthalene, are below the level of detection (<LOD). Table 4 shows results of chemical analyses of various POPs in organic samples (fish, mollusc, crustacean, and eggs) from the Map Ta Phut hotspot. There are measurable levels of PCDD/Fs, PCBs, chlorobenzenes (HCB, PeCB), HCBD, organochlorine pesticides (DDTs, HCH), brominated flame retardants (PBDEs, HBCD, and others), and PAHs in organic matrices from the hotspot.

Results of the analytical measurements of PCDD/Fs, PCBs, organochlorine pesticides (HCB, HCH, DDT, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin), and PAHs in samples of sediments, soils and ashes from the Samut Sakhon hotspot are presented in Table 5. All concentrations of the contaminants, except PCDD/Fs, PCBs, and PAHs, are below the level of detection (<LOD). The results of chemical analyses of various POPs in fish and eggs from the Samut Sakhon hotspot are shown in Table 6. There are measurable levels of PCDD/Fs, PCBs, DDTs, and PAHs in fish and eggs from this hotspot. Moreover, there are measurable concentrations of PBDD/Fs, chlorobenzenes (HCB, PeCB), HCBD, HCH, and PBDEs in at least one sample of eggs from Samut Sakhon.

Table 7 shows results of chemical analyses of various POPs (PCDD/Fs, PCB, chlorobenzenes, organochlorine pesticides, and PAHs) in inorganic samples (sediment and ash) from the Tha Tum hotspot area. Measurable values of PCDD/Fs, PCBs, and PAHs are detected in some sediment samples. Few sediment samples show measurable values of HCB and/or DDTs and one sample of sediment shows a measurable value of mirex. The results of chemical analyses of PCDD/Fs, PCBs, chlorobenzenes (HCB, PeCB), HCBD, and organochlorine pesticides (HCHs and DDTs) in organic matrices (two fish, one mollusc, and one egg) from Tha Tum are shown in Table 8. Concentrations of all measured POPs in the fish samples from Tha Tum are below the level of quantification (<LOQ). The egg sample has measurable concentrations of PCDD/Fs, PCBs, HCB, HCHs, and DDTs, while the mollusc sample has measurable concentrations of HCB and DDTs.

The results of chemical analyses of PCDD/Fs, PCBs, organochlorine pesticides (HCB, HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin), and PAHs in samples of sediments and one sample of ash from the Khon Kaen hotspot area are presented in Table 9. All levels of the contaminants in sediment samples are below the level of detection (<LOD). The sample of ash has measurable concentrations of PCDD/Fs, PCBs, and PAHs. Table 10 shows results of the chemical analyses of various POPs (PCDD/Fs, PCBs, HCB, PeCB, HBCD, HCHs, DDTs, PAHs) in organic samples (fish and eggs) from the Khon Kaen hotspot. The fish samples only show measurable levels of DDTs. The egg samples show measurable levels of PCDD/Fs, PCBs, HCB, HCHs, DDTs, and PAHs.

Tables 4, 6, and 8, show the results of CALUX bioassays to specify effects of PCDD/Fs and PCDD/Fs + DL PCBs in organic samples from the Map Ta Phut, the Samut Sakhon, and the Tha Tum hotspot areas. All treated samples are compliant and some of them are also below the level of quantification (<LOQ).

Tab. 3: *Results of inorganic samples from Map Ta Phut hotspot area. Complete results are listed in the Annex 1.*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 7 PCBs[1] [µg/kg DW]	HCB [µg/kg DW]	PeCB [µg/kg DW]	∑ 3 HCHs[2] [µg/kg DW]	∑ DDTs[3] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[4] [µg/kg DW]	Endosulfan[5] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ HBCDs[6] [µg/kg DW]	∑ 16 PBDEs[7] [µg/kg DW]	Napthalene [µg/kg DW]
MTP 1-2	ash	<LOD	**0.0042**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MTP 1-8	sediment	NA	NA	**0.258**	**0.079**	**0.075**	<LOD	**0.647**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-13	sediment	NA	NA	**0.167**	<LOD	**0.025**	<LOD	**0.326**	<LOD	<LOD	<LOD	<LOD	<LOD	**0.05**	<LOD	**0.5**
MTP 1-16	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.5**
MTP 1-17	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**1.7**
MTP 2-3	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.6**
MTP 2-5	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.7**
MTP 2-6	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.6**

1) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

2) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

3) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

4) Heptachlor epoxide is sum of isomers cis and trans.

5) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

6) ∑ HBCDs is sum of isomers α-HBCD, β-HBCD, and γ-HBCD.

7) ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.

Tab. 4: *Results of organic samples from Map Ta Phut hotspot area*

NAME	MATRIX	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs DR CALUX [ng BEQ/kg]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3] [µg/kg fat]	∑ DDTs[4] [µg/kg fat]	∑ 16 PBDEs[5] [µg/kg fat]	∑ HBCDs[6] [µg/kg fat]	∑ 6 BFRs[7] or ∑ 5 BFRs[8] [µg/kg fat]	∑ 16 PAHs[9] or ∑ 12 PAHs[10] [µg/kg fat]
MTP 1-10/1	fish	NA	NA	NA	**0.12**	**550.06**	**550.06**	<LOQ	**9.62**	<LOQ	<LOQ	**176.67**	**646.77**	**36.0**	<LOQ[7]	NA
MTP 1-10/2	fish	**0.1**	**0.001**	NA	NA	<LOQ	<LOQ	<LOQ	**20.16**	<LOQ	<LOQ	**52.67**	<LOQ	**86.6**	<LOQ[7]	**104[9]**
MTP 2-1/1	fish	NA	NA	NA	**0.15**	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**292.3**	<LOQ	**54.2**	<LOQ[7]	NA
MTP 2-1/2	fish	NA	NA	NA	**0.15**	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**113.54**	**36.49**	**19.6**	<LOQ[7]	NA
MTP 2-8	fish	NA	NA	NA	**1.9**	**19.57**	**19.57**	**45.84**	**2.47**	**2.47**	**3.04**	**27.58**	**49.88**	**9.8**	<LOQ[7]	NA
MTP 2-9	fish	**0.4**	**0.28**	NA	NA	**59.67**	**59.67**	**64.7**	**29.08**	**2.68**	**5.34**	**24.90**	**94.28**	**7.1**	<LOQ[7]	**77[9]**
MTP-2017-1A+1B	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**20**	NA	NA	NA	**14.67[10]**
MTP-2017-2	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**31.62**	<LOQ	**34.19[7]**	**5.98[10]**
MTP-2017-3	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**11.94**	<LOQ	<LOQ	<LOQ[7]	**19.4[10]**
MTP-2017-5	fish	NA	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ[7]	**375[10]**
MTP-2017-8	fish	NA	NA	NA	NA	NA	NA	NA	**4.55**	<LOQ	NA	NA	NA	NA	NA	**33.33[10]**
MTP 1-4	mollusc	**0.7**	**0.05**	NA	NA	<LOQ	<LOQ	<LOQ	**0.6**	<LOQ	<LOQ	**2.55**	NA	NA	NA	**1710[9]**
MTP 1-3	crustacean	<LOQ	**8**	0.3 (<LOQ)	0.6 (<LOQ)	**15.17**	**17.57**	NA	NA	NA	NA	NA	NA	NA	NA	**1210[9]**

NAME	MATRIX	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs DR CALUX [ng BEQ/kg]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3] [µg/kg fat]	∑ DDTs[4] [µg/kg fat]	∑ 16 PBDEs[5] [µg/kg fat]	∑ HBCDs[6] [µg/kg fat]	∑ 6 BFRs[7] or ∑ 5 BFRs[8] [µg/kg fat]	∑ 16 PAHs[9] or ∑ 12 PAHs[10] [µg/kg fat]
MTP 1-5	crustacean	<LOQ	**0.2**	0.1 (<LOQ)	0.2 (<LOQ)	**17.2**	**20.1**	NA	NA	NA	NA	NA	NA	NA	NA	**4900**[9]
MTP 1-9	crustacean	**12.2**	**51.69**	**0.56**	**0.67**	**30.4**	**35.5**	NA	NA	NA	NA	NA	NA	NA	NA	**2310**[9]
MTP 2-18	egg	**0.8**	**0.73**	NA	NA	**0.95**	**1.11**	**4.01**	<LOQ	<LOQ	**1.77**	**19.25**	**1.09**	**40.68**	**0.34**[8]	**280**[9]
MTP 2-19	egg	**2.3**	**0.95**	NA	NA	**3.54**	**4.46**	**6**	<LOQ	<LOQ	**1.68**	**8.43**	**3.3**	**166.81**	**0.27**[8]	**198**[9]
MTP 1-11	egg	**0.5**	**1.61**	NA	NA	**0.5**	**0.64**	**4.43**	<LOQ	<LOQ	**6.25**	**8.35**	**44.95**	**185.55**	**0.76**[8]	**1152**[9]
MAP-1	egg	**6.5**	**1.91**	NA	NA	**1.4**	**1.7**	NA	NA	NA	NA	NA	NA	NA	NA	**3166**[9]

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.

6) ∑ HBCDs is sum of isomers α-HBCD, β-HBCD, and γ-HBCD.

7) ∑ 6 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, PBEB, and PBT.

8) ∑ 5 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, and PBEB.

9) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

10) ∑ 12 PAHs is sum of phenanthrene, anthracene, fluoranthene, pyrene, benzo(a) anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a) pyrene, indeno(1,2,3-cd)pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 5: *Results of inorganic samples from Samut Sakhon hotspot area. Complete results are listed in the Annex 1.*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1)] [µg/kg DW]	∑ 7 PCBs[2)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs3) [µg/kg DW]	∑ DDTs4) [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide5) [µg/kg DW]	Endosulfan6) [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	Naphthalene [µg/kg DW]	∑ 16 PAHs7) [µg/kg DW]
SMS 1-11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**1.4**	NA
SMS 1-14	sediment	**12**	**1.54**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**	NA
SMS 2-4	ash	**40.5**	**5.67**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SMS 2-6	sediment	**8.05**	**1.71**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
A3	soil	**35.2**	**5.72**	**1.2**	**7.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1747**
A2	soil	**12.8**	**0.001**	**1.06**	**1.06**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**488**
A1	ash	**1.9**	**0.27**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**3210**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) Heptachlor epoxide is sum of isomers cis and trans.

6) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

7) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 6: *Results of organic samples from Samut Sakhon hotspot area*

NAME	MATRIX	PCDD/Fs [ng WHO-TEQ/kg fat]	PBDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3] [µg/kg fat]	∑ DDTs[4] [µg/kg fat]	∑ 16 PBDEs[5] [µg/kg fat]	∑ 5 BFRs[6] [µg/kg fat]	∑ 16 PAHs[7] [µg/kg fat]	∑ 4 PAHs[8] [µg/kg fresh] EU
SMS 1-12/1,2	fish	NA	NA	NA	0.1 (<LOQ)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SMS 1-12/1-(1-2)	fish	NA	NA	NA	NA	**112.21**	**112.21**	<LOQ	NA	NA	<LOQ	**81.87**	NA	NA	NA	NA
SMS 1-12/2-(1-2)	fish	NA	NA	NA	NA	**31.02**	**31.02**	<LOQ	NA	NA	<LOQ	**37.35**	NA	NA	NA	NA
SMS 1-12/3	fish	NA	NA	NA	NA	**43.25**	**43.25**	<LOQ	NA	NA	<LOQ	**39.12**	NA	NA	NA	NA
SMS 1-2/1-3	fish	**0.2**	NA	**0.05**	NA	**6.77**	**6.77**	<LOQ	NA	NA	<LOQ	**17.28**	NA	NA	**48**	NA
SMS 2F	fish	<LOQ	NA	**0.08**[9]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1.3**
SMS 2-13	egg	**6.2**	NA	**6**	NA	**7.08**	**8.07**	NA	**1.49**	<LOQ	NA	NA	NA	NA	**2730**	NA
Samut Sakhon	egg	**84.04**	**15.8**	**11.67**	NA	**11.4**	**12.97**	**4.21**	NA	NA	**0.31**	**2.85**	**3.1**	<LOQ	NA	NA

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.

6) ∑ 5 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, and PBEB.

7) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene , indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, dibenzo(a,h)anthracene.

8) ∑ 4 PAHs is sum of benzo(a)anthracene, chrysene, benzo(b)fluoranthene, and benzo(a)pyrene.

9) Value is in ng WHO-TEQ/kg fresh weight.

Tab. 7: *Results of inorganic samples from Tha Tum hotspot area. Complete results are listed in the Annex 1.*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	TeClB [µg/kg DW]	1,2,3,4-TeClB [µg/kg DW]	QClB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Aldrin [µg/kg DW]	Oktachlorstyren [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Chlordan[6] [µg/kg DW]	Oxychlordan [µg/kg DW]	Metoxychlor [µg/kg DW]	Mirex [µg/kg DW]	Endosulfan[7] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[8] [µg/kg DW]
TT 1-11	sediment	NA	NA	**0.28**	**0.28**	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
S1	sediment	**1.6**	**0.013**	<LOD	<LOD	**0.23**	<LOD	<LOD	<LOD	<LOD	**0.44**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**137**
S2	sediment	**1.27**	**0.026**	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**631**
S3	sediment	**3.76**	**0.022**	NA	NA	**0.22**	<LOD	<LOD	<LOD	<LOD	**0.14**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.32**	NA	NA	NA	**576**
S4	sediment	**0.22**	**0.048**	NA	NA	**0.30**	<LOD	<LOD	<LOD	<LOD	**2.2**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**85**
S5	ash	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**6683**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) Heptachlor epoxide is sum of isomers cis and trans.

6) Chlordan is sum of isomers cis and trans.

7) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

8) 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 8: *Results of organic samples from Tha Tum hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3] [µg/kg fat]	∑ DDTs[4] [µg/kg fat]
TT 2-8	Fish	NA	NA	0.1 (<LOQ)	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TT 2-6	Fish	NA	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TT 2-9	mollusc	NA	NA	NA	<LOQ	<LOQ	**2**	**0.8**	<LOQ	<LOQ	**4.35**
Tha Thum	Egg	**4.27**	**3.94**	NA	**0.39**	**0.39**	**1.51**	NA	NA	**0.23**	**0.83**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

Tab. 9: *Results of inorganic samples from Khon Kaen hotspot area. Complete results are listed in the Annex 1.*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Endosulfan[6] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[7] [µg/kg DW]
KK 5	ash	**0.9**	**1.04**	**0.29**	**0.33**	NA	NA	NA	NA	NA	NA	NA	NA	**310**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) Heptachlor epoxide is sum of isomers cis and trans.

6) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

7) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 10: *Results of organic samples from Khon Kaen hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	∑ 6 PCBs[1)] [µg/kg fat]	∑ 7 PCBs[2)] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg fat]	HCBD [µg/kg fat]	∑ 3 HCHs[3)] [µg/kg fat]	∑ DDTs[4)] [µg/kg fat]	∑ 16 PAHs[5)] [µg/kg fat]
KK 12/1	Fish	NA	NA	<LOQ	<LOQ	<LOQ	NA	NA	<LOQ	<LOQ	NA
KK 14/1	Fish	NA	NA	<LOQ	<LOQ	<LOQ	NA	NA	<LOQ	**9.08**	NA
KK 14/2	Fish	NA	NA	<LOQ	<LOQ	<LOQ	NA	NA	<LOQ	**18.61**	NA
KK 1	Egg	**1.5**	**0.83**	**1**	**1.16**	NA	NA	NA	NA	NA	**3985**
KK 1/1	Egg	NA	NA	NA	NA	**5.52**	<LOQ	<LOQ	**1.53**	**10.06**	NA
KK 1/2	Egg	NA	NA	NA	NA	**5.24**	<LOQ	<LOQ	**2.34**	**20.43**	NA

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a) pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, dibenzo(a,h)anthracene.

Tab. 11: *Results of inorganic samples from Praeksa hotspot area. Complete results are listed in the Annex 1.*

Name	Matrix	∑ 6 PCBs[1)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[2)] [µg/kg DW]	∑ DDTs[3)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[4)] [µg/kg DW]	Endosulfan[5)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[6)] [µg/kg DW]
PKS1	sediment	NA	NA	NA	NA	NA	NA	NA	NA	NA	**186**
PKS 2	sediment	NA	NA	NA	NA	NA	NA	NA	NA	NA	**285**
6x PR[7)]	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

3) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

4) Heptachlor epoxide is sum of isomers cis and trans.

5) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

6) 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

7) PCBs, HCB, HCHs, DDTs, heptachlor, heptachlor epoxides, endosulfan, dieldrin and endrin were also analyzed in samples of sediments PRE 1-1, PR 1, PR 2, PR 4, PR 5 and PR 8. Levels of all these chemicals were below LOD in those samples, so they are listed in Annex 1 only and here represented as one row for all.

Tab. 12: *Results of organic samples from Praeksa hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	PCDD/Fs + DL PCBs DR CALUX [ng BEQ/kg]	∑ 6 PCBs[1)] [µg/kg fat]	∑ 7 PCBs[2)] [µg/kg fat]	HCB [µg/kg fat]	∑ 3 HCHs[3)] [µg/kg fat]	∑ DDTs[4)] [µg/kg fat]	∑ 16 PAHs[5)] [µg/kg DW]
PR 3	Fish	NA	NA	0.1 (<LOQ)	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	NA
PR 7	Fish	NA	NA	NA	<LOQ	<LOQ	**2.5**	<LOQ	**4.17**	NA
PKS-EGG1	Egg	**6.17**	**3.41**	NA	**2.56**	NA	NA	NA	NA	**559.9**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

Tab. 13: *Results of background organic samples (supermarket in Bangkok and Thap Lan National Park)*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg fat]	DL PCBs [ng WHO-TEQ/kg fat]	∑ 6 PCBs[1] [µg/kg fat]	∑ 7 PCBs[2] [µg/kg fat]	HCB [µg/kg fat]	PeCB [µg/kg]	HCBD [µg/kg]	∑ 3 HCHs[3] [µg/kg]	∑ DDTs[4] [µg/kg fat]	∑ 16 PBDEs[5] [µg/kg fat]	∑ HBCDs[6] [µg/kg fat]	∑ 6 BFRs[7] [µg/kg]	∑ 16 PAHs[8] or ∑ 12 PAHs[9] [µg/kg fat]
PRN-2017-1	Fish	NA	NA	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	**51.28**	<LOQ	<LOQ	<LOQ	**28.21[9]**
PRN-2017-3A+3B	Fish	NA	NA	NA	NA	<LOQ	NA	NA	<LOQ	**47.62**	<LOQ	<LOQ	<LOQ	NA
PRN-2017-2	Fish	NA	NA	<LOQ	<LOQ	NA	<LOQ	<LOQ	NA	NA	NA	NA	NA	NA
Control group, supermarket	Egg	**0.1**	**0.001**	**0.22**	**0.22**	<LOQ	<LOQ	<LOQ	**0.52**	<LOQ	**3.1**	<LOQ	<LOQ	**233[8]**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.

6) ∑ HBCDs is sum of isomers α-HBCD, β-HBCD, and γ-HBCD.

7) ∑ 6 BFRs is sum of BTBPE, DBDPE, HBB, OBIND, PBEB, and PBT.

8) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

9) ∑ 12 PAHs is sum of phenanthrene, anthracene, fluoranthene, pyrene, benzo(a) anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a) pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

2.5 DISCUSSION

The POPs concentrations determined in the samples could be compared with background levels and pollution criteria. These values could be helpful to discuss and evaluate our results. The measured background levels of POP in fish and eggs are presented in Table 11, as background levels can be instrumental, as well as literature data of POPs. In the report conducted at the large brackish Songkhla Lake and the Gulf of Thailand, concentrations of DDTs (sum of p,p'-DDT, p,p'-DDE, and p,p'-DDD) were measured in 113 fish of four species (*Scatophagus argus*, *Protosus canius*, *Channa striata*, and *Zonichthys nigrofasciata*). The mean DDT concentrations at different locations in the analyzed fish species ranged from 33 to 170 µg/kg fat [34]. Levels of HCB, HCHs, DDTs, and PCBs in foodstuffs were investigated in Bangkok in 1991 [35]. Levels of these contaminants in five fish species from the investigation are shown in Table 12. Levels of organochlorine pesticides and PCBs in sediments collected from the east coast of Thailand were reported in 2014 [36]. The mean concentrations of contaminants from nine sampling sites are shown in Table 13.

Tab. 12: *Levels of organochlorine pesticide and PCBs in fish bought at fish markets in Bangkok[35].*

	n	Fat [%]	∑ PCBs [µg/kg fat]	∑ 4 HCHs[1)] [µg/kg fat]	∑ 4 DDTs[2)] [µg/kg fat]	HCB [µg/kg fat]
Red-tail finfoil barb (*Puntius altus*)	3	8.5	27	9.8	110	11
Catfish (*Clarias batrachus*)	3	11	18	7.9	130	0.91
Sneak-head fish (*Ophiocephalus striatus*)	3	1.9	110	18	150	3.3
Nile tilapia (*Tilapia nilotica*)	3	1.6	63	88	140	1.3
Climbing perch (*Anabas testudineus*)	3	3.3	30	20	70	1.8

1) Σ 4 HCHs is sum of isomers α-HCH, β-HCH, γ-HCH, and δ-HCH.

2) Σ 4 DDTs is sum of p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.

Tab. 13: *Range of organochlorine pesticide and PCBs levels in sediment samples from nine sampling sites at the east coast of Gulf of Thailand in 2013 [36]. "ND" means not detected.*

∑ PCBs[1)] [µg/kg DW]	∑ 3 HCHs[2)] [µg/kg DW]	∑ 4 DDTs[3)] [µg/kg DW]	HCB [µg/kg DW]
0.04-3.03	ND-0.78	0.11-2.6	0.02-0.22

1) ∑ PCBs is sum of 22 PCBs congeners.

2) Σ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

3) Σ 4 DDTs is sum of p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.

The pollution criteria of POPs for sediments and soils are presented in Table 14. Aside from Thai pollution criteria, American and Czech pollution criteria were used for comparison and as a substitution for missing criteria of some contaminants. There are two types of pollution criteria for sediments in Thailand. The first one is for the purpose of benthic animals' protection and the second is for the purpose of human health protection. As the second one is expressed only in units of microgram per kilogram of total organic carbon, we did not measure the content of organic carbon in sediment samples; only the first one's criteria expressed in micrograms per kilogram of dry weight of sediment can be used in discussion. Different Thai pollution criteria for soils are used for agricultural and habitat soils, rather than for soils with other purposes. Since soil samples were not collected from agricultural soil or from wildlife habitats, the pollution criteria for soils with other purposes were applied. Pollution criteria for sediments and soils in the Czech Republic and for soils in the USA are also of two area types-- residential and industrial. As sediment and soil samples were collected mostly at borderline communities and not located directly in industrial areas, pollution criteria for residential areas were applied.

Tab. 14: *Pollution criteria for sediments and soils in Thailand, United States, and Czech Republic.*

Chemical compound	Sediments				Soils			
	Thai[10]		Czech[11]		Thai[12]		Czech/USA[11]	
	For the protection of benthic animals	To protect humans via the food chain	Resident area	Industrial area	Agricultural and Habitat	Other purposes	Resident soil	Industrial soil
2,3,7,8-TCDD[1]	none	none	4.5 ng/kg DW	18 ng/kg DW	none	none	4.5 ng/kg DW	18 ng/kg DW
∑ HxCDDs[2]	none	none	94 ng/kg DW	390 ng/kg DW	none	none	94 ng/kg DW	390 ng/kg DW
∑ PCBs[3]	60 µg/kg DW	none	none	None	2200 µg/kg DW	10 000 µg/kg DW	none	none
Single congener of PCB	none	none	110 µg/kg DW	380 µg/kg DW	none	none	110 µg/kg DW	380 µg/kg DW
∑ 6 PCBs[4]	none	none	220 µg/kg DW	740 µg/kg DW	none	none	220 µg/kg DW	740 µg/kg DW
Chlordane	3 µg/kg DW	35 µg/kg TOC	none	None	16 000 µg/kg DW	110 000 µg/kg DW	none	none
Dieldrin	2 µg/kg DW	16.5 µg/kg TOC	30 µg/kg DW	110 µg/kg DW	300 µg/kg DW	1500 µg/kg DW	30 µg/kg DW	110 µg/kg DW

Chemical compound	Sediments				Soils			
	Thai[10]		Czech[11]		Thai[12]		Czech/USA[11]	
	For the protection of benthic animals	To protect humans via the food chain	Resident area	Industrial area	Agricultural and Habitat	Other purposes	Resident soil	Industrial soil
∑ DDTs[5]	5 µg/kg DW	24 µg/kg TOC	none	None	17 000 µg/kg DW	120 000 µg/kg DW	none	none
DDTs[6]			1 700 µg/kg DW	7 000 µg/kg DW			1 700 µg/kg DW	7 000 µg/kg DW
DDEs[7]	none	none	1 400 µg/kg DW	5 100 µg/kg DW	none	none	1 400 µg/kg DW	5 100 µg/kg DW
DDDs[8]	none	none	2 000 µg/kg DW	7 200 µg/kg DW	none	none	2 000 µg/kg DW	7 200 µg/kg DW
Endrin	2 µg/kg DW	360 µg/kg TOC	18 000 µg/kg DW	180 000 µg/kg DW	none	none	18 000 µg/kg DW	180 000 µg/kg DW
Heptachlor epoxide	2.5 µg/kg DW	1.5 µg/kg TOC	53 µg/kg DW	190 µg/kg DW	500 µg/kg DW	2700 µg/kg DW	53 µg/kg DW	190 µg/kg DW
α-HCH	none	none	77 µg/kg DW	270 µg/kg DW	none	none	77 µg/kg DW	270 µg/kg DW
β-HCH	none	none	270 µg/kg DW	960 µg/kg DW	none	none	270 µg/kg DW	960 µg/kg DW
γ-HCH	2.5 µg/kg DW	11 µg/kg TOC	520 µg/kg DW	2100 µg/kg DW	4400 µg/kg DW	29 000 µg/kg DW	52 µg/kg DW	2100 µg/kg DW
Aldrin	none	10 µg/kg TOC	29 µg/kg DW	100 µg/kg DW	none	none	29 µg/kg DW	100 µg/kg DW
Endosulfan	none	2900 µg/kg TOC	370 000 µg/kg DW	3 700 000 µg/kg DW	none	none	370 µg/kg DW	3700 µg/kg DW
Heptachlor	none	3 µg/kg TOC	110 µg/kg DW	380 µg/kg DW	1100 µg/kg DW	5500 µg/kg DW	110 µg/kg DW	380 µg/kg DW
Mirex	none	0.5 µg/kg TOC	27 µg/kg DW	96 µg/kg DW	none	none	27 µg/kg DW	96 µg/kg DW

Chemical compound	Sediments				Soils			
	Thai[10]		Czech[11]		Thai[12]		Czech/USA[11]	
	For the protection of benthic animals	To protect humans via the food chain	Resident area	Industrial area	Agricultural and Habitat	Other purposes	Resident soil	Industrial soil
Metoxychlor	none	none	310 000 µg/kg DW	3 100 000 µg/kg DW	none	none	310 000 µg/kg DW	3 100 000 µg/kg DW
HCB	none	490 µg/kg TOC	300 µg/kg DW	1 100 µg/kg DW	none	none	300 µg/kg DW	1 100 µg/kg DW
∑ PAHs[9]	1 600 µg/kg DW	none	none	None	none	none	none	none
Naphthalene	none	none	3 600 µg/kg DW	18 000 µg/kg DW	none	none	3 600 µg/kg DW	18 000 µg/kg DW
Acenaphthene	none	none	3 400 000 µg/kg DW	33 000 000 µg/kg DW	none	none	3 400 000 µg/kg DW	33 000 000 µg/kg DW
Fluorene	none	none	2 300 000 µg/kg DW	22 000 000 µg/kg DW	none	none	2 300 000 µg/kg DW	22 000 000 µg/kg DW
Anthracene	none	none	17 000 000 µg/kg DW	170 000 000 µg/kg DW	none	none	17 000 000 µg/kg DW	170 000 000 µg/kg DW
Fluoranthene	none	none	2 300 000 µg/kg DW	22 000 000 µg/kg DW	none	none	2 300 000 µg/kg DW	22 000 000 µg/kg DW
Pyrene	none	none	1 700 000 µg/kg DW	17 000 000 µg/kg DW	none	none	1 700 000 µg/kg DW	17 000 000 µg/kg DW
Benz(a)antracene	none	1080 µg/kg TOC	150 µg/kg DW	2 100 µg/kg DW	none	none	150 µg/kg DW	2 100 µg/kg DW
Chrysene	none	108 000 µg/kg TOC	15 000 µg/kg DW	210 000 µg/kg DW	none	none	15 000 µg/kg DW	210 000 µg/kg DW
Benzo(b)fluoranthene	none	none	150 µg/kg DW	2 100 µg/kg DW	none	none	150 µg/kg DW	2 100 µg/kg DW
Benzo(k)fluoranthene	none	none	1500 µg/kg DW	21 000 µg/kg DW	none	none	1 500 µg/kg DW	21 000 µg/kg DW

Chemical compound	Sediments				Soils			
	Thai[10]		Czech[11]		Thai[12]		Czech/USA[11]	
	For the protection of benthic animals	To protect humans via the food chain	Resident area	Industrial area	Agricultural and Habitat	Other purposes	Resident soil	Industrial soil
Benzo(a)pyrene	none	110 µg/kg TOC	15 µg/kg DW	210 µg/kg DW	600 µg/kg DW	2900 µg/kg DW	15 µg/kg DW	210 µg/kg DW
Indeno(1,2,3,-c,d) pyrene	none	none	150 µg/kg DW	2100 µg/kg DW	none	none	150 µg/kg DW	2 100 µg/kg DW
Dibenz(a,h)anthra-cene	none	none	15 µg/kg DW	210 µg/kg DW	none	none	15 µg/kg DW	210 µg/kg DW

1) 2,3,7,8-TCDD is 2,3,7,8-tetrachlorodibenzodioxin.

2) ∑ HxCDDs is sum of dibenzo-p-dioxin congeners with six chlorine atoms.

3) ∑ PCB is sum of all 209 congeners of PCB.

4) ∑ 6 PCB is sum of PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

5) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

6) ∑ DDTs is sum of p,p'-DDT and o,p'-DDT.

7) ∑ DDEs is sum of p,p'-DDE and o,p'-DDE.

8) ∑ DDDs is sum of p,p'-DDD and o,p'-DDD.

9) ∑ PAHs is sum of benz(a)anthracene, benzo(a)pyrene, and chrysene.

10) Sediment in Surface Water Quality Criteria in Thailand (Draft Regulation)

11) Methodical instruction of Czech Ministry of Environmental Affairs: Indicators of contamination 2013.

12) Notification of National Environmental Board No. 25, B.E. (2004) issued under the Enhancement and Conservation of National Environmental Quality Act B.E.2535 (1992) published in the Royal Government Gazette No. 121 Special Part 119 D dated October 20, B.E.2547(2004).

Maximum residue limits of organochlorine pesticides and maximum levels of PCBs and PCDD/Fs for organic samples are presented in Table 15. In addition to Thai maximum limits of POPs, the European and Czech maximum limits were used for comparison and as a substitution for missing limits of some contaminants. Thai maximum limits of POPs in foodstuffs are established for some organochlorine pesticides and not for other contaminants, such as PCBs and PCDD/Fs, but they are applicable for all kinds of organic samples designated as foodstuff. According to the Thai Agricultural Standard (TAS 9003 – 2004), an extraneous maximum residue limit was issued just as a voluntary standard. European and Czech legislation introduced legally-mandated obligatory maximum levels of PCBs and PCDD/Fs in eggs, fish, and crustaceans, and maximum residue levels of organochlorine pesticides in eggs. Unfortunately, maximum levels of organochlorine pesticides in fish and crustaceans are missing in the European Union. There are only voluntary maximum residue levels of organochlorine pesticides in fish in the Czech Republic. In the European Union and the Czech Republic, maximum levels of POPs in molluscs are not established at all[1].

1 There is only a maximum level of PAHs for smoked molluscs in the European Union.

Tab. 15: *Maximum residue limits of organochlorine pesticides and maximum levels of PCB and PCDD/F for eggs, fish, molluscs, and crustaceans in Thailand, European Union, and Czech Republic.*

Chemical compound	Eggs		Fish			Molluscs		Crustaceans	
	Thai	EU/Czech	Thai	EU	Czech	Thai	EU/Czech	Thai	EU/Czech
PCDD/F	none	2.5 ng WHO-TEQ/kg fat[4)]	none	3.5 ng WHO-TEQ/kg fresh[4)]		none	none	none	3.5 ng/kg fresh[4)]
PCDD/F + DL PCB	none	5 ng WHO-TEQ/kg fat[4)]	none	6.5 ng WHO-TEQ/kg fresh[4)]		none	none	none	6.5 ng/kg fresh[4)]
∑ 6 PCB[1)]	none	40 µg/kg fat[4)]	none	marine 75 µg/kg fresh[4)] freshwater 125 µg/kg fresh[4)]		none	none	none	75 µg/kg fresh[4)]
4 DDTs[2)]	100 µg/kg fresh[3)]	50 µg/kg fresh[5)]	1 000 µg/kg fat[3)]	none	500 µg/kg fresh or 5 000 µg/kg fat[7)]	1 000 µg/kg fat[3)]	none	1 000 µg/kg fat[3)]	none
HCB	<LOD[6)]	20 µg/kg fresh[5)]	<LOD[6)]	none	50 µg/kg fresh or 500 µg/kg fat[7)]	<LOD[6)]	none	<LOD[6)]	none
α-HCH	none	20 µg/kg fresh[5)]	none	none	none	none	none	none	none
β-HCH	<LOD[6)]	10 µg/kg fresh[5)]	<LOD[6)]	none	none	<LOD[6)]	none	<LOD[6)]	none
γ-HCH	<LOD[6)]	10 µg/kg fresh[5)]	<LOD[6)]	none	50 µg/kg fresh or 500 µg/kg fat[7)]	<LOD[6)]	none	<LOD[6)]	none
HCH (β + α)	none	none	none	none	20 µg/kg fresh or 200 µg/kg fat[7)]	none	none	none	none

1) ∑ 6 PCB is sum of PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 4 DDTs is sum of p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.

3) Thai: Pesticide Residues: Extraneous Maximum Residue Limits (EMRL), Thai Agricultural Standard (TAS 9003 – 2004).

4) EU: Commission Regulation (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.

5) EU: Commission Regulation (EC) No 149/2008 of 29 January 2008 amending Regulation (EC) No 396/2005 of the European Parliament and of the Council by establishing Annexes II, III and IV setting maximum residue levels for products covered by Annex I.

6) Thai: Pesticide Residues: Maximum Residue Limits (MRL), Thai Agricultural Standard (TAS 9002 – 2016).

7) Czech: Edict no. 381/2007 about assignation of Maximum Residue Limits of pesticides in food and feedstock

2.5.1 MAP TA PHUT INDUSTRIAL COMPLEX

Levels of most organochlorine pesticides (HCHs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin) in all sediment samples from the Map Ta Phut area are below the level of detection. Just two sediment samples (MTP 1-8 and MTP 1-13) have low levels of PCBs, PeCB, and DDTs. One sediment sample (MTP 1-8) has a low level of HCB and another one (MTP 1-13) has a low level of HCBDs. This result indicates generally low residue levels of organochlorine pesticides and PCBs in sediments from the Map Ta Phut area and is also consistent with very low or zero PCBs and pesticide (DDTs, HCB, and HCHs) concentrations found in sediments along the east coast of the Gulf of Thailand in 2013 (Table 13). Contrary to our conclusion, research conducted by Greenpeace Research Laboratories found trace levels of highly chlorinated compounds, such as PeCB and HCB, in the water streams flowing through the industrial complex in 2004. These chlorinated compounds can be formed as by-products of industrial processes involving chlorine compounds. They are highly persistent in the environment and many of them are able to accumulate in the bodies of animals and humans. [1] Six samples (MTP 1-13, MTP 1-16, MTP 1-17, MTP 2-3, MTP 2-5, MTP 2-6) showed relatively low levels of naphthalene (from 0.5 to 1.7 µg/kg DW) and were collected from water canals flowing through the industrial complex. The naphthalene concentrations were safely below the criteria for sediments at residential areas in the Czech Republic. The level of DL PCBs measured in one ash sample collected from a tank containing ash from a power plant was low, and PCDD/Fs were measured below LOQ in the same sample. Dioxin and DL PCBs were also measured by passive air samplers. Results are presented in a separate study in Chapter 4. Two samples of sediments were also analyzed for PBDEs. Results showed levels below LOQ.

Ten fish samples collected in the hotspot area (MTP 1-10/1, MTP 1-10/2, MTP 2-1/1, MTP 2-1/2, MTP 2-8, MTP 2-9, MTP-2017-1, MTP-2017-2, MTP-2017-3, MTP-2017-5) were analyzed for content of HCBD and organochlorine pesticides (HCB, PeCB, HCHs, and DDTs) and one more fish sample (MTP-2017-8) was analyzed for content of HCBD and PeCB. Concentrations of HCB, PeCB, HCBD, and HCHs in fish samples from the hotspot area are higher than background levels in fish from Thap Lan National Park (Table 11) in two, four, two, and two cases, respectively. Two fish samples (MTP 2-8 and MTP 2-9) have HCB and HCHs concentrations higher than the Thai maximum residue limits[2]. The occurrence of HCB, PeCB, HCBD, and HCHs is probably caused by industrial facilities operated in the hotspot area, particularly by several chlorine production plants.

Only two fish samples have DDTs concentrations below the level of quantification. Three fish samples (MTP 1-10/1, MTP 2-1/1, and MTP 2-1/2) have one order of magnitude higher DDT concentrations (176.67, 292.3, 113.54 µg/kg fat) than the background DDT levels in fish from Thap Lan National Park (51.28 and 47.62 µg/kg fat), but have same order of magnitude as certain fish samples from the large brackish Songkhla Lake (up to 170 µg/kg fat) [34] and fish bought at fish markets in Bangkok (up to 150 µg/kg fat) [35]. All fish samples from the hotspot area are safely below the maximum residue limits in Thailand and the Czech Republic. The occurrence of DDTs is probably from residue of pesticide usage in the past. This assumption is supported by the fact that the most common DDT isomer (metabolite) residue in the samples is p.p'-DDE. The ratio of p,p'-DDE /DDT is an indicator of whether the DDT observed was recently released, or had been emitted into the environment in the past [37].

Ten fish samples collected in the hotspot area (MTP 1-10/1, MTP 1-10/2, MTP 2-1/1, MTP 2-1/2, MTP 2-8, MTP 2-9, MTP-2017-1, MTP-2017-2, MTP-2017-3, MTP-2017-5) were analyzed for content of indicator congeners of PCBs (I-PCBs) and two of them (MTP 1-10/2, MTP 2-9) for content of PCDD/Fs and DL PCBs. Just three fish samples (MTP 1-10/1, MTP 2-8, and MTP 2-9) have measurable concentrations of I-PCBs (550.06, 19.57, and 59.67 µg/kg fat) that are also higher than PCBs levels in fish from Thap Lan National Park (below the level of quantification). Measurable, but relatively low concentrations of PCDD/Fs and DL PCBs were found in both of the analyzed samples. After the conversion on fresh weight, the concentrations of six indicate PCBs congeners, PCDD/Fs, and PCDD/Fs + DL PCBs in the analyzed fish samples are below the maximal

2 Thai maximum residue levels of HCB, β-HCH, and γ-HCH in fish are levels of detection.

levels for fish in the European Union and the Czech Republic (Table 15). Dioxins can be formed as an unintentional by-product in chlor-alkali and VCM plants. This assumption is supported by the fact that the fish with measurable PCDD/Fs levels were caught in the Chak Mak Canal or in its mouth to the sea. The canal is flowing around two factories producing chlorine, whose wastewaters are probably discharged into the canal. All the fish samples with measurable PCB levels in the hotspot area were caught in the Chak Mak Canal; therefore, there is probably a source of PCBs around the canal.

Brominated compounds (PBDEs, HBCDs, and BFRs) were analyzed in nine fish samples from the hotspot area (MTP 1-10/1, MTP 1-10/2, MTP 2-1/1, MTP 2-1/2, MTP 2-8, MTP 2-9, MTP-2017-2, MTP-2017-3, MTP-2017-5). Concentrations of PBDEs, HBCDs, and BFRs in the fish samples from the hotspot area were measurable and are also higher than the levels in the fish from Thap Lan National Park (below the level of quantification) in five, six, and one case respectively. Seven fish samples collected in the hotspot area (MTP 1-10/2, MTP 2-9, MTP-2017-1, MTP-2017-2, MTP-2017-3, MTP-2017-5, and MTP-2017-8) were analyzed for content of PAHs. All the samples have PAH concentrations in the same order of magnitude or one order of magnitude higher than the sample from the background locality in Thap Lan National Park (28.21 µg/kg fat). Significant PAH contamination was not found in the fish from the Map Ta Phut.

The one sample of mussels (*Perna viridis*) from the hotspot area (MTP 1-4) was analyzed for content of PCDD/Fs, PCBs, organochlorine pesticides (HCB, PeCB, HCHs, DDTs), HCBD, and PAHs. The temporal comparison of PCBs and organochlorine pesticide levels in mussels from coastal areas of Thailand is summarized in Table 16. The levels of PCBs and organochlorine pesticides in mussels in our study are lower than those found in previous studies. Moreover, according to the literature, the levels of organochlorine pesticides in mussels from Thailand are relatively lower than those in developed nations. [38]. The mussel sample complies to Thai maximum residue limits for organochlorine pesticides. For these reasons, organochlorine pesticides in the hot spot area do not represent a significant contamination of mussels. The mussel sample has measurable levels of PCDD/Fs, DL PCBs, and PeCB, indicating certain contamination by chlorinated compounds. It can be caused by pollution from industrial sources, especially from the chlorine-using or producing plants in the industrial complex. Concentrations of PAHs were measured in molluscs (*Ostrea pliculata*, *Perna viridis*, and *Amusium pleuronectes*) collected in the Upper Gulf of Thailand in 1982. The concentrations reported in the cited study indicate the presence of low levels of PAHs in the water of the Upper Gulf. PAHs detected include: acenaphthylene, benzo(a)pyrene, fluoranthene, phenanthrene, methylphenanthrene, and triphenylene. Benzo(a)pyrene was present in all species, at concentrations varying from 1.0 to 8.2 µg/kg fresh [39]. Concentrations of PAHs in the mussel sample from the Map Ta Phut hotspot area were mostly below the level of quantification with the exception of naphthalene and phenanthrene. The benzo(a)pyrene concentration in our sample (less than 10 µg/kg fresh) does not significantly exceed the level from the cited study.

Tab. 16: *Concentrations of organochlorine pesticides and PCBs in mussels (Perina viridis) from coastal areas of Thailand. "NA" means not analyzed.*

Year of sampling	Number of sampling sites	∑ PCBs[1)] [µg/kg fresh]	∑ DDTs[2)] [µg/kg fresh]	∑ 3 HCHs[3)] [µg/kg fresh]	HCB [µg/kg fresh]	Reference
1979	4	2 - 43	32 - 42	NA	NA	[40]
1989	9	NA	0.39–7.41	< 0.02–0.19[4)]	< 0.02–0.31	[41]
1994 – 1995	16	< 0.01 - 20	1.2 - 38[5)]	< 0.01 - 0.33	< 0.01 - 0.12	[39]
2002 – 2003	8	1.69 (0.32 - 3.7)	2.55 (1.17 - 3.86)	0.3 (< 0.01 - 0.49)	0.06 (< 0.01 - 0.10)	[42]
2016	1	< 0.35[6)]	0.13	< 0.15	< 0.05	This study

1) ∑ PCBs is sum of all PCB congeners.

2) ∑ 6 DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

3) ∑ 3 HCHs is sum of α-HCH, β-HCH, and γ-HCH.

4) This value is sum of α-HCH and γ-HCH.

5) This value is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, and p,p'-DDD.

6) This value is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

Contents of PCDD/Fs, PCBs, and PAHs were determined in three samples of crustaceans collected in the hotspot area (MTP 1-3, MTP 1-5, and MTP 1-9). Measurable levels of PCBs and PAHs have been found in all three samples, but only one sample shows a measurable level of PCDD/Fs. After the conversion on fresh weight, the concentrations of six indicate PCBs congeners, PCDD/Fs, and PCDD/Fs + DL PCBs in the analyzed crustacean samples are below the maximal levels in the European Union and the Czech Republic (Table 15). Dioxins and PCB pollution can be caused by industry sources, particularly by the chlorine-using or producing plants in the industrial complex.

Three egg samples from the vicinity of the industrial complex (MTP 2-18, MTP 2-19, and MTP 1-11) were analyzed for content of PCDD/Fs, PCBs, organochlorine pesticides (HCB, PeCB, HCHs, and DDTs), HCBD, PAHs, and brominated compounds (PBDEs, HBCDs, and BFRs). Moreover, one egg sample from the area (MAP-1) was analyzed for content of PCDD/Fs, PCBs, and PAHs. Concentrations of PCDD/Fs, PCBs, HCB, HCHs, DDTs, HBCDs, and BFRs in the egg samples from the hotspot area are higher than the levels in the background egg sample bought in the supermarket in Bangkok (Table 11). Concentrations of PAHs in egg samples significantly exceed the background levels in two samples (MTP 1-11 and MAP-1). Concentrations of PBDEs exceed the background levels in one sample (MTP 1-11). Concentrations of PeCB and HCBD in the egg samples are below level of quantification, as well as the background levels. Concentrations of HCB in all three egg samples are higher than the maximum residue limit in Thailand[3]. All the egg samples have lower concentrations of DDTs, HCB, and HCHs than maximal levels in eggs tolerable for the European market (Table 15), but one egg sample (MAP-1) exceeded the maximum levels of PCDD/Fs and sum of PCDD/Fs with DL PCBs in the European Union and the Czech Republic. Moreover, concentrations of PCDD/Fs and

3 Thai maximum residue level of HCB in eggs is a level of detection.

DL PCBs are relatively high in the other egg samples. One egg sample (MTP 2-19) has more than 90% of the maximum level of PCDD/Fs in the European Union and the Czech Republic. Dioxins and PCBs can be formed as an unintentional by-product in industries producing and using chlorine that are located in the industrial complex.

2.5.2 SAMUT SAKHON HOTSPOT AREA

Levels of organochlorine pesticides (HCB, HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin) in all sediment samples from Samut Sakhon are below the level of detection. This conclusion indicates generally low residue levels of organochlorine in sediments collected in the area. Two sediment samples (SMS 1-11 and SMS 1-14) showed relatively low levels of naphthalene (1.4 and 0.5 µg/kg DW) and were collected from a water canal and from a dried pond near metal smelting factories. The naphthalene concentrations are safely below the criteria for sediments at residential areas in the Czech Republic. Two sediment samples (SMS 1-14 and SMS 2-4) have significant levels of PCDD/Fs and DL PCBs, but both are below the criteria for sediments at residential areas in the Czech Republic.

Two soil samples (A2 and A3) collected from the hotspot area were analyzed for content of PCDD/Fs, PCBs, and PAHs. Concentrations of PCDD/Fs, PCBs, and PAHs indicate contamination from some industrial source. The PCDD/Fs and PCB levels in the samples are below the pollution criteria for soils in Thailand, the United States, and the Czech Republic, but concentration of the most toxic dioxin 2,3,7,8-TCDD at locality A3 (1.5 ng/kg DW) reaches up to 33% of pollution criteria for soils in residential areas in the United States and the Czech Republic. Both samples also have relatively high concentrations of PAHs with levels of benzo(a)pyrene (23 and 27 µg/kg DW) higher than the pollution criteria for soils in the United States and the Czech Republic (15 µg/kg DW). The first ash sample (A1) from the hotspot area contains measurable concentrations of PCDD/Fs (1.9 ng WHO-TEQ/kg DW), DL PCB (0.27 ng WHO-TEQ/kg DW), and PAHs (3210 µg/kg DW), indicating an industrial source of contamination. The second ash sample (SMS 2-4) from the hotspot area contains significant concentrations of PCDD/Fs (40.5 ng WHO-TEQ/kg DW). Soil and ash sample contamination is likely due to being in the vicinity of "recycling" factories. Many of them include small metallurgical facilities without any filters for pollutants formed during the process. Metallurgical plants are a known source of dioxins and other unintentionally produced POPs listed in Annex C to the Stockholm Convention [32, 43].

Four fish samples from the hotspot area (SMS 1-12/1, SMS 1-12/2, SMS 1-12/3, SMS 1-2) analyzed for content of organochlorine pesticides expose HCH and HCB concentrations lower than level of quantification and measurable levels of DDTs. Fish samples from the background locality (Thap Lan National Park in Table 11) show the same pattern: HCB and HCH concentrations lower than the level of quantification and measurable levels of DDTs. Moreover, the DDT levels in the fish samples from the hotspot area (17.28 – 81.87 µg/kg fat) are in the same order of magnitude as fish samples from the background locality (47.62 – 51.28 µg/kg fat). In comparison with concentrations of organochlorine pesticide in fish bought at fish markets in Bangkok in 1991 (Table 12), the levels of organochlorine pesticides in fish from the hotspot area are lower. Concentrations of DDT in fish samples from the hotspot area are safely below the maximum residue limits in Thailand and the Czech Republic. These findings mean that the organochlorine pesticide burden in the hotspot area does not cause considerable contamination.

The same four fish samples were analyzed for content of six I-PCBs. Levels of these PCB congeners in fish samples from the hotspot area (6.77 – 112.21 µg/kg fat) were considerably higher than in fish samples from the background locality (below the level of quantification), but were in a similar range as the PCB concentrations in fish samples bought at fish markets in Bangkok in 1991 (27 – 110 µg of unspecified PCB congeners /kg fat). Detected PCB contamination in the fish samples could be explained by residues from PCB usage before its ban in 2004 and partially by unintentional PCB production by combustion sources (small metallurgical plants, and open burning of waste at some locations) in the hotspot area. The analyzed fish samples were collected from the Tha Chin River and from ponds on the seashore, not in a direct vicinity of small facilities handling waste; therefore the influence of industries cannot be directly responsible for the contamination. Levels of six indicate

PCB congeners in the fish samples (0.13 – 0.38 μg/kg fresh after the conversion) were safely below the maximal PCB level in the European Union and the Czech Republic (40 μg/kg fresh). Two fish samples (SMS 1-2 and SMS 2F) were analyzed for content of PCDD/Fs and one of them (SMS 1-2) had a measurable PCDD/F level (0.2 ng WHO-TEQ/kg fat). The positive sample collected from the Tha Chin River was below the maximum PCDD/F level in the European Union and the Czech Republic (3.5 ng WHO-TEQ/kg fat). PCDD/F contamination of samples can be explained by unintentional production in a factory using chlorine and dumping wastewater in Tha Chin River near the sampling point.

Two egg samples collected in the hotspot area contain unsafe levels of POPs. The first egg sample (SMS 2-13) was analyzed for content of PCDD/Fs, PCBs, PeCB, HCBD, and PAHs. Concentrations of all the analyzed contaminants in the sample, except a concentration of HCBD (below the level of quantification), exceed levels in the background egg sample bought in the supermarket in Bangkok (Table 11). The concentrations of PCDD/Fs (6.2 ng WHO-TEQ/ kg fat) and PCDD/Fs + DL PCBs (12.2 ng WHO-TEQ/ kg fat) are two folds higher than the maximal levels in eggs tolerable for the European market (Table 15). The contamination of the egg sample by PCDD/Fs and DL PCBs could originate from waste burning in small waste "recycling" facilities placed nearby a household where the hens are kept. This conclusion is supported by presence of other contaminants such as PeCB and PAH, that could be produced by waste burning and/or small metallurgical facilities. Furthermore, this hypothesis is supported by fact that residues of burned waste were found on a courtyard of the household. The second egg sample (notation: Samut Sakhon) was analyzed for content of PCDD/Fs, polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs), PCBs, HCB, HCHs, DDTs, PBDEs, and BFRs. Concentrations of HCHs, PBDEs, and BFRs in the sample are lower or the same as levels in the background egg sample bought in the supermarket in Bangkok (Table 11) and other contaminants (PCDD/Fs, PCBs, HCB, and DDTs) in the sample exceed these levels. Concentrations of β-HCH (0.31 μg/kg fat) and HCB (4.21 μg/kg fat) are higher than the maximum residue limits for eggs in Thailand[4]. The concentrations of PCDD/Fs (84.04 ng WHO-TEQ/kg fat) and PCDD/Fs + DL PCBs (95.71 ng WHO-TEQ/kg fat) are 33 folds and 19 folds higher, respectively, than the maximal egg levels tolerable for the European market (Table 15). Additionally, the concentration of PBDD/Fs (15.8 ng WHO-TEQ/kg fat) without the maximal tolerable levels poses additional risks for human health. The contamination of the second egg sample can be caused by breeding hens around a small a waste "recycling" facility placed nearby burning waste, including e-waste. Both the egg samples are seriously unsafe for human consumption due to the content of PCDD/Fs, DL PCBs, and PBDD/Fs.

2.5.3 THA TUM INDUSTRIAL COMPLEX

The first group of twelve sediment samples (TT 1-1, TT 1-2, TT 1-3, TT 1-4, TT 1-5, TT 1-6, TT 1-7, TT 1-8, TT 1-9, TT 1-10, TT 1-11, and TT 2-1) collected in the hotspot area in February 2016 were analyzed for content of PCBs and organochlorine pesticides (HCHs, DDTs, heptachlor, heptachlor epoxide, endosulfan, dieldrin, and endrin). All samples from the first group have concentrations of all measured contaminants below the level of detection, except for one sample (TT 1-11) that has a very low level of I-PCBs (0.28 μg/kg DW). The pollution criteria for sediments in Thailand and the Czech Republic are not exceeded in any of the sediment samples from the group.

The second group of four sediment samples (S1, S2, S3, and S4) collected in the hotspot area in February 2015 were analyzed for content of PCDD/Fs, PCBs, PAHs, organochlorine pesticides (HCHs, DDTs, heptachlor, heptachlor epoxide, aldrin, oktachlorstyren, chlordan, oxychlordan, metoxychlor, and mirex), and chlorobenzenes (HCB, TeClB, 1,2,3,4-TeClB, QClB). Concentrations of organochlorine pesticides and chlorobenzenes were mostly below the levels of detection, but three samples (S1, S3, and S4) show measurable levels of HCB and DDT, and one sample (S3) shows measurable levels of mirex (0.32 μg/kg DW). The occurrence of HCB and mirex is surprising because these pesticides have never been imported or used in Thailand, according to the National Implementation Plan. The presence of HCB in the sediments can be explained by unintentional production from the industrial facilities in the hotspot area. This assumption is supported by content of PCDD/Fs and DL PCBs in the same samples. All these contaminants are produced unintentionally in chemical processes (bleaching of paper) or during the incineration of fuels,

4 Thai maximum residue levels of HCB and β-HCH in eggs are levels of detection.

including coal-containing chlorine (power plants). Concentrations of PAHs in soil samples were in a common range, but one sample (S3) has a concentration of dibenzo (a, h) anthracene (37 µg/kg DW) higher than the Czech pollution criteria for sediments in a residential area (15 µg/kg DW).

The only ash sample (S5) collected 30 km south from the Tha Tum industrial area at a eucalyptus plantation was analyzed for content of PAHs. Concentrations of PAHs in the ash sample were in a common range typical for ash, but the sample had a relatively high concentration of benzo(a)pyrene (76 µg/kg DW).

Concentrations of PCBs, HCB, PeCB, HBCD, HCHs, and DDTs in two fish samples collected in water canals in the hotspot area (TT 2-8 and TT 2-6) are below the levels of quantification and both the fish samples comply with the Thai, Czech, and European maximal residue levels. One sample of freshwater mussels was collected in a water canal in the hotspot area. Concentrations of PCBs, HCBD, and HCHs in the mussel sample are below the levels of quantifications and the concentrations of HCB, DDTs, and PeCB in this sample are measurable. Moreover, the HCB concentration in mussels exceeds the maximal residue level in Thailand[5]. While the occurrence of DDTs is probably from pesticide usage in the past, the presence of HCB and PeCB could be caused by a variety of industrial facilities operated in the industrial area, particularly by bleaching paper in the pulp and paper plant.

The one egg sample (notation: Tha Thum) collected in the hot spot area contains dangerous levels of POPs. The sample was analyzed for content of PCDD/Fs, PCBs, and organochlorine pesticides (HCB, HCHs, and DDTs). While concentrations of I-PCBs (0.39 µg/kg fat) and HCHs (0.23 µg/kg fat) in the sample are the same order of magnitude as levels in the background egg sample bought in the supermarket in Bangkok (Table 11), the concentrations of PCDD/Fs, DL PCBs, HCB, and DDTs in the sample exceed background levels. Concentrations of β-HCH (0.23 µg/kg fat) and HCB (1.51 µg/kg fat) in the egg sample are higher than the maximum residue limits for eggs in Thailand[6]. Both the concentrations of PCDD/Fs (4.27 ng WHO-TEQ/ kg fat) and PCDD/Fs + DL PCBs (8.21 ng WHO-TEQ/ kg fat) are significantly higher than the maximal levels for eggs tolerable in the EU (Table 15). The egg sample is unsafe for human consumption due to the content of PCDD/Fs and DL PCBs.

2.5.4 PRAEKSA LANDFILL

The first two sediment samples (PKS 1 and PKS 2) collected in the hotspot area in November 2015 were analyzed for content of 16 PAHs only among POPs. Measured levels of 186 and 285 µg/kg DW, respectively, were rather low in comparison with some other hot spots, and none of PAHs exceeded pollution criteria set either in Thailand or in the Czech Republic. Naphthalene had the highest concentrations among PAHs in both samples. The other sediment samples were analyzed for organochlorine pesticides and I-PCBs. Their concentrations were all below LOQ (see results in Annex 1).

Concentrations of PCBs, HCB, HCHs, and DDTs in a fish sample from a nearby pond were all below LOQ, as well as the level of PCDD/Fs and DL PCBs analyzed by bioassay as DR CALUX (see Table 12).

The most significant levels of POPs were measured in a pooled egg sample from Praeksa in which PCDD/Fs exceeded the EU standard set for eggs. The level of PCDD/Fs and DL PCBs in an egg sample from Praeksa exceeded the EU standard for eggs almost twice.

2.5.5 PULP AND PAPER INDUSTRIAL AREA NEAR KHON KAEN

According to the literature, the occurrence of organochlorine pesticides and PCBs in sediments is not common in the broader region of the Mekong Basin. In 2014, a survey of 21 organochlorine pesticides and PCBs in sediments was conducted on the wetlands of the Mekong Basin, which is part of the Phong River. Only a few organochlorine pesticides measured in 531 sediment samples occurred in high concentrations. Aldrin, heptachlor, and mirex were not detected in any samples. Chlordane, dieldrin, HCHs, and metoxychlor were detected infrequently and at low concentrations. DDTs, endosulfan, HCB, and endrin were most commonly detected in the study. Only 4 out of the 61 analyzed samples contained PCB [44]. The study conducted at the Phong River

5 Thai maximum residue levelo of HCB in eggs is a level of detection.

6 Thai maximum residue levels of HCB and β-HCH in eggs are levels of detection.

Tab. 17: *Concentrations of organochlorine pesticides and PCBs in sediments at Phong River around the industrial area near Khon Kaen in 2005.[45]*

	∑ PCBs [µg/kg DW]	∑ 3 DDTs [µg/kg DW]	∑ 3 HCHs [µg/kg DW]	HCB [µg/kg DW]
Upstream Pong River	6.6	0.59	9.9	0.066
Discharge point, Pong River	0.18	0.211	0.015	0.003
Discharge point, Pong River	0.78	0.77	0.199	0.018
Project Green, Paper factory	5.0	0.027	0.005	0.001
Project Green, Paper factory	47	0.8	0.01	0.015
Downstream Pong River	0.55	0.13	0.28	0.005

1) ∑ PCBs is sum of all PCB congeners.

2) ∑ 3 DDTs is sum of residues p,p'-DDT, p,p'-DDE, and p,p'-DDD.

3) ∑ 3 HCHs is sum of α-HCH, β-HCH, and γ-HCH.

around the industrial area near Khon Kaen found low levels of organochlorine pesticides and PCBs in sediments in 2005. Concentrations of organochlorine pesticides and PCBs found in the study are displayed in Table 17. The range of concentrations of PCBs in sediments from the hotspot area was 0.18–47 µg/kg DW. According to the study, higher concentrations of PCBs were found in the area of the eucalyptus plantation (Project Green) than in the main stream of the Phong River. The pulp and paper plant started operation in 1982, while Project Green, which receives irrigation from treated wastewater of the plant, was initiated in 1994. A higher concentration of PCBs in this location suggests main exposure sources from the plant activity. [45]

Contrary to the study mentioned above, all levels of organochlorine pesticides and PCBs in our sediment samples are below the level of detection. It can be explained by the declining use of pesticides and PCBs levels in the Phong River and other water bodies due to the negligible or zero increase of contaminants, and fluvial transport of sediments accelerated by the vertical erosion of riverbeds on this section of the Phong River (a result of the Ubolratana Dam). Moreover, we did not sample the particular spots of the eucalyptus plantation where the highest concentration of PCB was found in 2005. All sediment samples collected in the hotspot area comply with criteria for organochlorine pesticides and PCBs of Thailand, the United States, and the Czech Republic. The only ash sample (KK 5) has measurable concentrations of PCDD/Fs, PCBs, and PAHs. This sample was found around a road near the power plant in the industrial area and is probably fly or bottom ash from the power plant or other industrial plant in the area. If this assumption is true, there is a significant source of PCDD/Fs and PCBs from the combustion processes in the industrial area.

Fish samples meet the requirements for maximal content of organochlorine pesticides and PCBs. All three fish samples collected in the hotspot area

were analyzed for content of PCBs, HCHs, HCB, and DDTs, but in two fish samples (KK 14/1 and KK 14/2), only the DDT content was above level of quantification. Concentrations of DDT in these two samples (9.08 and 18.61 µg/kg fat) were few folds below the background level of DDT in fish from Thap Lan National Park and were also well below the maximum residue limit for fish in Thailand, the European Union, and the Czech Republic.

Egg samples collected in the hotspot area have significantly higher concentrations of PCDD/Fs, PCBs, PAHs, and organochlorine pesticides (HCHs, HCB, and DDTs) than levels in the background egg sample bought in the supermarket in Bangkok (Table 11). Two egg samples (KK 1/1 and KK 1/2) exceed Thai maximum residue limit of HCB[7]. The presence of HCB at the hotspot area could be explained by unintentional production from the chlorine production facilities in the pulp and paper plant. Hexachlorobenzene was also used as a pesticide, but according to the Thai National Implementation Plan, it has never been imported or used in Thailand. The egg sample (KK 1) mixed from the two eggs shows measurable levels of PCDD/Fs, PCBs, and PAHs. Concentrations of PCDD/Fs and PCBs in the egg sample were below the maximum levels of these contaminants in the European Union and the Czech Republic, but the level of PCDD/Fs (1.5 ng WHO-TEQ/kg fat) reaches up to 60% of the maximum level and the level of PCDD/Fs + DL PCBs (2.33 ng WHO-TEQ/kg fat) reaches up to 47% of the maximum level. This PCDD/F and PCB concentration in the egg sample indicates that there is a contamination source in the hotspot area. PCDD/Fs can be produced as by-products during chlorine bleaching in pulp and paper mills. The EPA's national dioxins source assessment reported that bleached pulp and paper production was ranked fourth overall as a source of dioxins contamination [46]. A scientific survey conducted around the pulp and paper plant near Khon Kaen found high PCDD/F concentrations in sediments in 2006. Dioxin levels in sediments at the hotspot area ranged from 36 to 130 ng TEQ/kg with a mean value of 76.5 ng TEQ/kg. The highest concentration of PCDD/Fs (130 ng TEQ/kg) was found in a sediment sample collected from the discharge point of the pulp and paper plant, which indicated PCDD/F contamination from the plant's operations [3]. Our results show that PCDD/F contamination from the plant can persist and is present in the food chain. For a better understanding of the PCDD/Fs contamination and its proliferation in the area, more measurements of organic and inorganic matrices are needed.

2.5.6 COMPARISON OF HOTSPOTS

For comparison, samples of fish and eggs were used because they were collected from all the hotspot areas and the background locality, and they were analyzed for some POPs with detectable values. Concentrations of I-PCBs and DDTs in fish samples from different hotspot areas are plotted in Figures 1 and 2, respectively. The highest concentration of I-PCBs in fish was found in sample MTP 1-10/1 from Map Ta Phut. The sample is determined as a needlefish (family *Belonidae*), which is a group of carnivorous fish. Concentrations of I-PCBs are higher than the level of quantification in some other fish samples from Map Ta Phut and Samut Sakhon hotspot areas, while fish samples from Tha Tum, Khon Kaen, and Thap Lan National Park were below the level of quantification. Concentrations of DDTs in the four fish samples exceeded the values found in fish samples from Thap Lan National Park. These are from Map Ta Phut (three samples) and Samut Sakhon (one sample).

7 Thai maximum residue level of HCB in eggs is a level of detection.

Fig. 1: *Comparison of 7 I-PCBs concentrations in the fish samples from the hotspot areas and from the background locality*

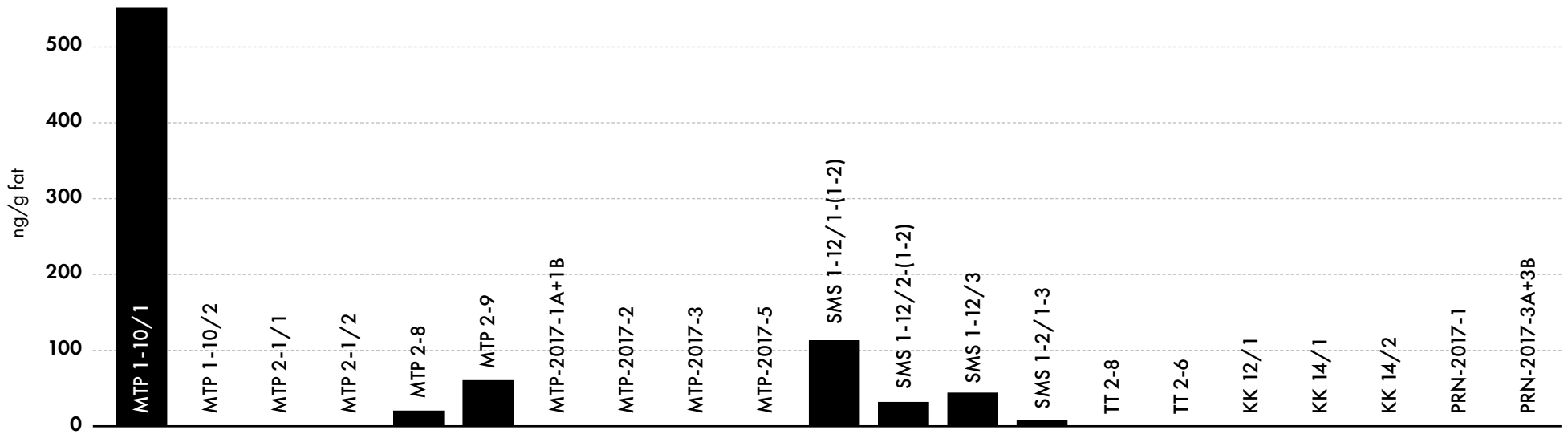
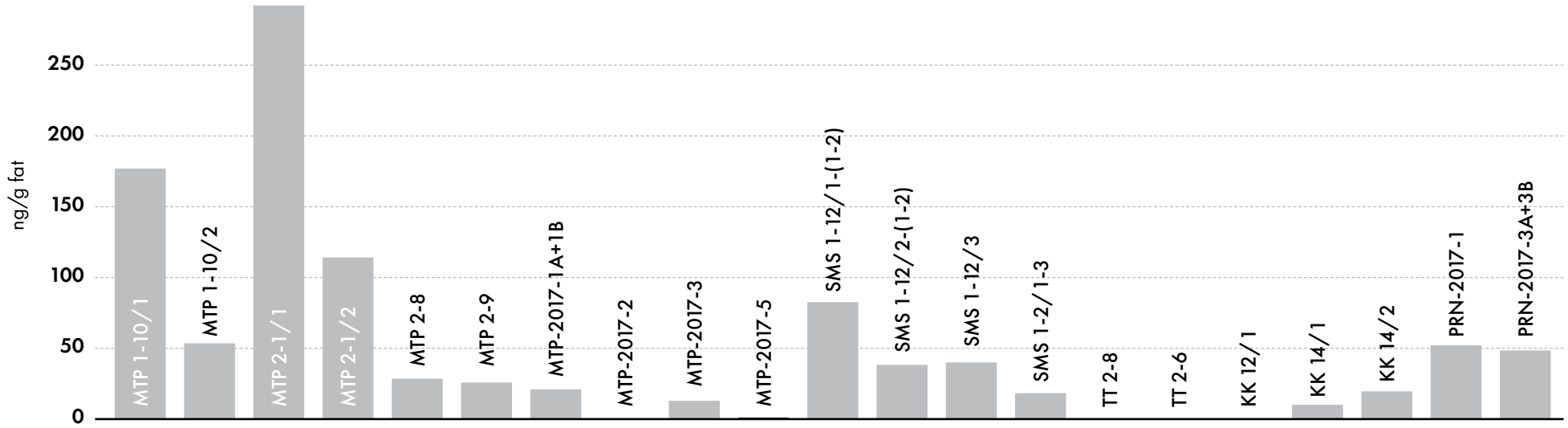


Fig. 2: *Comparison of DDTs concentrations in the fish samples from the hotspot areas and from the background locality*



Concentrations of PCDD/Fs and DL PCBs, I-PCBs, and PAHs in egg samples from different hotspot areas are plotted in Figures 3, 4, and 5, respectively. Concentrations of PCDD/Fs and DL PCBs in all the egg samples from the hot spot areas are higher than levels of these contaminants in the sample from the supermarket in Bangkok. The highest values of PCDD/Fs and DL PCBs were found in the two egg samples from Samut Sakhon. The same pattern was found for I-PCB concentrations in egg samples: all samples from hotspot areas are higher than the egg sample from the supermarket, and the highest values are in the two eggs samples from Samut Sakhon. Concentrations of PAHs in most egg samples from the hotspot areas are higher than the value in the sample from the supermarket in Bangkok, except for one egg sample from Map Ta Phut (MTP 2-19). The highest values of PAHs were found in the egg sample from the Khon Kaen hotspot area (KK 1) and the second highest value was found in the egg sample from Map Ta Phut hotspot area (MAP-1).

Fig. 3: *Comparison of PCDD/Fs and DL PCBs concentrations in the egg samples from the hotspot areas and from the background locality*

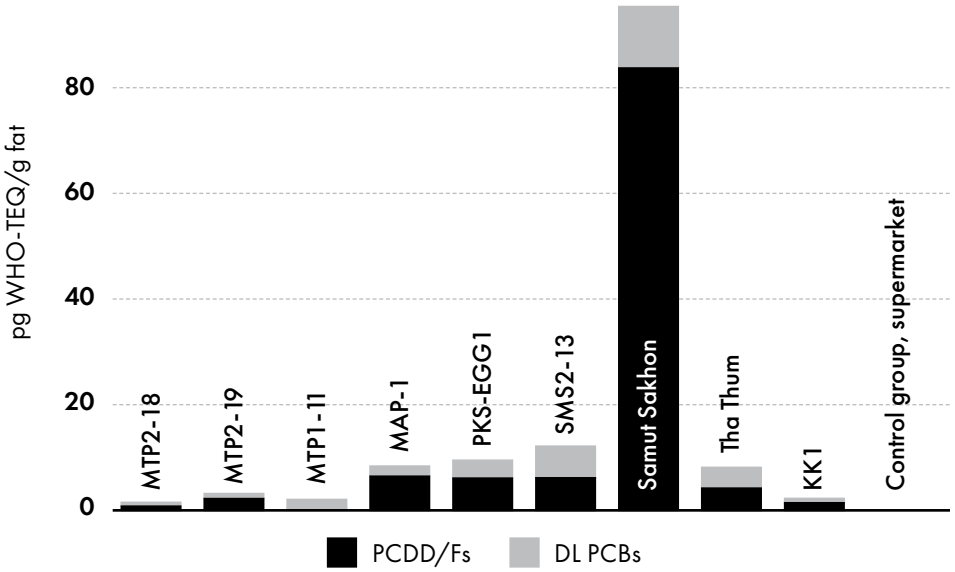


Fig. 4: *Comparison of 7 I-PCBs concentrations in the egg samples from the hotspot areas and from the background locality*

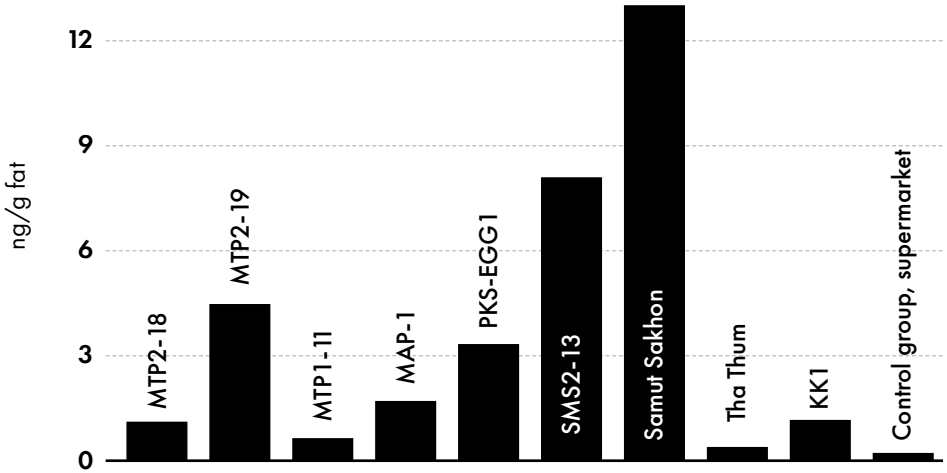
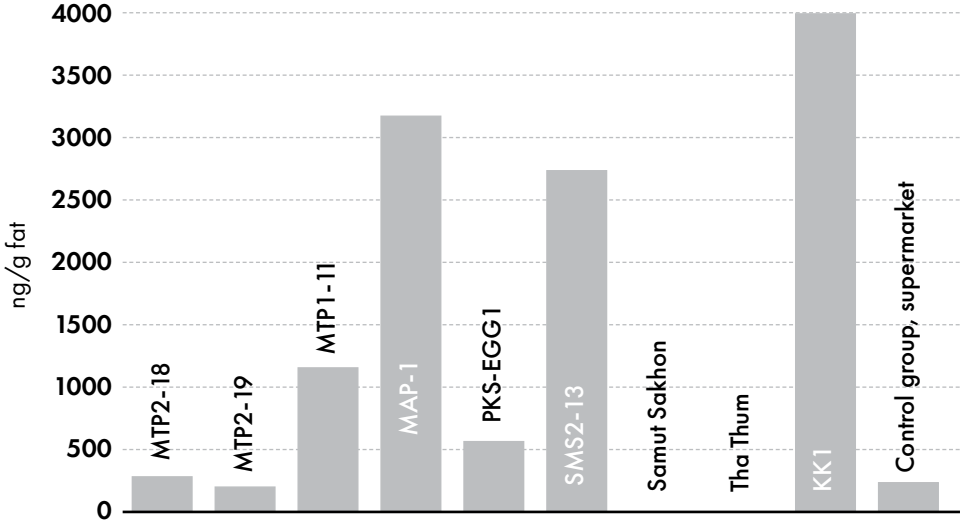


Fig. 5: *Comparison of 16 PAHs concentrations in the egg samples from the hotspot areas and from the background locality*



2.6 GENERAL ASSESSMENT OF PERSISTENT ORGANIC POLLUTANT DISTRIBUTION IN THAILAND

Organochlorine pesticides, mainly DDTs, were commonly used in Thailand in the past and their levels in the environment are still decreasing. The monitoring of organochlorine pesticides in Thailand conducted in the 1970s showed that organochlorine pesticides persisted in a majority of the samples, roughly 50% in water, 90% in sediments and aquatic animals, and 90% in soil samples. Aside from the most common compounds, such as DDTs, the other organochlorine pesticides frequently found in environmental samples include: α-HCH, endrin, aldrin, dieldrin, and heptachlor. After discovering evidence that all these organochlorine compounds had widely distributed in the food chain and the environment, they were progressively banned. During 1987-1989, there was a nationwide monitoring program for residue levels of organochlorine pesticides in the environment to observe levels of these chemicals after their uses had been decreasing. The results revealed that organochlorine pesticides were found to have been distributed in all agricultural areas and ended up in living organisms, such as fish and shellfish. This is the same situation as it was 10 years ago, only the amounts of accumulation were not alarming and had a tendency to decline [27]. The results from our monitoring of organochlorine pesticides showed relatively low levels and confirm the continuous tendency to decline, as we found generally lower levels than were presented in the cited literature [34-36].

Contrary to the information from the Thai National Implementation Plan of the Stockholm Convention saying that mirex and HCB were never imported and used in Thailand, we found one sediment sample containing mirex and a relatively frequent presence of HCB mainly in organic samples. Hexachlorobenzene contamination can originate from the usage of fungicides or as an impurity in pesticide formations and other chemicals, but it is also formed as a by-product of various chlorinating processes and the combustion of industrial and municipal wastes. The occurrence of HCB found in our study is consistent with previous studies [35, 36].

There are some factors that have an influence on the distribution of POPs in Thailand and in tropical zones in general. Seasonal variation and the effect of temperature are some of these factors. The effect of seasonal variation on the accumulation of POPs in aquatic animals was studied on spot barbs (*Puntius bimaculatus*) widely found across Thailand. [47] For the study, spot barbs were collected in both dry and wet seasons for measurement of accumulated pollutants. The results indicated that both PCBs and organochlorine compound concentrations in freshwater fish collected in the dry season were higher than that in the wet season due to lipid content. Since we had taken samples in the dry season, there were lower levels of POPs in freshwater fish during the wet season than is presented in our study.

Temperature has a much wider effect on the distribution of POPs in the environment. Increasing temperatures provide thermodynamic forces to drive POPs out of reservoirs, like soil, vegetation and water, and into the atmosphere, where they can be transported rapidly by winds, and then redistributed among environmental media to reach locations where lower temperatures prevail. A widely-cited hypothesis to explain why some POPs are found in remote, cold environments at concentrations that are a cause for concern is the effect of low temperatures on physiochemical properties that enhance deposition within such environments. This process has been termed “global fractionation” or “cold trapping” [48]. According to this flux model, emission to air will tend to occur primarily in “global source areas” where POPs are used or released. POPs can potentially migrate from warmer to colder areas and become “fractionated” on latitudinal or altitudinal gradients. The Polar Regions will become “global sinks” for POPs released or used elsewhere on Earth. For example, DDT usage has been extensive through the tropics, and the high temperatures in the tropics will mean greater volatilization rates of DDTs than locations in a cooler climate [49].

Temperature can significantly affect the distribution of POPs between different phases, and promote POPs to migrate from the land to the atmosphere. Consequently, in the tropical environment, there are more POPs dispersed through the air and retained less in sediments. The ratios of organochlorine concentrations in sediment and water phases were positively correlated with the latitude of sampling. [50] Moreover, the presence of organochlorine compounds in aquatic ecosystems was less significant, and its residence time

was quite short; whereas its transfer to the atmosphere was much larger due to the high temperature. It is probably the reason why we found relatively low levels of POPs in the sediment samples in all hotspot areas in Thailand, because high temperatures cause volatilization of POPs from the soils and sediments.

Higher temperature in tropical zones can also influence the toxicity of POPs. Numerous studies have concluded that the bioavailability and toxicity of POPs in organisms increases with the increase of temperature. Possible mechanisms for this are as follows: 1) the dynamic toxicity effect of compounds increases with the increasing temperature, 2) warming gives rise to a weak immune ability of wildlife to POPs, which results in increasing toxicity of POPs. [51] For this reason, more rigorous maximal allowed levels in foodstuffs, in comparison with the European Union, is necessary for tropical countries such as Thailand, because relatively low levels found in the organic samples can have a stronger toxic effect on human health.

2.7 CONCLUSIONS

Our results show that there are residues of organochlorine pesticides still present in the environment of Thailand. The most common organochlorine pesticide is DDT and its residues, which agrees with literature information and amounts of pesticides used, according to the National Implementation Plan of Thailand. Contrary to the information from the National Implementation Plan of Thailand, we found residues of mirex.

The most problematic POPs found in the hotspot areas are unintentionally produced contaminants, such as PCDD/Fs, HCB, PeCB, PCBs, HBCD, and HCHs. These contaminants are unintentionally produced by industrial processes, such as the bleaching of paper, small metallurgical facilities used as waste recycling operations, open burning of waste and e-waste in particular (e.g. for purpose of collecting remaining metals from wastes), chlor-alkali production, and the production of plastics or waste incineration.

The most contaminated matrix is eggs, because most of the egg samples exceed the maximum residue limits of HCB or HCH for Thailand or maximum levels of PCB and PCDD/F for the European Union and the Czech Republic. Two egg samples collected in the Samut Sakhon hotspot area contain unsafe levels of unintentionally produced POPs. One of the two egg samples from Samut Sakhon has concentrations of PCDD/Fs (84.04 ng WHO-TEQ/kg fat) and PCDD/Fs + DL PCBs (95.71 ng WHO-TEQ/kg fat) that are 33 folds and 19 folds higher than the maximal levels in eggs tolerable for the European market. Moreover, this egg sample also contains a concentration of PBDD/Fs (15.8 ng WHO-TEQ/kg fat). The contamination of the egg samples from Samut Sakhon can be caused by breeding hens around a small a waste “recycling” facility located near a waste burning facility, including e-waste. One egg sample collected in the Map Ta Phut hotspot area contains unsafe levels of PCDD/Fs (6.5 ng WHO-TEQ/kg fat) and PCDD/Fs + DL PCBs (8.41 ng WHO-TEQ/kg fat) that exceed the maximal levels in eggs tolerable for the European market. The contamination of the egg sample from Map Ta Phut can be caused by the immediate vicinity of the chemical industry.

3. Chicken eggs as an indicator of POPs pollution in Thailand

RNDr. Jindřich Petrlík

3.1 INTRODUCTION

In this study, we present the results of monitoring free-range chicken eggs from selected sites in Thailand, which are contaminated by persistent organic pollutants (POPs). Free-range chicken eggs were used for monitoring levels of contamination by POPs in various locations in many previous studies [52-57]. Eggs have been found to be sensitive indicators of POP contamination in soils or dust and are a significant exposure pathway from soil pollution to humans. Eggs from contaminated areas can readily lead to exposures which exceed thresholds for the protection of human health [58-60]. Chickens and their eggs might, therefore be ideal "active samplers": an indicator species for the evaluation of contamination levels of sampled areas by POPs, particularly by dioxins (PCDD/Fs) and PCBs. Based on this assumption, we have chosen a sampling of free-range chicken eggs and their analyses for selected POPs as one of the monitoring tools within the project "Increasing Transparency in Industrial Pollution Management through Citizen Science" (further information about the project can be found at http://english.arnika.org/thailand or http://earththailand.org/en/). The data and analyses of free-range chicken eggs discussed in this report were obtained during several field visits in 2015 and 2016 as a result of the two above-mentioned joint projects of Thai and Czech NGOs. A description of sampled localities and a list of samples can be found in General Introduction.

3.1.1 SAMPLING AND ANALYTICAL METHODS

Samples of free-range chicken eggs were collected at seven localities in Eastern, Central, and Southern Thailand. One sample was taken from a supermarket in the city of Bangkok, considered as a background sample for Thailand, as suggested e.g. by Dvorská [61]. Chosen localities were expected to be contaminated by POPs to a certain level. The larger areas of Map Ta Phut, Samut Sakhon, Saraburi, Tha Tum and Khon Kaen were expected to be polluted by POPs, as industry estate parks contain different types of industries. High levels of dioxins in sediments were collected in the Khon Kaen area in 2006 [3]. There is a large abandoned landfill in Praeksa where a large fire occurred in 2014 (see chapter 1.3.6), so it was expected to be contaminated by unintentionally produced POPs (U-POPs) mainly. Koh Samui is a popular tourist island; however, there is a large municipal solid waste landfill and an abandoned waste incinerator, both of which are expected to be potential sources of POPs pollution. The assumption about potential contamination by POPs was also based on data from the Dioxin Sampling and Analysis Program held in Thailand in 1997 [62], and the Thai National Implementation Plan for the Stockholm Convention [27], as selected industries are considered and proven to be sources of unintentionally produced POPs.

More information about the selected sites can be found in General Introduction. To obtain representative samples, pooled samples of individual egg samples were collected at each of the selected sampling sites. The list of samples in General Introduction summarizes the basic data about sample size and measured levels of fat content in each of the pool samples. 11 pool samples of free-range chicken eggs were taken in total, plus the one sample taken in Bangkok, where we bought chicken eggs in a supermarket. The last of the above-mentioned samples was used to exhibit background levels of POPs as suggested by Dvorská [61]. Two samples were taken in 2015, and nine in the following year (2016).

Most of the samples were analyzed for content of individual PCDD/Fs, an extended list of PCB congeners, and 16 PAHs by HRGC-HRMS at Axys Varilab, an accredited laboratory in Vrane nad Vltavou, Czech Republic and/or in an accredited laboratory in the State Veterinary Institute in Prague, Czech Republic.

Egg samples were also analyzed for content of OCPs, PeCB, HCBD and BFRs in a certified Czech laboratory (Institute of Chemical Technology, Department of Food Chemistry and Analysis). The analytes were extracted by a mixture of organic solvents hexane: dichloromethane (1:1). The extracts were cleaned by means of gel permeation chromatography (GPC). The identification and quantification of the analyte was conducted by gas chromatography coupled with tandem mass spectrometry detection in electron ionization mode. The method of ultra-performance liquid chromatography, coupled with tandem mass spectrometry detection (UHPLC–MS/MS), was chosen for the analysis of isomers of HBCD. The other BFRs were analyzed via a previously mentioned technique.

3.2 THE THAI AND EU LIMITS FOR POPs IN EGGS

Chicken eggs are a major component of the human diet, and it is common practice for Thai people to raise their own chickens. However, there is a limited number of Thai chemical laboratories, and this fact is likely to limit the values/hygienic standards that are set for a limited number of POPs. We have not found limits for PCDD/Fs and PCBs in Thai legislation, so we had to compare the results of analyses for POPs with EU standards. The limit values we used for free-range chicken eggs are summarized in Table 1.

Table 1: *Limit Concentration Values for OCPs, PCBs and PCDD/Fs TEQs in Chicken Eggs.*

	Hen eggs		
	Thai[1]	EU ML[2]/MRL[3]	
Unit	**ng g^{-1}**	**pg g^{-1} fat**	**ng g^{-1} fat**
WHO-PCDD/Fs TEQ	None	2.5	-
WHO-PCDD/Fs-dl-PCB TEQ	None	5.0	-
PCBs[5]	None	-	40
	ng g^{-1} fresh weight		
DDT total[6]	100 [7]	-	50 (fresh)
γ-HCH (lindane)	<LOD[8]	-	10 fresh
α-, β-HCH**	none; <LOD[8]	-	20, 10
HCB	<LOD[8]	-	20 (fresh)

1) For PCDD/Fs and PCBs was not Thai standard set yet

2) EU Regulation (EC) N°1259/2011 [63] sets maximum levels for dioxins, dioxin-like PCBs and non dioxin-like PCBs in foodstuffs.

3) Regulation (EC) N°149/2008 [64]. Maximum residue level (MRL) means the upper-legal level of a concentration for a pesticide residue in or on food or feed set in accordance with the Regulation, based on good agricultural practice and the lowest consumer exposure necessary to protect vulnerable consumers.

5) sum of PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180

6) sum of p,p´-DDT, o,p´-DDT, p,p´-DDE and p,p´-DDD

7) Thai: Pesticide Residues: Extraneous Maximum Residue Limits (EMRL), Thai Agricultural Standard (TAS 9003 – 2004)

8) Thai: Pesticide Residues: Extraneous Maximum Residue Limits (EMRL), Thai Agricultural Standard (TAS 9002 – 2016)

** for each isomer is MRL set separately

3.3 RESULTS

13 pooled samples of eggs were analyzed for PCDD/Fs and DL PCBs, and 12 samples for other POPs[8], nine for OCPs and PAHs, eight for HCBDs and PeCBs, and six for BFRs. GCMS-HRMS analyses were chosen for a confirmation of contamination by dioxins and dioxin-like PCBs of sampled chicken eggs. The same samples were also analyzed for other POPs and OCPs: hexachlorobenzene (HCB), hexychlorocyclohexanes (HCHs) and DDT and its metabolites. HCB is also considered to be an unintentionally produced POP (U-POP) in the same processes as dioxins and DL PCBs [43], although it is commonly measured together with other OCPs. Also, two other U-POPs, pentachlorobenzene (PeCB) and hexachlorobutadiene (HCBD) were analyzed in some samples. The results for U-POPs and OCPs are summarized in Table 2, for PAHs in Table 3 and for BFRs in Table 4. Discussion about the results of the analyses for POPs will focus on dioxins and dioxin-like POPs, PAHs and brominated flame retardants in this study. Other POPs such as, organochlorine pesticides (OCPs) were already discussed sufficiently in the report by Mach, Teebthaisong et al. [65].

3.3.1 DIOXINS (PCDD/Fs) AND PCBs

Dioxins belong to a group of 75 polychlorinated dibenzo-p-dioxin (PCDD) congeners and 135 polychlorinated dibenzofuran (PCDF) congeners, 17 of which are of toxicological concern. Polychlorinated biphenyls (PCBs) are a group of 209 different congeners, which can be divided into two groups according to their toxicological properties: 12 congeners exhibit toxicological properties similar to dioxins, and are often referred to as 'dioxin-like PCBs' (DL PCBs). The other PCBs do not exhibit dioxin-like toxicity, but have a different toxicological profile and are referred to as 'non dioxin-like PCB' (NDL PCBs) [63]. Levels of PCDD/Fs and DL PCBs are expressed in total WHO-TEQ calculated, according to toxic equivalency factors (TEFs) set by a WHO experts panel in 2005 [66]. These new TEFs were used to evaluate dioxin-like toxicity in 11 pooled samples of chicken eggs from Thailand. Six out of 13 samples from Thailand exceeded the EU ML of PCDD/Fs and/or PCDD/Fs and DL PCBs, expressed as WHO TEQ in chicken eggs (compare Tables 2 and 1; see graph at Figure 1); [63]. The background levels for PCDD/Fs and DL PCBs measured in chicken eggs from a supermarket in Bangkok were 0.08 and 0.001 pg WHO-TEQ g^{-1} fat, respectively. The highest levels of dioxins (84.04 pg WHO-TEQ g^{-1} fat) and DL PCBs (11.67 pg WHO TEQ g^{-1} fat), were measured in eggs from Samut Sakhon, sampled in an area of a small artisanal recycling facility where metals are reclaimed from wastes after they are burned. The same sample was analyzed by the bioassay DR CALUX method and a level of 100 pg BEQ g^{-1} fat was measured. It also contained high levels of polybrominated dioxins (see subchapter 3.2).

Another egg sample from Samut Sakhon, located in an area close to "recycling" facilities that focused on secondary metal production, also exceeded the EU standard for dioxins in eggs, as well as egg samples from Praeksa (PKS-EGG1) and Map Ta Phut (MAP-1), see graph at Figure 1. From the collected egg samples exceeding the EU standard for dioxins, only those from an artisanal recycling facility area-- as well as those from Tha Tum and some samples from Map Ta Phut area (e.g. MAP-1) and Praeksa-- were used for the chicken owners' personal consumption. The others were meant to be used for raising cockerels. Total WHO-TEQ levels of PCDD/Fs and DL PCBs in samples from most Thai hotspots are lower than in selected samples from Chinese, Kazakhstani and Belorussian hotspots selected in other recent studies; however, the highest level of dioxins measured in eggs from Samut Sakhon belongs to the highest levels observed in free-range chicken eggs during the last years. Places with higher egg contamination than found in Samut Sakhon were observed in Vietnam, in areas sprayed by herbicides contaminated by dioxins during the Vietnam war [67], and/or in Portugal, at a locality where pentachlorophenol was used as a wood preservative [68]. The dioxin level in the eggs sample from Samut Sakhon is comparable with levels observed in Pontypool, UK, near a hazardous waste incinerator [69], Kovachevo, Bulgaria [70] and Oroville, California, in an area where accidental fires in a pentachlorophenol wood treatment facility occurred [71, 72].

8 Sample KK1 is a pooled sample from KK1/1 and KK1/2. It comes from two different fanciers living close to each other. It was handled as two separate samples for certain analyses, while for the other analyses were handled as one pooled sample. See Table 2.

Figure 1: *Graph of PCDD/Fs concentrations in chicken eggs samples from selected hot spots and the Bangkok supermarket in Thailand collected in 2015 – 2016 (in pg WHO-TEQ g^{-1} fat)*

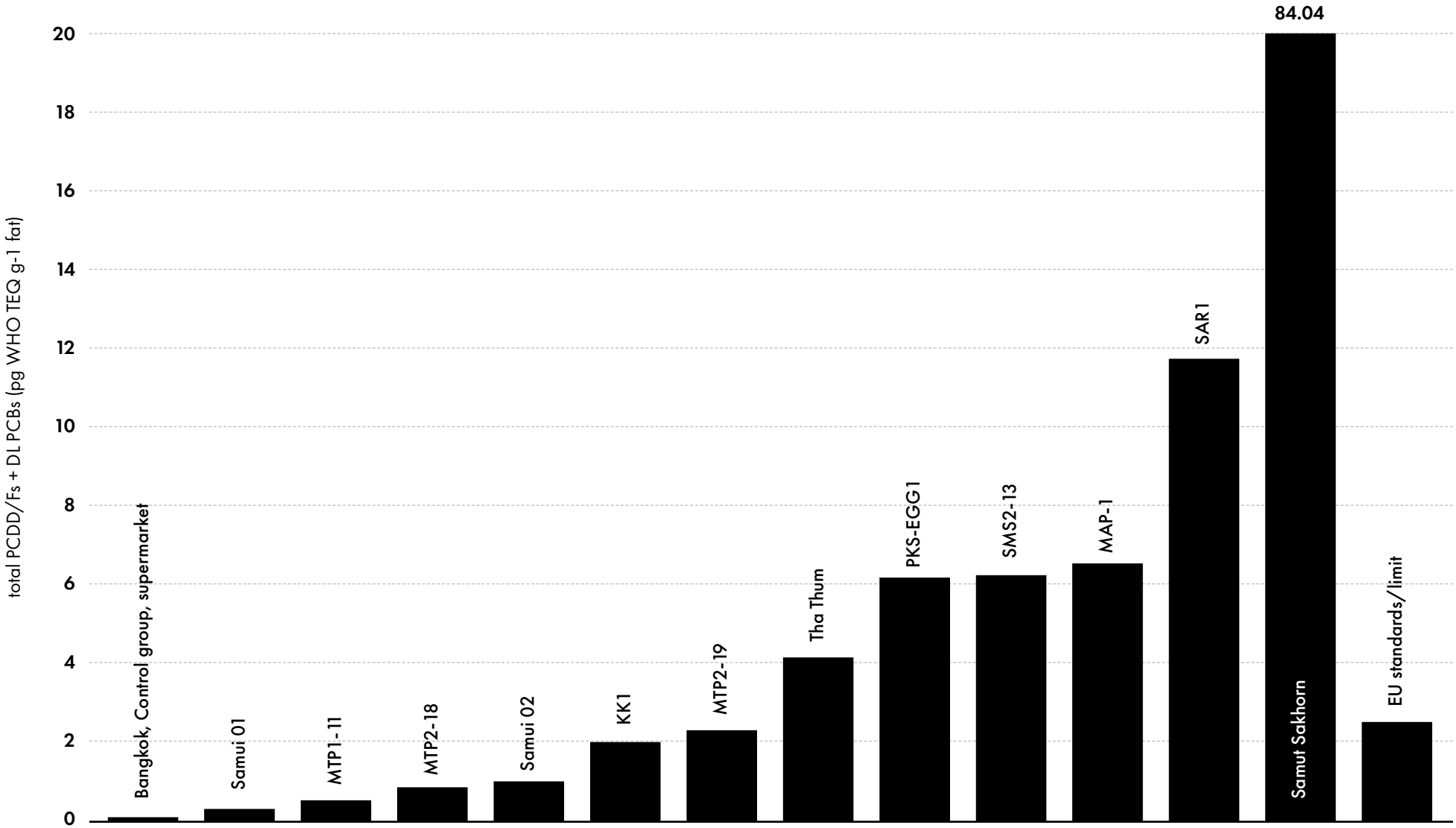


Table 2: *Summarized results of analyses for POPs for eleven pooled free-range chicken eggs samples collected at selected localities in Thailand in a two-year period (2015 - 2016), plus a background sample from a supermarket in Bangkok, sampled in 2016.*

Locality	Samut Sakhorn	Samut Sakhorn	Tha Tum	Sarabu-ri	Khon Kaen	Khon Kaen	Khon Kaen	Map Ta Phut	Map Ta Phut	Map Ta Phut	Map Ta Phut	Koh Samui	Koh Samui	Praek-sa	Bangkok	EU
Sample	**Samut Sakhorn**	**SMS2-13**	**Tha Thum**	**SAR1**	**KK1**	**KK1/1**	**KK1/2**	**MAP1**	**MTP2-18**	**MTP2-19**	**MTP1-11**	**Samui 01**	**Samui 02**	**PKS-EGG1**	**Control gr., superm.**	**stan-dards /limits**
Fat content	11.6	19.4	12.5	11.1	13	16.3	14.1	17.0	14.7	18.5	18.2	14.1	14.7	18.1	11.6	
PCDD/Fs (pg WHO TEQ g^{-1} fat)	84.04	6.23	4.14	11.73	1.99	NA	NA	6.53	0.84	2.29	0.51	0.29	0.99	6.17	0.08	2.50
DL PCBs (pg WHO TEQ g^{-1} fat)	11.67	6.00	3.94	6.71	0.83	NA	NA	1.92	0.73	0.95	1.61	0.01	0.001	3.40	0.001	
Total PCDD/Fs + DL PCBs (pg WHO TEQ g^{-1} fat)	95.71	12.23	8.09	18.44	2.82	NA	NA	8.45	1.57	3.24	2.12	0.30	0.99	9.57	0.08	5.00
HCB (ng g^{-1} fat)	4.21	NA	1.51	NA	NA	5.52	4.54	NA	3.62	6.81	4.79	1.84	NA	NA	<0.18	-
PeCB (ng g^{-1} fat)	NA	1.49	NA	NA	NA	<0.31	<0.35	NA	<0.34	<0.27	<0.27	<0.35	NA	NA	<0.43	
HCBD (ng g^{-1} fat)	NA	<0.26	NA	NA	NA	<0.31	<0.35	NA	<0.34	<0.27	<0.27	<0.35	NA	NA	<0.43	
7 PCB (ng g^{-1} fat)	12.97	8.07	0.39	2.68	1.16	NA	NA	1.70	1.11	4.46	0.64	0.91	1.27	3.32	0.22	-
6 PCB (ng g^{-1} fat)	11.40	7.08	0.39	2.23	1.00	NA	NA	1.40	0.95	3.54	0.50	0.72	1.07	2.56	0.22	40.00
Sum of HCH (ng g^{-1} fat)	0.31	NA	0.23	NA	NA	1.53	2.34	NA	1.77	1.68	6.04	2.55	NA	NA	0.52	
Sum of DDT (ng g^{-1} fat)	2.85	NA	0.83	NA	NA	10.06	20.43	NA	19.25	8.43	8.08	37.80	NA	NA	<LOQ***	

*** Levels of quantification for individual DDT metabolites varied between 0.25 – 2.15 ng/g fat.

Levels observed in one third of the samples were lower than the median level found in chicken eggs in a recent Chinese dietary intake study focused on PCDD/Fs and DL PCBs [73]. The lowest levels of PCDD/Fs 0.29 and 0.99 pg WHO TEQ g^{-1} fat, respectively, were observed in free-range chicken eggs collected at Koh Samui, even though these samples were collected in an area near a municipal waste landfill and abandoned waste incinerator covered by a forest. All samples of free-range chicken eggs had levels of PCDD/Fs and DL PCBs higher than those observed in the pool sample of eggs bought in a Bangkok supermarket, which is used as a control sample showing background levels of PCDD/Fs and DL PCBs in chicken eggs from Thailand for this study. On this topic, see also the discussion about background levels in other studies focused on POPs in free-range chicken eggs [54, 74].

Figure 2: *Graph showing balance between DL PCBs and PCDD/Fs (in WHO-TEQ) in analyzed pooled egg samples from Thailand.*

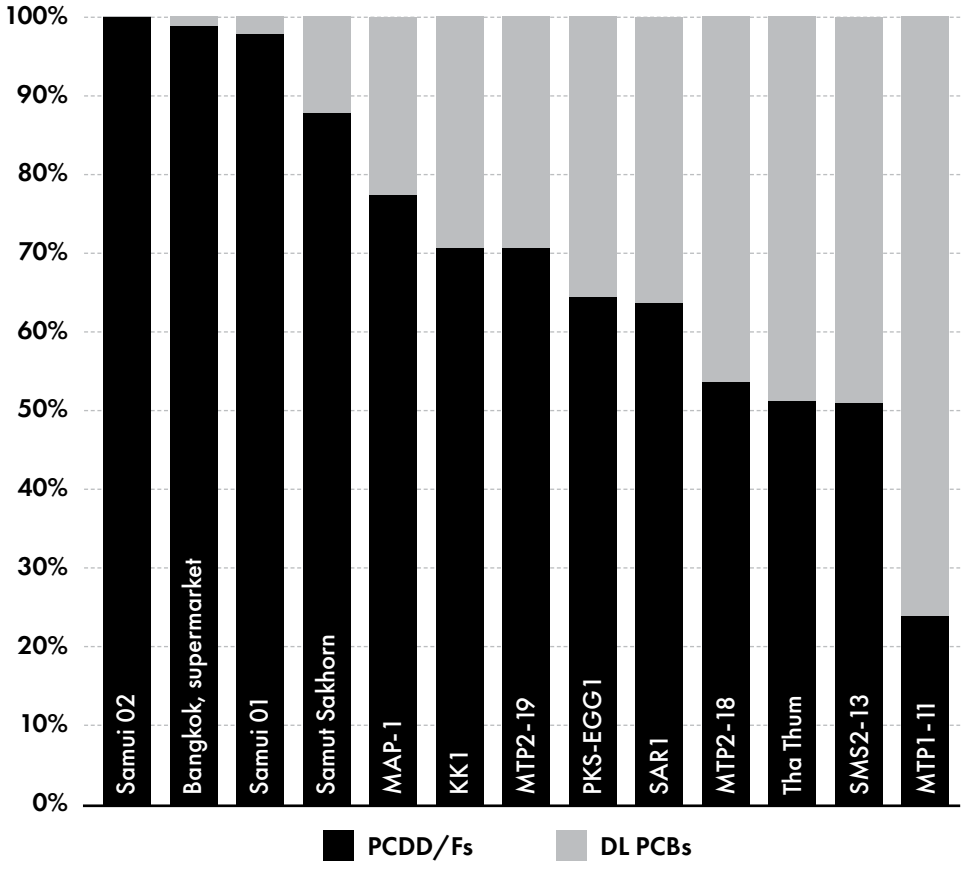
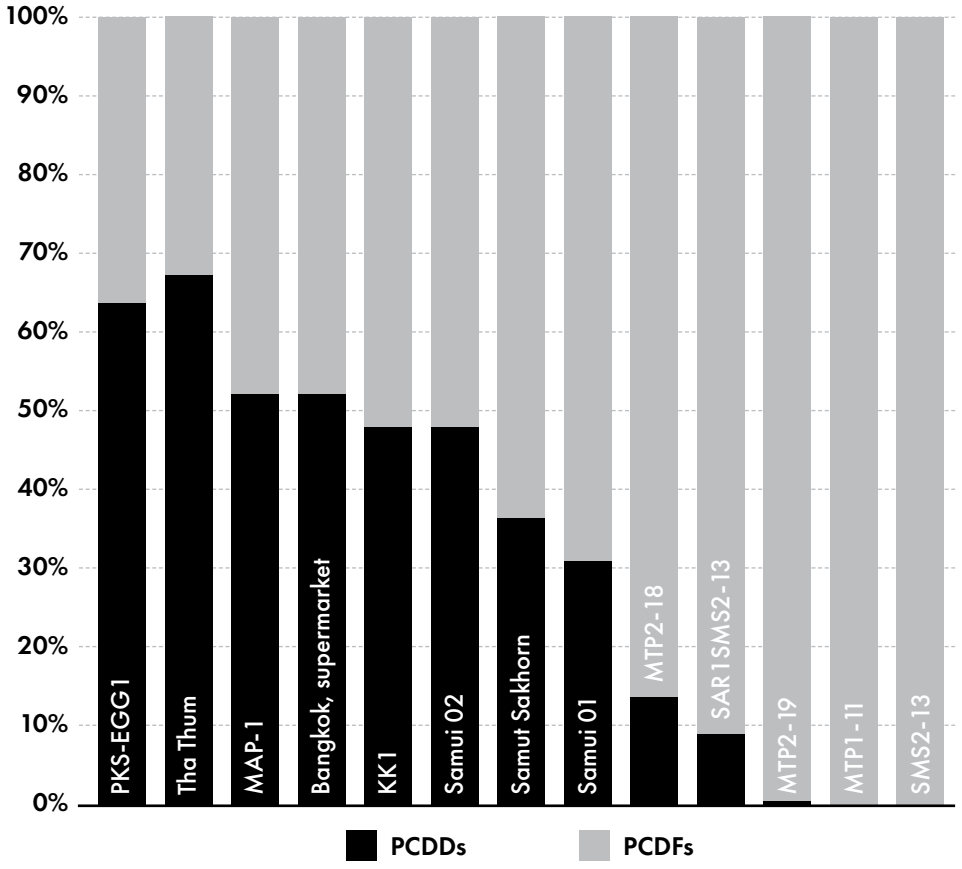


Figure 3: *Graph showing balance between PCDDs and PCDFs from WHO-TEQ levels of PCDD/Fs in analyzed pooled egg samples from Thailand.*

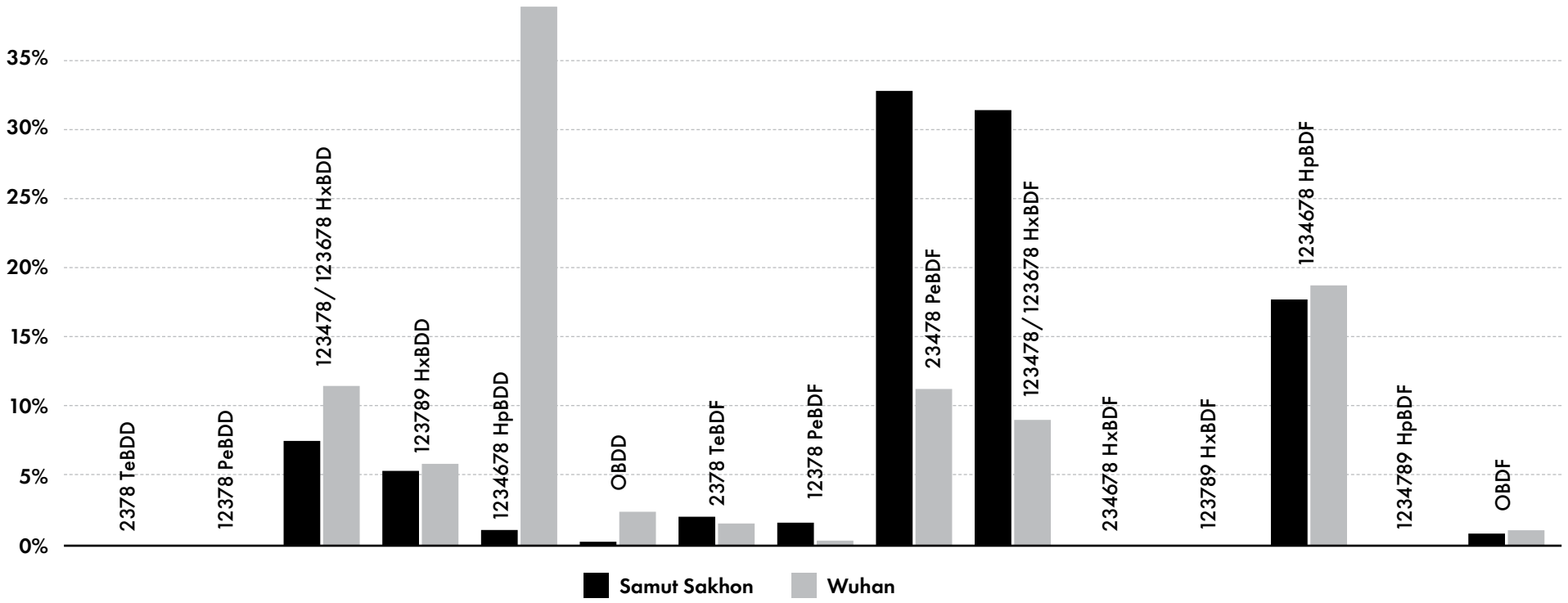


PCDD/Fs cause a substantial part of the overall toxicity of chicken eggs in nine out of 13 samples analyzed in this study, and PCDFs largely prevail in seven out of 13 samples over PCDDs (see graphs at Figures 2 and 3). This is a completely different situation in comparison with the samples from Kazakhstan [74]. It reflects the fact that the Thai environment, overall, is not so seriously contaminated by PCBs in Kazakhstan and other countries, e.g. the Czech Republic or Slovakia. Also indicator PCB congeners are not presented in high levels in almost all egg samples, except one from Samut Sakhon in which the level of indicator congener PCBs reached one fourth of EU ML, which is 40 ng g^{-1} fat [63], so it is still well below the EU limit for PCBs in eggs.

3.3.2 POLYBROMINATED DIOXINS (PBDD/Fs)

Polybrominated dioxins and furans (PBDD/PBDFs) are formed from the brominated flame retardants present in e-waste plastic [75]. Pollution by these dioxins can be expected at sites with e-waste plastic or cable burning, and likely result in the contamination of grazing animals at these sites. It has recently been established in a UK food survey that polybrominated dibenzo-p-dioxin and dibenzofurans can also contribute significantly to total dioxin exposure for the UK population [76]. They are also formed as U-POPs in BFR production, as well as in waste incineration [77] and other combustion processes [78, 79] with the presence of brominated compounds.

Figure 4: *PBDD/Fs congeners profile in egg samples from Samut Sakhon, Thailand and Wuhan, China. Percentange calculation was made from balance of congeners on total WHO-TEQ level.*



The eggs sampled in Samut Sakhon in February 2015 were also analyzed for PBDD/Fs. The level of these chemicals measured in these eggs at 15.8 – 22.9 pg WHO-TEQ g-1 fat was the second highest level ever measured in chicken eggs globally. A higher level of 27.3 – 29.2 was measured in free-range chicken eggs sampled in Wuhan, China in a neighborhood that contained a municipal waste incinerator [80, 81]. The Figure 4 Graph shows the difference between brominated dioxin congeners profiles for the egg samples from both Samut Sakhon and Wuhan. The presence of individually-detected congeners is the same; however, their balance is quite different.

3.3.3 POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) were analyzed in only eleven samples of the total group of samples. Results of these analyses are summarized in Table 3, and a comparison of total sums of 16 PAHs between samples is in the graph in Figure 5. Naphthalene and phenanthrene were the most dominant homologues from 16 measured PAHs in analyzed samples. Balance between these two PAHs in individual samples is shown in the graph in Figure 6.

The highest level of PAHs was measured in egg samples from Khon Kaen (3985 ng g^{-1} fat), followed by the samples from Map Ta Phut (3166 ng g^{-1} fat) and Samut Sakhon (2730 ng g^{-1} fat). PAHs in two samples from Map Ta Phut (MTP 2-18 and 2-19), and one sample from Koh Samui (Samui 02) were below or slightly above the level of PAHs in eggs from the Bangkok supermarket. Apart from those samples, the levels of PAHs in other samples from selected localities in Thailand were much higher than in free-range chicken eggs from Mangystau Region, Kazakhstan, and some of them were also well above the level of PAHs in eggs from Likeng, China sampled near a municipal waste incinerator.

Figure 5: *Comparison of total sums of 16 PAHs between chicken eggs samples from Thailand.*

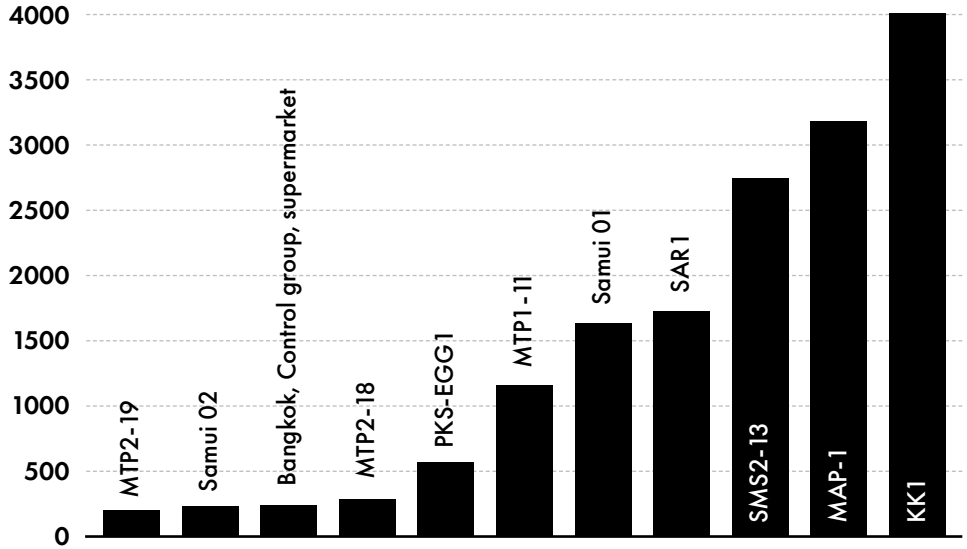


Figure 6: *Balance between phenanthrene and naphthalene in chicken eggs samples from Thailand.*

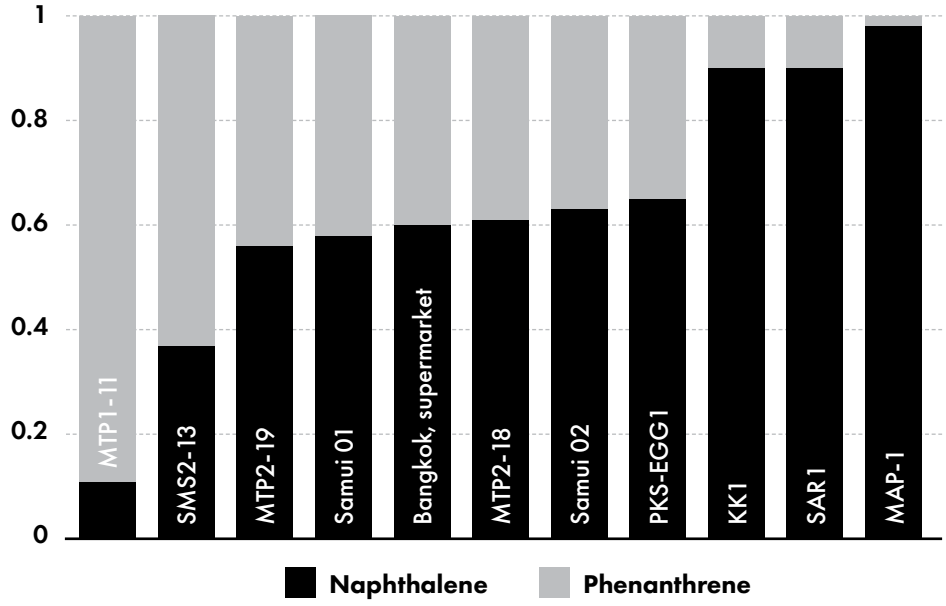


Table 3: *Summarized results of analyses for 16 PAHs in free -range chicken eggs samples from Thailand collected in 2015 – 2016 (in ng g^{-1} fat).*

Sample	SMS2-13	SAR1	KK1	MAP-1	MTP2-18	MTP2-19	MTP1-11	PKS-EGG1	Bangkok, superm.	Samui 01	Samui 02
Locality	Samut Sakhon	Saraburi	Khon Kaen	Map Ta Phut	Map Ta Phut	Map Ta Phut	Map Ta Phut	Praeksa	Bangkok	Koh Samui	Koh Samui
Naphthalene	690	1300	3100	3 000	170	110	86	330	140	220	140
Acenaphthylene	< 30	62	42	14	< 30	< 30	< 20	11	< 30	33	< 30
Acenaphthene	< 30	75	< 30	26	< 30	< 30	< 20	4	< 30	< 30	< 30
Fluorene	50	130	270	19	< 30	< 30	< 20	7	< 30	41	< 30
Phenanthrene	1200	150	360	65	110	88	700	180	93	160	83
Anthracene	460	< 40	110	10	< 30	< 30	190	4	< 30	72	< 30
Fluoranthene	220	< 40	47	14	< 30	< 30	120	9	< 30	110	< 30
Pyrene	110	< 40	56	15	< 30	< 30	56	12	< 30	110	< 30
Benzo(a)anthracene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	< 2	< 30	110	< 30
Chrysene	< 30	< 40	< 30	3	< 30	< 30	< 20	3	< 30	110	< 30
Benzo(b)fluoranthene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	2	< 30	110	< 30
Benzo(k)fluoranthene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	< 2	< 30	150	< 30
Benzo(a)pyrene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	< 2	< 30	94	< 30
Indeno(1,2,3-cd)pyrene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	< 2	< 30	100	< 30
Benzo(ghi)perylene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	< 2	< 30	100	< 30
Dibenzo(a,h)anthracene	< 30	< 40	< 30	< 3	< 30	< 30	< 20	< 2	< 30	100	< 30
Sum of PAHs	2730	1717	3985	3166	280	198	1152	562	233	1620	223

The potential source of egg contamination in Khon Kaen can be attributed to fly ash, which was distributed to the local people as fertilizer by Phoenix Pulp and Paper Plc. Ltd. Samples of chicken eggs were collected from fanciers where chickens had access to this ash, either spread out on gardens or in piles in front of their homes. Chickens would pick at their feed near these potential sources of contamination. Most likely, the source of egg contamination in Samut Sakhon is either secondary production of metals, or open-air burning of waste in the area that hens use to breed. It is necessary to note that the eggs sampled in that location in Samut Sakhon were not used for food consumption, but for raising new chickens-- roosters in particular. Chicken eggs in sample MAP-1 from Map Ta Phut were most likely contaminated because they are raised very close to one of the industrial real estates (RIL) of petrochemical industry in Map Ta Phut.

3.3.4 BFRS AND POLYBROMINATED DIOXINS (PBDD/Fs) IN EGGS

A broad family of brominated flame retardants, including those used as alternatives to older ones, such as polybrominated diphenyl ethers (PBDEs) and/or hexabromocyclododecane (HBCD), were analyzed in free-range chicken eggs from Samut Sakhon, Map Ta Phut, Koh Samui, as well as in a sample of eggs from the Bangkok supermarket. Results can be found in Table 4.

The highest level of PBDEs was measured in a sample of eggs from Samut Sakhon. The source of the contamination can be attributed to recycling facilities in the surrounding area where the eggs were sampled. In an IPEN report focused on different hotspots, the maximum level of HBCD (160 ng g^{-1} fat) in free-range chicken eggs was observed in a sample from the Dandora landfill in Nairobi. The highest level of PBDEs (107 ng ng g^{-1} fat) in that report was observed in a sample from the vicinity of a hazardous waste incinerator in Turkey [82]. The sample from Samut Sakhon had PBDE levels four times higher than the maximum levels found in the IPEN study; however, the study is more than ten years old. The level of HBCD in samples from several sites is comparable to what was found at the Dandora landfill, but again, this is in comparison with a situation from ten years ago.

On more than two occasions, poultry eggs in the vicinity of the Chinese municipal solid waste incinerator [80] and e-waste recycling site in Eastern China [83] registered PBDEs levels four times higher than those found in eggs from Samut Sakhon.

3.4 DISCUSSION ABOUT POTENTIAL EXPOSURE TO POPs FROM CHICKEN EGGS

At some of the locations, we received information that the eggs were not intended to be consumed as food, but for raising new chickens and roosters. So instead, we used the eggs for a comparison of potential exposure, as they are commonly used for biomonitoring. The eggs collected as samples from Samut Sakhon, Tha Tum, MAP-1, MTP 1-11, KK 1/1, KK 1/2, PKS-EGG1, Samui 01 and Samui 02 were intended for food consumption.

The egg share in total food consumption in Thailand in 2007 was close to 1.5% of total food basket per day, according World Atlas – Food Security data [9] [84], and its share changes were not constantly increasing or decreasing. It would mean that 2017 consumption could remain approximately the same, about 26 g per person per day, if the trend continued. If we count 50 g per one chicken egg as the average weight, it would mean consumption of half an egg per person per day as the general consumption pattern for the current Thai population. We tried to calculate dietary intake for the following groups of contaminants per day: 1) PCDD/Fs plus DL PCBs; 2) PBDEs and 3) 16 PAHs. Calculation of daily intake levels was made by using the following formula: DI_{adult} = (((C . F%)/100) . 26)/70; DI_{child} = (((C . F%)/100) . 26)/35, where DI = daily intake; C = concentration of certain group of chemicals (PCDD/Fs, DL PCBs etc.), and F% = fat content in sample. Results are summarized in Table 5. Results were then compared with available information about the daily intake of evaluated chemicals: 1) **PCDD/Fs + DL PCBs**: Calculations for PCDD/Fs and DL PCBs

9 The food consumption refers to the amount of food available for human consumption as estimated by the FAO Food Balance Sheets. However, the actual food consumption may be lower than the quantity shown as food availability depending on the magnitude of wastage and losses of food in the household. Food consumption per person is the amount of food, in terms of quantity, for each individual in the total population. Food from eggs relates to the quantity of eggs used also for preparation the food such as bakery products.

Table 4: *Summarized results of analyses for different BFRs in chicken eggs samples from Central Kazakhstan, in comparison with selected samples from Thailand (in ng g^{-1} fat). The levels below LOQ were counted as "0" for calculation of sums of the groups of BFRs .*

Sample	SMS2-13	MTP2-18	MTP2-19	MTP1-11	Samui 01	Bangkok, supermarket
Locality	Samut Sakhon	Map Ta Phut	Map Ta Phut	Map Ta Phut	Samui	Bangkok
HBB	<0.26*	<0.20*	<0.16*	0.16	<0.21*	<0.26*
Sum of PBDEs **	426.89	1.09	3.30	44.95	0.92	3.10
PBEB	<0.26*	<0.20*	<0.16*	<0.16*	<0.21*	<0.26*
α-HBCD	159.18	38.91	165.41	184.12	<0.92*	<1.12*
β-HBCD	<1.28*	<0.88*	<0.70*	<0.71*	<0.92*	<1.12*
γ-HBCD	<1.28*	<0.88*	<0.70*	<0.71*	<0.92*	<1.12*
Suma HBCD	159.18	38.91	165.41	184.12	<LOQ	<LOQ
BTBPE	<0.26*	0.34	0.27	0.60	<0.21*	<0.26*
OBIND	<2.55*	<1.70*	<1.35*	<1.37*	<1.77*	<2.16*
DBDPE	<5.10*	<3.40*	<2.70*	<2.74*	<3.54*	<4.31*
Sum of new BFRs	<LOQ	0.34	0.27	0.60	<LOQ	<LOQ

***** below LOQ

****** Following congeners were analyzed: BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207 and BDE 209

Table 5: *Summarized results of calculation of dietary intake of selected POPs by eating a daily portion of eggs (26 g) from chickens raised at some Thai hotspots or eggs bought in a supermarket in Bangkok from chickens raised at a commercial farm. Twenty six grams of egg is the approximate current average consumption per person per day in Thailand based on calculation from available data [84]. Total daily intakes of selected POPs from literature are given for comparison (see explanation below table).*

Sample	Samut Sakhon	SMS2-13	Tha Tum	SAR1	KK1	PKS-EGG1	MAP-1	MTP2-18	MTP2-19	MTP1-11	Samui 01	Samui 02	Bangkok, supermarket	Suggested levels
Data about samples of free range chicken eggs														
Fat content	11.6	12.5	19.4	11.1	13	18.1	17	14.7	18.5	18.2	11.6	14.1	14.7	-
PCDD/Fs + DL PCBs (pg WHO-TEQ g^{-1})	95.71	12.23	8.09	18.44	2.82	9.58	8.45	1.57	3.24	2.12	0.30	0.99	0.08	5*
PBDEs (ng g^{-1})	NA	426.89	NA	NA	NA	NA	NA	1.09	3.30	44.95	0.92	NA	3.10	-
16 PAHs (ng g^{-1})	NA	1890	NA	1450	3460	562	3166	280	198	786	804	223	233	-
Daily intake of toxic chemicals from eggs per kg body weight by adults (DI_{adult})														
PCDD/Fs + DL PCBs (pg kg^{-1} bw)	4.12	0.88	0.38	0.76	0.14	0.64	0.53	0.09	0.22	0.14	0.02	0.05	0.00	2**
PBDEs (ng kg^{-1} bw)	NA	30.76	NA	NA	NA	NA	NA	0.06	0.23	3.04	0.05	NA	0.13	1.88***
16 PAHs (ng kg^{-1} bw)	NA	136	NA	60	167	38	200	15	14	53	42	12	10	-
Daily intake of toxic chemicals from eggs per kg body weight by approx. 10 years old child (body weight 35 kg); (DI_{child})														
PCDD/Fs + DL PCBs (pg kg^{-1} bw)	8.25	1.76	0.75	1.52	0.27	1.29	1.07	0.17	0.44	0.29	0.03	0.11	0.01	2**
PBDEs (ng kg^{-1} bw)	NA	61.52	NA	NA	NA			0.12	0.45	6.08	0.10	NA	0.27	1.88***
16 PAHs (ng kg^{-1} bw)	NA	272	NA	120	334	76	400	31	27	106	84	24	20	-

* EU Regulation (EC) N°1259/2011 [63] sets maximum levels for dioxins, dioxin-like PCBs and non dioxin-like PCBs in foodstuffs

** DI suggested by EFSA [85, 86].

*** DI in Sweden [87]

were compared with TWI, suggested by the Scientific Committee on Food (SCF) at a level of 14 pg WHO-TEQ/kg of body weight per week = 2 pg WHO-TEQ/kg of b. w. per day [85, 86]; 2) **PBDEs**: There is an estimated availability of the daily intake of these two groups of BFRs in Sweden at the beginning of this century [87]. We compared our data with those available in the Swedish study for egg consumption. 3) For **16 PAHs,** no DI value was found and used. See the comparison in Table 5.

Among samples intended to be used for consumption as food, the most critical levels of POPs were found in the sample from Samut Sakhon. Levels of PCDD/Fs, DL PCBs and PBDD/Fs were far too high in comparison with most of the samples collected in other countries during a new round of free-range chicken egg sampling, organized by IPEN and Arnika [74, 80, 88, 89]. Just by eating approximately half an egg from the sample collected in an artisanal recycling facility area, one would exceed the daily intake of dioxins and DL PCBs by at least double, and this is without the inclusion of comparably toxic PBDD/Fs factored into this calculation. It is too much when we take into account that dioxins and DL PCBs are contained in other foods as well [65]. Also, the intake of PCDD/Fs and DL PCBs from samples SMS 2-13 (Samut Sakhon), Tha Tum, SAR1 (Saraburi), MAP-1 (Map Ta Phut), and PKS-EGG1 (Praeksa) is at a troubling level. The intake of PBDEs in eggs from SMS 2-13 (Samut Sakhon) would be very high, as well as from MTP 1-11, although it is 10 times lower. By eating half an egg that was laid at both of these sites, one would exceed the daily intake, like eating eggs in Sweden in 1998 – 99, as researched by Lind, Aune et al. [87]; (see Table 5).[10] The highest dietary intake of PAHs can be obtained from eating eggs sampled in Map Ta Phut (MAP-1), Khon Kaen (KK 1) and Samut Sakhon (SMS 2-13) followed by the sample from Saraburi (SAR 1).

10 The study by Törnkvist et al. (2011) shows that the levels, and intake, of different POPs (including HBCD) from food of animal origin, in the Swedish market basket of 2005 seem to have decreased since the market basket study in 1999. 90.
Törnkvist, A., et al., *PCDD/F, PCB, PBDE, HBCD and chlorinated pesticides in a Swedish market basket from 2005 – Levels and dietary intake estimations.* Chemosphere, 2011. **83**(2): p. 193-199..

3.5 CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated some emerging problems of pollution by POPs in relation to the growing industry in Thailand. Sites with a large concentration of industrial facilities, although there were many limitations[11], create a broad and exhaustive picture of POPs in free-range chicken eggs in such a large country. This study has discovered serious contamination within the food chain by various POPs in Samut Sakhon, with a dense concentration of secondary metal production from artisanal recycling facilities, which quite often burn waste, including e-wastes, for reclamation of metals. These facilities are common sources of U-POPs [43], as well as BFRs. To prevent the release of these chemicals, Samut Sakhon would require better organization and regulation of such facilities. Existing facilities should be replaced by more appropriate recycling facilities that utilize clean technologies. It would require assistance from the authorities and potentially the state. It could be included among other actions into the updated NIP for the Stockholm Convention on POPs. The eggs sampled in Samut Sakhon in February 2015 were also analyzed for PBDD/Fs. Level of these chemicals measured in the eggs was the second highest level ever measured in chicken eggs globally. Relatively low levels of indicator PCBs in free-range chicken eggs show very low contamination levels by technical PCBs used in transformer oils, which confirms findings in NIP [27]. MAP-1 was the sample with the highest concentration of PAHs from the Map Ta Phut area, and the highest potential dietary intake of this group of chemicals among all egg samples in this study. MTP 1-11 was more contaminated by PAHs and BFRs than the remaining two samples from the Map Ta Phut area. Additional analyses from the same sampling location should highlight whether contamination was brought via canal from the industrial area located north of this site, and whether it is located on the seashore or not. Mainly, this sample, in addition to significant levels of PCDD/Fs and PAHs in another sample, confirms that the concentration of the chemical industry brings more pollution by POPs in the area as well. There are many chemical factories producing, for example, PVC or specialized chemical products that were recognized to be significant sources of U-POPs [43, 91]. Four samples of free-range chicken eggs

11 Limitations of the study are discussed in chapter 6.

cannot give us the full picture of the potential pollution of an area by POPs. Soil additive-containing ash from the power plant in Khon Kaen is most likely the source of the high level of PAHs measured in free-range chicken eggs collected there. The eggs contained the highest level of PAHs among all samples from Thailand. This practice cannot be considered as environmentally sound management of coal burning power plant residue.Chicken eggs are an important part of the human diet. The eggs from localities polluted by POPs can significantly burden the body, as demonstrated in Chapter 3.5 of this report, although eggs are a less common in food for the Thai population, in comparison with some other countries. The solution is not to discourage the public from eating chicken eggs or punish the chicken farmers, but to prevent further contamination of the food chain at certain hotspots by addressing the issues of POPs being released into the environment. We used chicken eggs, as they are a proven indicator of potential contamination within the food chain. We didn't sample meat, but results of some other studies demonstrated simultaneous contamination of chicken eggs and meat from contaminated sites [69, 71].

3.6 LIMITATIONS OF THE STUDY

The major limitations of the study were the limited financial, temporal and personal resources. Therefore, only a limited number of chicken egg samples could be taken, and only a limited scale of analyses could be conducted. We could not repeat whole ranges of analyses for each sample, which created some loopholes in the data available for our final evaluation. We also lack data about the level of total dietary intake of different contaminants in Thailand, and for some, even globally, e.g. PAHs. We worked with the limited information available instead. Still, an impression of the situation, including the identification of major issues in relation to potential pathways of contaminants into the food chain (represented by free -range chicken eggs in this study) in Central, Eastern and Southern Thailand, was obtained. However, future investigations in this field are still necessary. The results presented here cannot be considered exhaustive; rather, expressing the need for extended research in future. The comparison of pollutant concentration levels found in the samples with legal standards also has its limitations. Each of the legal standards are defined in a different way, and for a different purpose. In addition, there are no existing legal standards for some of the pollutants and some legal limits or TDI levels might be outdated. The estimation of a potential risk to humans and the environment cannot be conducted by consulting legal standards only; an extensive risk analysis based on a sufficient number of samples and detailed description of the state of the area and the potential risk receivers is crucial. We tried to draw a basic evaluation of the health risk expressed as the daily intake of some crucial pollutants through consumption of eggs from free range-chickens raised at selected hotspots, in order to give at least a basic idea about the level of human exposure to different pollutants. We believe that it is of the utmost importance to begin to address the overall pollution by contaminants, such as PCDD/Fs, BFRs as well as by PAHs in Thailand.

4. Evaluation of passive air sampler measurements close to the Map Ta Phut industrial estate, Thailand

Alice Dvorská, Ph.D.

4.1 INTRODUCTION

Passive samplers are chemical accumulators that can be used to assess ambient concentrations in either the homogeneous or heterogeneous media into which they are deployed. They are increasingly employed in investigations of persistent organic pollutants (POPs) [92]. There are various PAS sampling media and designs used. In contrast to high-cost active air samplers, passive air samplers (PAS) do not require pumps, sampling heads, or a source of electricity. They are inexpensive and small and therefore, increasingly used for POP monitoring and spatial studies at local, regional and continental scales [93]. In some regions, they are the only source of information on POP levels. Passive air monitoring programs measuring POPs include the Global Atmospheric Passive Sampling (GAPS) Network, the Monitoring Network (MONET) in Europe, Africa and Asia, the Latin American Passive Atmospheric sampling Network (LAPAN) and others [94].

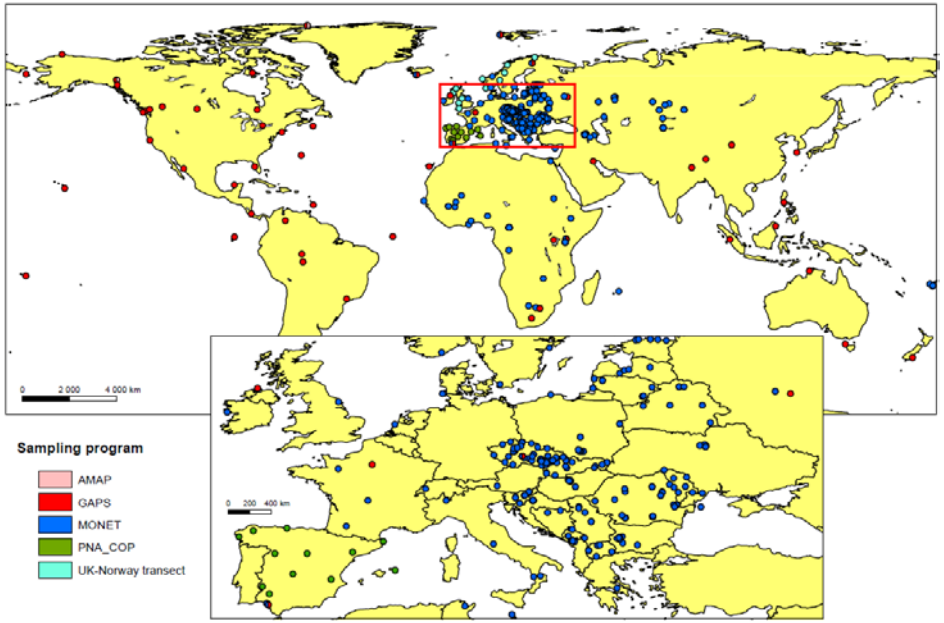
The objective of the Stockholm Convention (SC) on POPs is to protect human health and the environment from POPs by reducing or eliminating releases to the environment. Parties of the SC have agreed that they need a mechanism to measure whether this objective is reached. The Global Monitoring Plan (GMP) for POPs is an important component of the effectiveness evaluation of the SC. Monitoring activities under the GMP are focused on generating measurement data from core media: ambient air, human milk and human blood and surface water for water-soluble POPs. The objective of ambient air sampling is to obtain representative data for assessing the baseline levels and changes in concentrations over time and space, as well as the regional and global transport of POPs. Passive (Figure 1) and active air sampling is employed under the GMP [95].

When using and interpreting PAS data, significant differences compared to active air samplers have to be considered. While active sampling relates sequestered amounts of analytes to the measured volume of air in order to derive chemical concentrations in air, this volume is uncertain for passive sampling. Therefore, a sampling rate (i.e. a characteristic volume of air that is stripped by the passive sampling medium per unit of time) is being determined. The calculation or estimation of compound-specific or generic sampling rates and determination of the most important parameters affecting these rates have been a subject of numerous studies [97] and references therein. The most precise measure of the air volume sampled may be achieved by

spiking the sorbent prior to exposure with known quantities of depuration compounds. Then it is possible to report semi-quantitative concentrations for a polyurethane foam (PUF) PAS with an expected accuracy within about a factor of 2 [98].

PUF PAS are usually deployed for three months which provides an equivalent air sample volume of approximately 360 m^3. This is sufficient for the detection of most of POPs. Shorter integration periods of one month have also been incorporated successfully [96]. In contrast to this long period, active air samplers are deployed episodically, e.g. for 24 hours. The greater uncertainty associated with air concentration values derived from PAS is thus balanced by the benefit that PAS provides a time-weighted, average air concentration, which integrates the "highs" and "lows" that can be missed by episodic sampling [94].

Figure 1: *Passive air sampling sites operating under existing air monitoring programmes for POPs that are contributing to the GMP as of 2013 [96].*



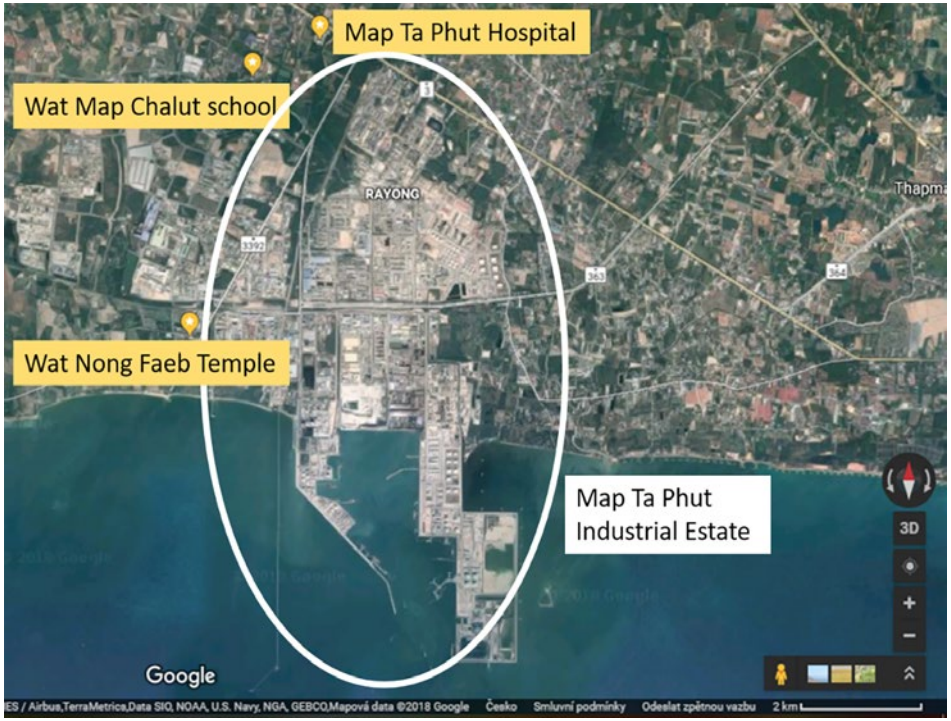
4.2 SAMPLING CAMPAIGN

The air samples in the close vicinity of the Map Ta Phut Industrial Estate were taken by the passive sampling method. Three sampling spots of interest (see also Table 1 and Figure 2) were chosen: the Map Ta Phut Hospital, the Wat Map Chalut School and the Wat Nong Faeb Temple. Samplers were installed at all three sampling spots on July 25, 2017 and uninstalled on September 12, 2017. Thus, the passive air samplers were exposed for 50 days. The weather during sampling was hot with average temperatures of 28.6°C and 28.9°C in July and September 2017, respectively. The predominant wind direction was southwest in July and August and west in September. Additionally, two blank samples were taken in order to exclude sources of unintentionally introduced contamination during transport, storage and analysis.

Table 1: *List of samples*

Name (sample number)	Coordinates	Sampling spot description
Map Ta Phut Hospital (MTP Air-1)	12°43'43.9"N 101°08'10.6"E	No combustion sources in the vicinity of the site, no waste or biomass burnt nearby, no residential houses nearby, sampled south of the hospital 6 m above ground on a water tower next to play ground
Wat Map Chalut School (MTP Air-2)	12°43'24.6"N 101°07'33.4"E	No combustion sources in the vicinity of the site, no waste or biomass burnt nearby, occasional cremations conducted nearby, for eventual cooking in school LPG is used, sampled at the school premises at 6 m above ground on a water tower
Wat Nong Faeb Temple (MTP Air-3)	12°41'10.3"N 101°06'58.9"E	Sometimes general waste and dry leaves are burnt nearby, charcoal, firewood and LPG used for cooting and heating in residential houses nearby, incense being burnt only inside of the temple and quite far from the sampling spot. Sampled at the temple tower in front of the temple, 1st floor, about 5-6 m above ground, north side
Blank - Sept		Field blank brought onsite during uninstallation of samplers in September 2017
Blank No. 2		Blank kept in the fridge

Figure 2: *Map of sampling sites*



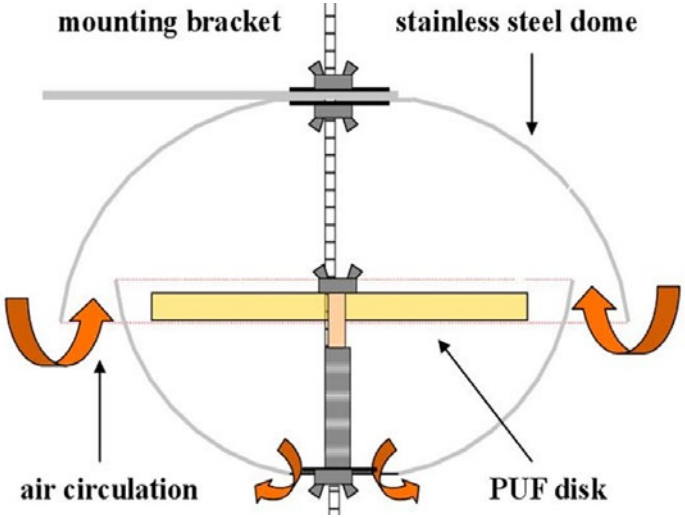


Figure 3: *Scheme and deployment of a passive air sampler*

The PAS used in this study consist of a PUF disc housed in a stainless-steel chamber consisting of two bowls, one with a diameter of 30 cm and the other of 24 cm (Figure 3). The sampling occurs through spontaneous diffusion of the analyte to the sorbent media – PUF. POPs are sampled as air naturally diffuses into the sampler housing and around the PUF, which then sorbs the target compounds. Subsequently, the POP content in the PUF is determined using analytical methods [99].

4.3 ANALYSIS

Precleaned PUF discs for PAS were obtained from E&H services, Prague, Czech Republic. This company specializes in POPs elimination and passive sampling techniques and runs an accredited laboratory. The PUF discs were wrapped in two layers of aluminium foil and stored in a plastic bag in a fridge. The exposed discs were analyzed for content of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (DL PCBs). The analysis was conducted using h*igh-resolution gas chromatography*/h*igh-resolution* mass spectrometry at the accredited laboratories of the State Veterinary Institute, Department of Chemistry, Prague, Czech Republic. Before analysis, the discs were cut into three pieces, which were weighed individually. Table 2 contains information on the approximate weight of each disc obtained by adding up weights of individual disc pieces.

Table 2: *Approximate weight of PUF discs*

Sample number	PUF disc weight (g)
MTP Air-1	6.57
MTP Air-2	7.26
MTP Air-3	6.93
Blank - Sept	6.81
Blank No. 2	6.80

4.4. RESULTS

Results of chemical analyses of PCDD/Fs and DL PCBs are presented in Tables 3 and 4, respectively. A graphical visualization of the results is presented in Figures 4 and 5. The units used are pg of analyte per g of PUF disc, as reported by the laboratory. Analyte concentrations in blanks are predominantly below the limit of detection (LOD) and considerably lower than in samples taken in the vicinity of the Map Ta Phut Industrial Estate. DL PCBs and PCDFs exhibit predominantly measurable concentrations in samples taken in the vicinity of the Map Ta Phut industrial estate, while PCDDs concentrations were often below LOD.

Table 3: *Analysis results for PCDD/Fs in pg/g*

	MTP Air-1	MTP Air-2	MTP Air-3	Blank Sept	Blank No. 2
2,3,7,8-TCDD	0.093	<0.061	<0.061	<0.061	<0.061
1,2,3,7,8-PeCDD	0.161	0.099	<0.074	<0.074	<0.074
1,2,3,4,7,8-HxCDD	<0.079	<0.087	<0.079	<0.079	<0.079
1,2,3,6,7,8-HxCDD	0.127	0.107	<0.066	<0.066	<0.066
1,2,3,7,8,9-HxCDD	<0.093	<0.097	<0.059	<0.059	<0.059
1,2,3,4,6,7,8-HpCDD	0.430	0.383	0.402	0.135	0.119
OCDD	0.810	0.831	0.535	0.367	0.319
2,3,7,8-TCDF	0.535	0.505	0.498	<0.039	<0.039
1,2,3,7,8-PeCDF	0.630	0.531	0.283	<0.081	<0.081
2,3,4,7,8-PeCDF	0.581	0.474	0.580	<0.073	<0.073
1,2,3,4,7,8-HxCDF	0.416	0.399	0.306	<0.080	<0.080
1,2,3,6,7,8-HxCDF	0.411	0.383	0.258	<0.061	<0.061
1,2,3,7,8,9-HxCDF	<0.057	<0.057	<0.057	<0.057	<0.057
2,3,4,6,7,8-HxCDF	<0.074	<0.068	0.239	<0.068	<0.068
1,2,3,4,6,7,8-HpCDF	0.555	0.456	0.464	<0.078	<0.078
1,2,3,4,7,8,9-HpCDF	<0.064	<0.064	<0.064	<0.064	<0.064
OCDF	<0.183	<0.183	<0.183	<0.183	<0.183
WHO-PCDD/F-TEQ*	0.637	0.498	0.483	0.212	0.212

***** sum of toxicity equivalents of the 17 toxicologically most important dioxins and furans (according to the WHO 2005 scheme). Upperbound concentrations are calculated assuming that all values of the different congeners less than the LOD are equal to the LOD.

Table 4: *Analysis results for DL PCBs in pg/g*

	MTP Air-1	MTP Air-2	MTP Air-3	Blank - Sept	Blank No. 2
PCB 81	0.672	0.558	0.604	<0.078	<0.078
PCB 77	3.850	3.490	2.640	0.321	0.251
PCB 123	0.510	0.489	<0.317	<0.317	<0.317
PCB 118	15.700	14.100	7.420	2.530	3.110
PCB 114	0.997	1.120	0.911	<0.292	<0.292
PCB 105	6.370	6.300	2.900	0.669	0.545
PCB 126	1.350	1.290	1.440	<0.086	<0.086
PCB 167	1.050	1.150	1.230	0.393	0.361
PCB 156	2.570	2.340	2.580	1.070	0.927
PCB 157	0.492	0.594	0.542	<0.254	<0.254
PCB 169	0.202	0.149	0.165	<0.143	<0.143
PCB 189	0.359	0.468	0.661	<0.274	<0.274
WHO-PCDD/F-PCB-TEQ*	0.779	0.633	0.633	0.225	0.225

***** total dioxin equivalent, i.e. the sum of WHO-PCDD/F-TEQ and WHO-PCB-TEQ (according to the WHO 2005 scheme). Upperbound concentrations are calculated assuming that all values of the different congeners less than the LOD are equal to the LOD.

Figure 4: *Analysis results for PCDD/Fs in pg/g (concentrations below LOD are not displayed)*

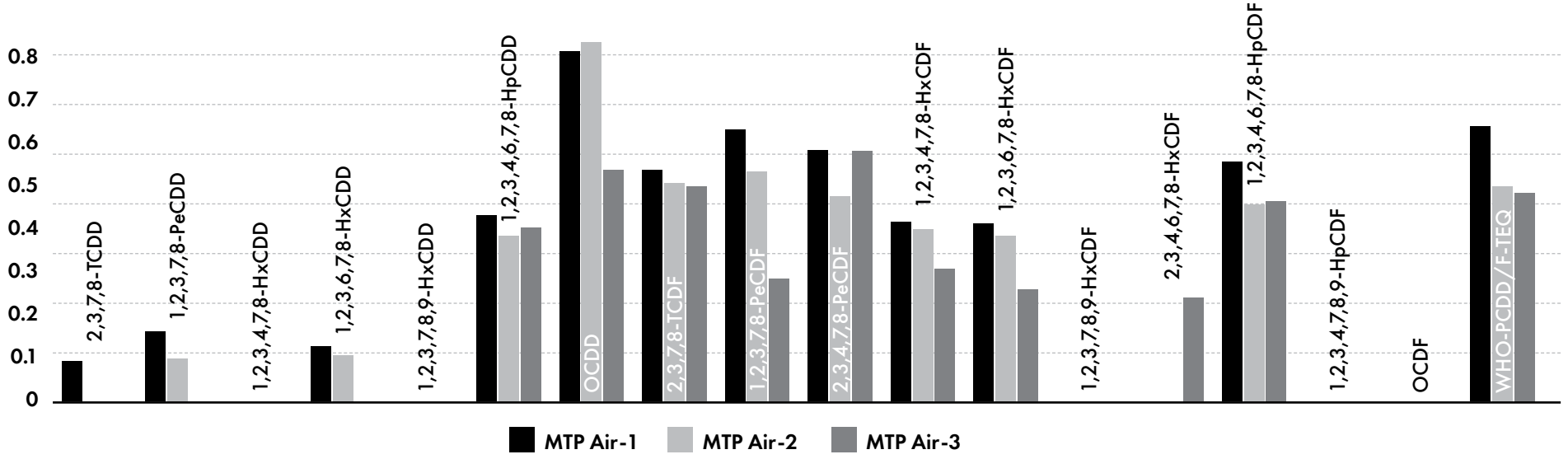
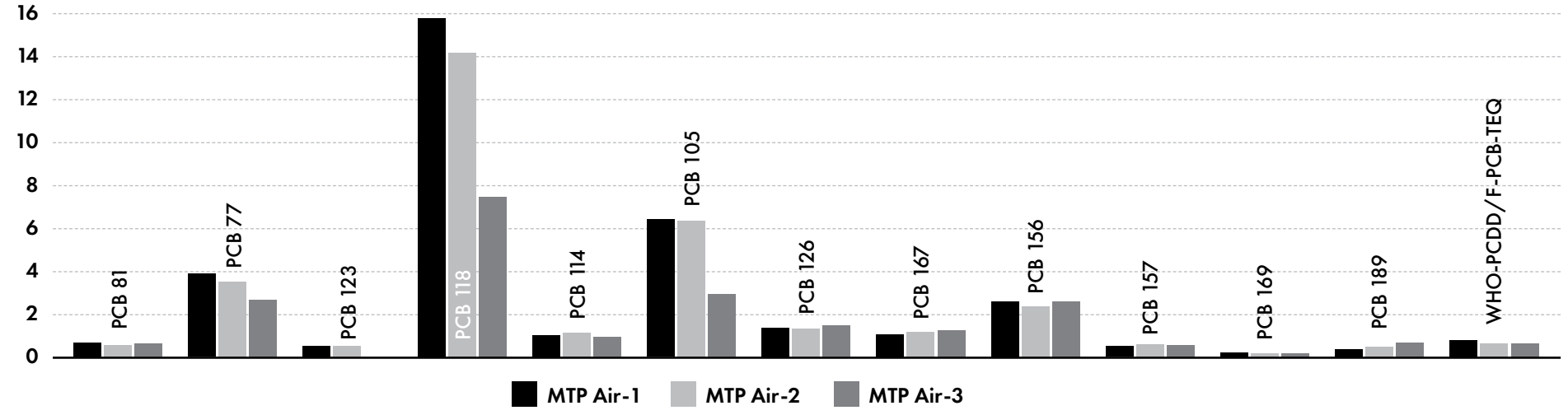


Figure 5: *Analysis results for DL PCBs in pg/g (concentrations below LOD are not displayed)*



Samples MTP Air-1 (Map Ta Phut Hospital) and MTP Air-2 (Wat Map Chalut School) exhibit similar concentrations of most PCDD/F congeners, while sample MTP Air-3 (Wat Nong Faeb Temple) has lower concentrations of some PCDD/F congeners. However, the WHO-PCDD/F-TEQ in sample MTP Air-3 is similar to sample MTP Air-2 and both are slightly lower than in sample MTP-Air-1. Many of DL PCB congeners have the lowest concentrations in sample MTP Air-3 (Wat Nong Faeb Temple); however, its WHO-PCDD/F-PCB-TEQ is the same as for sample MTP Air-2 (Wat Map Chalut School) and both are lower than in sample MTP Air-1 (Map Ta Phut hospital).

4.5 DISCUSSION

When considering the WHO-PCDD/F-TEQ and WHO-PCDD/F-PCB-TEQ values (Tables 3 and 4), the Wat Map Chalut School and Wat Nong Faeb Temple samples exhibit very similar PCDD/Fs and DL PCBs concentrations. The northernmost sampling site at the Map Ta Phut Hospital exhibits the highest burden, i.e. the determined PCDD/Fs and DL PCBs levels are about a quarter higher than at the other two sites. It is interesting to note that the Wat Nong Faeb Temple is the only site with known nearby combustion sources (occasional burning of general waste, leaves and incense [100, 101]; seems to be the least polluted one among the investigated sites.) One of the reasons might be the different land-sea breeze interactions and resulting air mixing, as the Wat Nong Faeb Temple is the site closest to the coastline. The Wat Nong Faeb Temple sample congener profile is also slightly different from the congener profile of the other two samples (Figure 4), which might suggest a different relative contribution of individual pollutant source types.

PCDD/Fs and DL PCBs congener profiles (Figures 4 and 5) and ratios determined in ambient air samples are often used for pollutant source characterization by comparing them with source specific congener profiles and ratios [102]. However, here we restrain from making this attempt for two reasons. First, PCDD/Fs appear mainly in the particle phase [103]. However, PUF disc PAS of the design depicted in Figure 3 were originally targeting mainly gas-phase compounds and their efficiency of sampling atmospheric particles is low compared to other types of PAS and active air samplers [104]. This might shift the PUF PAS-determined PCDD/Fs congener profile and ratios at the Map Ta Phut sampling sites in comparison with source specific profiles and ratios reported in scientific literature, as these are usually obtained by active air samplers. Second, a complex mixture of possible industrial, transport and residential PCDD/Fs and DL PCB sources is present in Map Ta Phut, making it hard to identify individual sources due to the frequent overlap of source specific ratios (e.g. [105] and references therein).

As the here used PAS PUF was not spiked with depuration compounds prior to exposure, it is not possible to determine the site-specific air sampling rates and thus, obtain semiquantitative air concentrations within about a factor of 2 [98], which is an approach used in scientific papers reporting PAS PUF based PCDD/Fs air concentrations. Here, we use units of pg of analyte per weight of a whole PUF disc (Table 2) for the comparison of Map Ta Phut results (Tables 5) with other sites. As the approximate weight of each disc is different, the WHO-PCDD/F-PCB-TEQ for samples MTP Air-2 and MTP Air-3 is different, although it is the same when expressed in pg/g (Table 4). In order to compare the level of PCDD/Fs and DL PCBs air burden in a close vicinity of the Map Ta Phut Industrial Estate with sampling at background, urban and industrial sites elsewhere, the range of 3.35-4.19 pg WHO-PCDD/F-TEQ / disc and 0.94-1.04 pg WHO-PCB-TEQ /disc (Table 5) is used.

Table 5: *Analysis results for WHO-PCDD/F-TEQ and WHO-PCB-TEQ in pg/disc*

	MTP Air-1	MTP Air-2	MTP Air-3
WHO-PCB-TEQ*	0.936	0.979	1.039
WHO-PCDD/F-TEQ**	4.185	3.615	3.349

* sum of toxicity equivalents of the 12 DL PCBs which have been assigned TEFs (according to the WHO 2005 scheme). Upperbound concentrations are calculated assuming that all values of the different congeners less than the LOD are equal to the LOD.

** sum of toxicity equivalents of the 17 toxicologically most important dioxins and furans (according to the WHO 2005 scheme). Upperbound concentrations are calculated assuming that all values of the different congeners less than the LOD are equal to the LOD.

Table 6 contains information on WHO-PCB-TEQ and WHO-PCDD/Fs-TEQ levels at various urban, suburban, background and remote sites. Information on PCDD/Fs and DL-PCBs air concentrations at these sites was obtained from the Global Environmental Assessment and Information System GENASIS [106]. Samplers were exposed for three months [107]. African MONET sites were chosen because the same PAS used in this monitoring network is the same used when sampling air close to the Map Ta Phut Industrial Estate. Unfortunately, PAS PCDD/Fs and DL PCBs measurements within the MONET network do not cover tropical Asian regions. Thus, predominantly African tropical sites were chosen and coastal sites were included into the selection in order to make the comparison with the tropical and coastal Map Ta Phut site reasonable. High winds at coastal sites might lead to higher PAS sampling rates [108], thus making such sites specific. Two industrial sites were added into the selection, although they are located in subtropical climate regions.

Table 6: *WHO-PCB-TEQ and WHO-PCDD/F-TEQ median values observed at MONET-Africa sampling sites between 2008 and 2017, in pg/disc. WHO 2005 TEF scheme and upperbound concentrations were used for TEQ calculation. More detailed site characteristics can be obtained from MONET [109].*

Site name	Coordinates	Type of site	Observed concentrations
Cairo, Egypt	30°4'16.1"N, 31°18'54.3"E	Industrial	WHO-PCB-TEQ: NA WHO-PCDD/F-TEQ: 480.3
Vanderbijl Park, South Africa	26°43'0.0"S, 27°52'59.9"E	Industrial	WHO-PCB-TEQ: 1.29 WHO-PCDD/F-TEQ: 7.29
Nairobi, Dandora, Kenya	1°14'35.1"S, 36°54'22.2"E	Suburban, impacted	WHO-PCB-TEQ: 40.89 WHO-PCDD/F-TEQ: 256.37
Dakar, Ngoye, Senegal	14°38'5.7"N, 16°25'47.9"W	Urban background	WHO-PCB-TEQ: 0.39 WHO-PCDD/F-TEQ: 6.59
Lusaka, Zambia	15°19'0.0"S, 28°26'60.0"E	Urban background	WHO-PCB-TEQ: NA WHO-PCDD/F-TEQ: 1.87
Asela, Ethiopia	7°57'0.0"N, 39°7'0.0"E	Urban, high altitude	WHO-PCB-TEQ: 0.57 WHO-PCDD/F-TEQ: 5.49
East Legon, Ghana	5°39'6.9"N, 0°9'55.7"W	Urban, coastal	WHO-PCB-TEQ: 4.88 WHO-PCDD/F-TEQ: 21.69
Reduit, Mauritius	20°13'59.5"S, 57°29'54.5"E	Suburban, background, island	WHO-PCB-TEQ: 0.91 WHO-PCDD/F-TEQ: 10.71
Mt. Kenya, Kenya	0°1'48.0"S, 37°13'12.0"E	Background, remote, mountainous	WHO-PCB-TEQ: 0.11 WHO-PCDD/F-TEQ: 2.63

NA – not available

The comparison of concentration values in Tables 5 and 6 suggests that WHO-PCDD/F-TEQ levels in the close vicinity of the Map Ta Phut Industrial Estate are two orders of magnitude lower than at the extremely polluted African sites of Nairobi, Dandora in Kenya (affected by biomass burning) and Cairo, Egypt (affected by industrial activities). They are also slightly lower than at the industrial South African Vanderbijl Park sampling site. The coastal urban East Legon site in Ghana has WHO-PCDD/F-TEQ levels an order of magnitude higher than the vicinity of the coastal Map Ta Phut Industrial Estate. The levels measured at Map Ta Phut correspond to the African urban background levels and are less than two times higher than at the remote mountainous sampling site Mt. Kenya. WHO-PCB-TEQ levels in Map Ta Phut are similar to the South African Vanderbijl Park industrial site and suburban background site Reduit at the island of Mauritius. They are an order of magnitude lower than at the extremely polluted African site of Nairobi, Dandora in Kenya and five times lower than in coastal East Legon, Ghana. However, the Map Ta Phut WHO-PCB-TEQ concentrations are about two times higher than at the African urban sites of Dakar (Senegal) and Asela (Ethiopia) and one order of magnitude higher than at the remote mountainous sampling site Mt. Kenya. It is important to note that the PUF PAS in Thailand were exposed for about half of the time compared to the samplers in Africa. It is reasonable to assume that if exposed only for 50 days, the African samples would exhibit lower concentrations of PCDD/Fs than reported in table 6. However, a simple recalculation of the concentrations determined in samples from Africa in a 50-day sampling period was not conducted as a linear uptake of pollutants into the PUF. Therefore, it might not be assured during longer sampling periods, and the sampling rate is dependent on local environmental conditions (Heo and Lee, 2014). Another option is to report the PUF PAS-based PCDD/Fs and DL-PCBs concentrations in pg/day units, which is an approach applied in two scientific papers reporting air levels of these pollutants in South Korea [110, 111]. Table 7 contains information on DL-PCBs and PCDD/Fs levels at various types of sites in South Korea. Table 8 gives information on DL-PCBs and PCDD/Fs concentrations at the three Map Ta Phut sites recalculated to pg/day units and the TEF scheme used in the South Korean papers for PCDD/Fs.

Table 7: *DL-PCBs and PCDD/Fs average concentrations observed at South Korean sampling sites between 2011 and 2013 [111] and in 2010 and 2011 [110]. PCDD/Fs concentrations are given in pg I-TEQ/day using the NATO international TEF scheme from 1988. DL-PCBs concentrations are given in pg WHO-TEQ/day using the WHO TEF scheme from 2005.*

Site names	Type of site	Year	Observed concentrations
Suwon, Goyang, Guri	Urban, residential	2011-2013	DL-PCBs: 0.015 PCDD/Fs: 0.209
Ansan, Siheung, Bucheon	Industrial	2011-2013	DL-PCBs: 0.062 PCDD/Fs: 0.625
Yangju, Dongducheon, Pocheon	Urban, rural mixed	2011-2013	DL-PCBs: 0.040 PCDD/Fs: 0.810
Yangpyeong	Rural	2011-2013	DL-PCBs: 0.008 PCDD/Fs: 0.122
Suwon	Urban, residential	2010-2011	DL-PCBs: 0.004 PCDD/Fs: 0.123
Ansan	Industrial	2010	DL-PCBs: 0.041 PCDD/Fs: 0.661

Table 8: *Analysis results for the Map Ta Phut sites. PCDD/Fs concentrations are given in pg I-TEQ/day using the NATO international TEF scheme from 1988. DL-PCBs concentrations are given in pg WHO-TEQ/day using the WHO TEF scheme from 2005.*

	MTP Air-1	MTP Air-2	MTP Air-3
DL-PCBs	0.019	0.020	0.021
PCDD/Fs	0.090	0.080	0.079

The DL-PCBs WHO-TEQ/day concentrations at Map Ta Phut are very similar to the South Korean urban residential sites sampled in 2011-2013 and two to three times lower than the South Korean industrial sites. Regarding the PCDD/Fs, the Map Ta Phut I-TEQ/day levels are most similar (but still 1.5 times lower) to the lowest South Korean sampling results, at a rural site sampled in 2011-2013 and urban residential site sampled in 2010-2011. Other South Korean sites exhibit an order of magnitude higher PCDD/Fs I-TEQ/day levels than the three Map Ta Phut sites.

4.6 CONCLUSIONS

The study presented gives a rough impression of the PCDD/Fs and DL PCB air concentrations in the close vicinity of the Map Ta Phut Industrial Estate, Thailand. It is not possible to determine a clear spatial gradient as only three samples were taken. There are no legal standards defined for POP concentrations measured in the air by PAS, thus a comparison of the found concentrations with PAS determined PCDD/Fs and DL PCBs levels were conducted elsewhere. The Map Ta Phut DL PCBs levels are similar to South Korean urban residential sites and PCDD/Fs levels are an order of magnitude lower than at both rural and industrial South Korean sites. PCDD/Fs and DL PCBs concentrations found in Map Ta Phut are also similar to levels at African urban sites and do not indicate an extremely serious pollution level as in, e.g. industrial areas of Cairo, Egypt. However, it is important to consider that the sampling in Map Ta Phut was conducted at sites with an accumulation of vulnerable parts of the general population (children at the Wat Map Chalut School and patients at the Map Ta Phut Hospital) or at a site of spiritual importance (Wat Nong Faeb Temple). Unfortunately, the sampling was not conducted in the respiration height (approximately 1.5 m above ground), but higher, in order to allow for free air flow around the PAS.

Concentrations of PCDDs/Fs in Africa determined by PAS measurements are similar to concentrations reported for Europe based on active air sampling [112]. However, PAS determined PCDD/Fs levels probably underestimate the real occurence of these POPs in air, as PUF PAS does not sample PCDD/Fs with complete efficiency due to the incomplete sampling of the atmospheric particular fraction [104]. Thus, it is not possible to suggest that Map Ta Phut's PCDD/Fs air concentrations are similar to European levels because they are similar to African urban levels. On the contrary, it is reasonable to anticipate real PCDD/Fs air concentrations in Map Ta Phut to be higher than reported in this study, and thus, higher than in Europe. This drawback does not apply to DL PCBs, as these occur predominantly in the gas-phase [113] and differences between active and passive air sampling should be much less pronounced.

5. Monitoring of air pollution in industrial regions in Thailand

Ing. Marek Šír, PhD.

5.1 INTRODUCTION

The brief study was focused on the monitoring and evaluation of pollution by organic pollutants in industrial regions in Thailand. The method of active air sampling was used to collect samples using sorbent tubes. The concentration of the seven volatile organic compounds (VOCs) was measured in the air. These include benzene, toluene, heptane, ethyl acetate and also three chlorinated VOCs (chloroform, trichlorethylene, dichloromethane). The measured concentrations of VOCs were compared with the legislative limits and with the concentrations measured in other urban and suburban areas.

5.2 SAMPLING PROCEDURES AND ANALYTICAL METHODS

10 sets of samples were taken at various locations: Map Ta Phut (6 sets of samples), Tha Tum (3 sets of samples), and Rayong IRPC industrial zone (1 set of samples). A method of active air flowing through a sorbent filled tube was used, as described in the EN ISO 16017-2:2003 standard [114]. The principle of the active sampling method is to expose the sampling device (sorption tube) of the air passage over the measured time interval. Air is actively flowing into the tube with a small pump (AirChek 52, SKC Instrument). Volatile organic compounds (VOCs) passing through the tube are captured with a suitable sorbent. The choice of a suitable sorbent depends on the analyte to be captured and the prevailing conditions in the sample space. Two types of sorbents (Tenax ® and Chromosorb ®) were used. Tenax ® was used to capture benzene, toluene, heptane and ethyl acetate; Chromosorb ® was used to capture chlorinated VOCs. The air flow rate through the sorbent tube was 0.58 L/min for the Tenax ® tube and 0.32 L/min for the Chromsorb ® tube. The active flow time through the tube was five minutes. Stainless steel sorption tubes (Markes International, 89 mm, OD 6.4 mm) and 200 mg of sorbent were used. Prior to sampling, it is necessary to ensure the purity of the sorbent. The tubes were conditioned by desorption at a temperature equal to or slightly larger than the desorption temperature in the analysis for 10 minutes with carrier gas flow 65 ml.min-1 and sealed with long-term storage caps (PTFE seals). Exposed sorption tubes were thermally desorbed on Unity ™ with the Ultra ™ autosampler (Markes International). The total desorption time was 10 minutes at 200 ˚ C, where the analytes were captured on a cryofocus column cooled to -8 ˚ C. Desorption of this column also occurred at 200 ˚ C for three minutes. A concentration of organic pollutants was measured by Shimadzu GC-17A (Shimadzu) (non-chlorinated volatile organic compounds) and by GC ECD Hewlett Packard 5890 (Hewlett Packard) (chlorinated volatile organic compounds).

5.3 SAMPLING

Table 1: *Sampling sites and description of samples.*

Sample ID	Sampling site	GPS	Comment
Map Ta Phut			
MTP 2-7	Map Ta Phut	N 12° 40′ 30.871″ E 101° 09′ 27.400″	Near factory PTT MTT
MTP 2-16	Map Ta Phut	N 12° 43′ 20.899″ E 101° 07′ 34.702″	Map Chalut temple and school near passive sampling MTP2 – 12, next to the road with low traffic
MTP 2-17	Map Ta Phut	N 12° 41′ 30.998″ E 101° 09′ 05.101″	Middle of the industrial estate, lot of traffic
MTP 2-20	Map Ta Phut	N 12° 42′ 27.400″ E 101° 09′ 46.001″	Open space in front of school building, 10 m from the road, low traffic
MTP 2-21	Map Ta Phut	N 12° 42′ 53.302″ E 101° 09′ 50.101″	Elementary Ban Map Ta Phut school, main road with heavy traffic
MTP 2-22	Map Ta Phut	N 12° 45′ 25.099″ E 101° 10′ 43.799″	Noppaket village also known as Noen Phayon park, road with middle traffic behind small bush fence. Monitoring station n. 7.
Tha Tum			
TT 2-2	Tha Tum	N 13° 55′ 42.200″ E 101° 34′ 07.201″	In front of houses for workers
TT 2-3	Tha Tum	N 13° 55′ 11.600″ E 101° 34′ 59.801″	In the middle of industrial area
TT 2-4	Tha Tum	N 13° 55′ 44.498″ E 101° 35′ 25.001″	Near temple
Rayong IRPC zone			
IRCP 1	Rayong IRPC zone	N 12° 49′ 09.499″ E 101° 18′ 56.099″	Between two fishing ponds

5.4 RESULTS

Table 2: *Concentration of volatile organic compounds in air.*

Sample ID	$CHCl_3$	TCE	DCM	ETAC	Benzene	Heptane	Toluene
Units	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3
Map Ta Phut							
MTP 2-7	5.4	5.8	58.5	36.0	15.8	16.4	395.1
MTP 2-16	10.2	<LOD	50.9	31.3	9.1	16.2	265.5
MTP 2-17	32.6	5.8	82.5	36.3	14.2	21.8	472.8
MTP 2-20	18.8	7.8	71.3	41.0	8.2	21.0	640.6
MTP 2-21	12.5	6.0	80.3	34.3	8.9	18.6	689.8
MTP 2-22	19.4	6.1	105.6	36.0	10.2	18.4	714.6
Tha Tum							
TT 2-2	<LOD	1,7	18.4	30.2	6.3	11.4	<LOD
TT 2-3	<LOD	1.7	21.6	33.0	4.7	10.2	20.7
TT 2-4	12.3	<LOD	40.6	31.3	8.4	16.4	205.1
Rayong IRPC zone							
IRCP 1	<LOD	<LOD	161.5	31.3	4.1	16.4	321.7

$CHCl_3$- chloroform, TCE – trichloroethylene, DCM – dichloromethane, ETAC - Ethylacetate

5.5 LEGAL STANDARDS

The monitored substances are not included in the National Ambient Air Quality Standards (NAAQSs) in Thailand. Ambient air quality limits are set only for benzene from all pollutants measured, which are valid under European legislation and also in the Czech Republic. In response to the fact that humans can be adversely affected by exposure to air pollutants in ambient air, the European Union has developed an extensive body of legislation, which establishes health-based standards and objectives for a number of pollutants present in the air. DIRECTIVE 2008/50/EC sets the limit value of **5 µg.m^{-3} for benzene** [115]**.** This value refers to the average period of one calendar year. Act 201/2012 Coll. sets limit values for the protection of human health and the maximum number of their exceedances in the Czech Republic [116]. The limit value **for benzene 5 µg.m^{-3} a**s the average period of one calendar year is also set. If the emmission limit value is exceeded, the Ministry in cooperation with the relevant regional authority or municipal authority develops an air quality improvement program for a given zone or agglomeration. In terms of pollution control, emissions of specific substances with regard to emission sources are rather monitored. DIRECTIVE 2010/75 / EU deals with the permissible level of pollution and its detection [117]. Decree No. 415/2012 Coll. on the permissible level of pollution and its detection and implementation of some other provisions of the Act on Air Protection defines the emission limits that are valid in the Czech Republic [118]. From this point of view, the limit values for benzene concentration are exceeded in all samples from Map Ta Phut and in two of the three samples from Tha Tum. In this study, comparison to only approximate values can be done because only one sample was collected at each site, and the average period of measurement should be one calendar year.

5.6 COMPARISON OF ORGANIC POLLUTANTS LEVELS

5.6.1 BENZENE

In the Czech Republic, the value of the emmission limit of benzene 5 µg.m^{-3} was not exceeded in 2017 in any of the 34 monitored sites. Average concentrations of benzene at urban and suburban monitoring stations were around 1.3 µg.m^{-3} in 2017. The highest concentrations were reached at Ostrava-Radvanice ZU station, where the average annual concentration was 4.1 µg.m^{-3} in 2017. The annual average concentration of benzene in the Czech Republic reached its peak in 2006 in the period of time from 2005 to 2017. Average concentrations of benzene at urban and suburban monitoring stations were around 4 µg.m^{-3} in 2006 [119]. The average annual concentration was around 1 µg.m^{-3} in 2009, and the U.S. Average benzene concentrations declined 66 percent from 1994 to 2009 in the U.S. [120]. **Benzene** has been detected in urban air samples in London, U.K., Southampton, U.K., Budapest, Hungary, Oslo, Norweigh, St. Petersburg, Russia, Boston, Chicago, Los Angeles, Houston, Sydney, Australia, and Tokyo, Japan at 9, 16, 27, 18, 30, 1, 1.3, 2.7, 18, 2.6, and 1.8 ppb, respectively (1997). **Benzene** concentrations were reported for 586 ambient air samples collected from 10 Canadian cities. The overall mean was 4.4 µg.m^{-3}, with Ottawa and Montreal ranging between 5.1 and 7.6 µg.m^{-3} (1996). Most of the data was obtained from HSDB database [121]. (1 ppb = 3.19 µg.m^{-3})

5.6.2 TOLUENE

Average **toluene** concentrations in US cities range from 0.8-37 ppb, with maximum values ranging from 6.5-1,110 ppb (1971 - 1983) [120]. **Toluene** was detected in Middelsbrough, UK and London, UK at 1.55 and 7.475 ppb, respectively (1995). The average concentration of **toluene** inside buses and cars in Taipei, Taiwan was reported as 367 and 599 µg.m^{-3} (1995). **Toluene** was detected in various streets in Europe at concentrations of 87-127 µg.m^{-3} (1994). The concentration of **toluene** inside automobiles in Paris, France was 178-258 µg.m^{-3} (1995). Toluene had the highest measured concentration (average 64 mg/m^{3}) of several organic compounds in the urban air of Turin, Italy in 1991. Average concentrations of toluene measured in Canadian residences range from 11.5 to 34.4 µg/m3 (2005). Most of the data was obtained from HSDB database [122]. (1 ppb = 3.70 µg.m^{-3})

5.6.3 HEPTANE

The median and range of **n-heptane** concentrations in 831 air samples from 39 U.S. cities collected from 1984 to 1985 were 4.7 and 0.1-233 ppb. The average and range of concentrations of n-heptane measured in southern California in September, 1993 were 3.75 and 1.30-9.50 µg.m^{-3}, respectively [120]. The concentration of **n-heptane** in air samples collected on a street in London, England

was 8.3 ppb (1993). The concentration range of n-heptane measured in the atmosphere of Athens, Greece during the summers of 1993 and 1994 was 0.4-7.8 ppb. n-Heptane was detected in Berlin air at a residential area and a street site with average concentrations of 0.67 and 1.22 ug/cu m, respectively (1999). **n-Heptane** air concentrations of 1.4, 2.4, 0.7, and 2.0 ppb were reported for Vienna, Austria, Athens, GA, Sydney, Australia, and Osaka, Japan, respectively (2003). The arithmetic mean concentrations of n-heptane in air samples from Vienna, Austria (5 samples), Sydney, Australia (140 samples), Leningrad, Russia (30 samples), and Berlin, Germany (118 samples) were 9.7, 4.9, 78, and 18.3 ppb, respectively (1990). The concentrations of n-heptane measured in air samples from Bangkok, Thailand were 53 and 24 $\mu g.m^{-3}$ in two vehicular traffic areas, 25 $\mu g.m^{-3}$ at a dump site, and 2 and 3 $\mu g.m^{-3}$ in communities near the dump site(1990). n-Heptane was detected in urban air samples collected in Porto Alegre, Brazil from 1996 to 1997 at a mean concentration of 5.1 $\mu g.m^{-3}$. Most of data was obtained from the HSDB database [123]. (1 ppb = 4.03 $\mu g.m^{-3}$)

5.6.4 ETHYLACETATE

Average concentrations of **ethyl acetate** in urban air samples collected from four different sites in Stockholm ranged from 0.27 to 2.64 ppb; the average concentration at a site 12 km outside Stockholm was 0.23 ppb (1985). **Ethyl acetate** was detected at an arithmetic mean of 2.6 $\mu g.m^{-3}$ using 37 outdoor samples from 27 sites in Melbourne, Australia, sampled in summer/early autumn (2002). Data used in this paragraph was obtained from HSDB database [124]. (1 ppb = 3.54 $\mu g.m^{-3}$)

5.6.5 CHLOROFORM

The average concentration of **chloroform** found in 103 air samples from Chicago was 0.3 $\mu g.m^{-3}$ (max 1.6 $\mu g.m^{-3}$) and from 83 air samples from East St. Louis was 0.5 $\mu g.m^{-3}$ (max 6.6 $\mu g.m^{-3}$), samples were collected from May 1986 to April 1990. **Chloroform** was found in 1739 urban/suburban US samples at an average of 0.072 ppb (1982). **Chloroform** was detected in 36 winter and 33 summer of 1999 New York City samples at 0.23 and 0.33 $\mu g.m^{-3}$, respectively [120]. **Chloroform** was found at <0.013-1.36 $\mu g.m^{-3}$ outside 13 homes Feb 1995 and at 0.0305-1.69 $\mu g.m^{-3}$ outside 30 homes July 1995 in Katsushika, Tokyo, Japan. Outside Bayside Offices in Rio de Janeiro, Brazil, **chloroform** was reported as not detected to 1.6 $\mu g.m^{-3}$ (1998). The mean concentration of **chloroform** was reported as 1.7 $\mu g.m^{-3}$ at 25 locations throughout Toronto, Canada in 1990. **Chloroform** was detected in 27 Uppsala, Sweden samples collected February to May 1998 at 0.02 $\mu g.m^{-3}$. In samples collected from June to August 1996 from Frohnau, Nansenstrasze, and Frankfurter Allea, Berlin, Germany, **chloroform** was detected at 0.06 $\mu g.m^{-3}$. **Chloroform** was reported at <0.1-16.2 ppb in 32-12 hour air samples collected August to December 2000 in Perth Australia. **Chloroform** was detected at 0.161-8.320 $\mu g.m^{-3}$ in air samples collected from urban/suburban locations of Italy (2009). Most of the data was obtained from the HSDB database [125]. (1 ppb = 5.00 $\mu g.m^{-3}$)

5.6.6 TRICHLOROETHYLENE

Trichloroethylene was measured in air samples collected from urban and suburban locations in Chicago at average concentrations of 0.82-1.16 and 0.52 $\mu g.m^{-3}$, respectively. **Trichloroethylene** was found in outside air in Minneapolis, MN at concentrations of 0.0-1.0 $\mu g.m^{-3}$ in winter and at concentrations of 0.1-0.7 $\mu g.m^{-3}$ in spring 2000. Air samples collected as part of the Urban Baseline VOC Measurement Program in the District of Columbia from March 1990 to March 1991 contained **trichloroethylene** at a mean concentration of 0.33 ppb (range 0.17-2.83 ppb) [120]. **Trichloroethylene** was detected in air samples set up by the North Rhine-Westphalia State Center for Air Quality Control and Noise Abatement (76 stationary stations and 8 mobile monitoring stations); annual average concentrations in 1990 ranged from 0.17 to 0.62 $\mu g.m^{-3}$. Air samples collected in Porto Alegre, Brazil from March 1996 to April 1997 contained **trichloroethylene** at an average concentration of 0.367 ppb (range = 0.1-1.2 ppb). **Trichloroethylene** was detected in 37 Nagoya, Japan outdoor air samples taken Feb 1998 at 1.79 $\mu g.m^{-3}$ and in 27 Uppsala, Sweden samples taken February to May 1998 at 0.10 $\mu g.m^{-3}$. Most of the data was obtained from HSDB database [126]. (1 ppb = 5.28 $\mu g.m^{-3}$)

5.6.7 DICHLOROMETHANE

A mean concentration of 0.5 $\mu g.m^{-3}$ of **dichloromethane** was detected in 2966 air samples collected from 78 sites in populated areas of the US (1994). **Dichloromethane** was detected in 24 of 38 ambient air samples collected from Porto Alegre between March 20, 1996 and April 16, 1997 at concentrations

ranging from 0.1 to 2.4 ppb. **Dichloromethane** was detected in 10 ambient air samples collected from Boston, Chicago, Houston and the Seattle and Tacoma area in 1988 at concentrations ranging between 0.29 to 0.42 ppb. **Dichloromethane** was detected in air samples collected from four representative areas in Arizona between 1994 and 1996 with average concentrations ranging from 0.61 to 1.62 ppb. Outdoor air samples collected at homes of high school students in the Harlem area of New York City contained a mean **dichloromethane** concentration of 1.96 $\mu g.m^{-3}$ in the winter and 1.10 $\mu g.m^{-3}$ in the summer (2005). From 2002 to 2003, outdoor air monitoring was carried out at 74 residential homes in Ottawa, Canada, and **dichloromethane** had a concentration range of 0.06-3.49 $\mu g.m^{-3}$ (mean of 0.32 $\mu g.m^{-3}$). Most of the data that was obtained from the HSDB database [127]. (1 ppb = 3.41 $\mu g.m^{-3}$)

5.7 CONCLUSIONS

In this study, 10 sets of samples were collected in three locations (Map Ta Phut, Tha Tum, Rayong IRPC zone) to get information on ambient air quality. The main findings are the relatively high concentrations of benzene, which is the most dangerous for the health of inhabitants. The concentration of benzene exceeded the limits for ambient air (Air quality standards) given by European legislation in all samples from Map Ta Phut (up to three times) and in two of the three samples from Tha Tum (up to 1.7 times). The concentration of benzene in the measured locations is also significantly higher than in similar urban or suburban locations elsewhere in the world today. Concentrations of toluene and heptane are close to concentrations in other urban and suburban areas. The concentration of chlorinated volatile organic compounds are significantly higher than those found in other urban or suburban locations elsewhere in the world. High attention should be paid to the measurement of these substances, especially at the Map Tha Put site.

Substances emitted from industrial plants and transport can participate in the measured values in the case of benzene, toluene and heptane. The source of chlorinated volatile organics compounds and ethylacetate is most likely industrial plants. It should also be mentioned that the limited number of samples and only single measurements at each sampling point may represent the limitations of this study. Long-term monitoring of air quality in these areas is recommended.

6. Impact of heavy metals from toxic hotspots in Thailand on inhabitants and the environment

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6.1 INTRODUCTION

This study is focused on the presentation and discussion of the data related to the contamination of soils and sediments by heavy metals. Environmental samples were obtained during a sampling campaign conducted in Thailand in February 2016.

Sampling campaigns represent an important part of the project "Increasing Transparency in Industrial Pollution Management through Citizen Science." This is a joint project of the Czech non-governmental organization, Arnika Association and the Thai partner, Ecological Alert and Recovery – Thailand (EARTH). The main goals of the project are to increase the negotiating power of communities affected by industrial pollution in their demands for corporate and government accountability, and to increase transparency in industrial pollution management policies and processes in Thailand. These goals comprise: 1) enabling communities affected by industrial pollution to generate scientific evidence, 2) broadening awareness about environmental and health damages from industrial pollution, and 3) promoting citizen right-to-know in Thailand and to raise awareness on good practices of right-to-know legislation from the European Union, as a participatory mechanism for pollution reduction and prevention.

6.2 SAMPLING AND ANALYTICAL METHODS

Sediment and soil samples for this study were taken at eight hot spot areas in several regions of Thailand. The hot spot areas are as follows: Loei, Khon Kaen, Map Ta Phut, Tha Tum, Samut Sakhon, Praeksa, Chachoengsao, and Rayong River Estuary. One sediment sample was taken at a background locality in Chanthanburi Province. The sampling procedure and the detailed list of samples are presented in General Introduction.

After transport to the laboratory, the samples were homogenized and a representative part (50 g) was used for the determination of dry matter by a gravimetric method. Another representative part was taken for an analysis of metals (cadmium, copper, chromium, lead, zinc, mercury, and arsenic) by a mineralization procedure. An analytical procedure of mineralization went as follows: 5 g of a sample was placed into a beaker together with 30 ml of distilled water and 10 ml of concentrated nitric acid. The sample was boiled for a period of two hours. Then, it was filtered through a fluted filter paper. Metals were determined and mineralized by atomic absorption and emission spectrometer SensAA. Mercury was measured directly in solid samples by an AMA analyzer (AMA254, Altec). The content of metals was expressed in mg/kg of dry matter.

6.3 RESULTS

Results of the analytical measurement of heavy metals are presented in Table 1 in the Annex 2.

6.4 DISCUSSION

Various legal standards and auxiliary evaluation criteria are presented in this chapter. Then, the metal concentrations determined in samples from the investigated sites are compared to respective legal standards. Finally, target samples with high contents of metals were chosen for the calculation of carcinogenic and non-carcinogenic risks associated with them.

6.4.1 LEGAL STANDARD

The pollutant concentrations determined in the samples from investigated sites were compared to maximum or approximate allowed concentrations of these pollutants, as defined in national and international decrees, norms, and laws. The pollution criteria of heavy metals for sediments and soils are presented in the Table 1.

First, concentrations of pollutants in sediments were compared with values in a drafted regulation establishing Sediment Quality Criteria. There are two types of drafted Sediment Quality Criteria in Thailand. The first one is for the purpose of benthic animal protection, and the second is for the purpose of human health protection. The second one is expressed only in units of micrograms per kilograms of total organic carbon. As we did not measure content of organic carbon in sediment samples, we used only Sediment Quality Criteria for the protection of benthic animals. If the concentration of a substance is not more than three times the threshold, it shows that substances are likely to affect the benthic animals, so surveillance should be conducted. If the concentration of a substance is more than three times the threshold, it shows that substances can affect benthic animals, so the release of hazardous substances from the source should be controlled. In that case, hazardous substances in contaminated sediments should be reduced by dredging or other methods.

Concentrations of pollutants in soils were compared with values of Soil Quality Standards established by the Notification of National Environmental Board No. 25, B.E. (2004) issued under the Enhancement and Conservation of National Environmental Quality Act [128]. Different Thai Soil Quality Standards are used for agricultural and habitat soils than for soils with other purposes. As soil samples were not collected from agricultural soil or in wildlife habitats, Soil Quality Standards for soils with other purposes were applied.

For a comparison, RSL (Regional Screening Levels) are also presented in the list of pollution criteria in Table 1. These levels were derived using exposure parameters and factors representing the maximum justifiable chronicle exposure. This exposure is based on direct contact with target compounds. Regional screening levels were derived by the US EPA (United States Environmental Protection Agency) for some compounds that have a CAS registration number. RSLs are concentrations of chemical compounds in the environment (soils, sediments, water or air). If RSLs are exceeded, further exploration or a removal of contamination should be carried out. Some specifics should be taken into account when RSLs are used, such as the content of some substances as a result of geological conditions. [129]

6.4.2 EVALUATION OF POLLUTANTS LEVELS

The overall mean value of the total arsenic for different soils is estimated at 6.83 mg/kg. The background contents of various soil groups range from <0.1 to 67 mg/kg. The background levels of mercury in soils are not easy to estimate due to the widespread mercury pollution. Data reported for various soils on a worldwide basis show that mean concentrations of mercury in surface soils do not exceed 1.5 mg/kg. Most top soils contain increased amounts of mercury, especially near mining and smelting areas. The range of mercury in soils is usually between 0.004 to 0.3 mg/kg. The general values for the average total zinc contents in soils of different groups, all over the world, range between 60 and 89 mg/kg. Contents of zinc are closely associated with soil texture and usually are the lowest in light sandy soil. Its elevated concentration is often observed in calcareous and organic soils. The world average soil cadmium concentration is estimated as 0.41 mg/kg. The main factor determining cadmium contents of soils is parent material. The average contents of

Table 1: *Legal standards for sediments and soils (As arsenic, Hg mercury, Zn zinc, Cd cadmium, Cu copper, Cr chromium, Pb lead). The content of elements is given in mg/kg of dry matter. Source: [129]*

	As	Hg	Zn	Cd	Cu	Cr	Pb
Sediment quality criteria for protection of benthic animals (Draft Regulation in Thailand)	10	0.2	80	0.16	21.5	45.5 (Cr^{Total})	36
Three times of threshold of sediment quality criteria for protection of benthic animals (Draft Regulation in Thailand)	30	0.6	240	0.48	64.5	136.5 (Cr^{Total})	108
Soil Quality Standards for Habitat and Agriculture (Thailand)	3.9	23	-	37	-	300 (Cr^{6+})	400
Soil Quality Standards for Other Purposes (Thailand)	27	610	-	810	-	640 (Cr^{6+})	750
Levels of pollution limits – industrial areas (based on US EPA)	2.4	43	310,000	800	41,000	5.6 (Cr^{6+})	800
Levels of pollution limits – other areas (based on US EPA)	0.61	10	23,000	70	3,100	0.29 (Cr^{6+})	400

cadmium in soils lie between 0.2 and 1.1 mg/kg. The general values for the average total copper contents in soils of different groups all over the world range between 14 and 109 mg/kg. Contents of copper are closely associated with soil texture and usually are the lowest in light sandy soils and the highest in loamy soils. The world soil average content of chromium in soils has been established as 60 mg/kg. The overall mean value of total lead for different soils is estimated as 27 mg/kg. Its background average contents given for soils of different countries varies from 18 to 27 mg/kg. Background Thai concentrations of heavy metals in the sediment sample from Chanthanburi (notation CHA 1 in Table 1 in Annex 1) are lower or in the worldwide ranges mentioned above.

6.4.2.1 Loei

Based on the measured data, the location below the dam of the settling pond in the Loei hot spot area shows increased concentrations mainly of arsenic, cadmium and copper. Several sediment samples exceeded three times the threshold of sediment quality criteria for protection of benthic animals from arsenic, cadmium and copper. The highest concentrations of arsenic (162.17 mg/kg) and cadmium (39.25 mg/kg) were found in the upper part of the sediment in sample LOE 8. Increased concentrations of metals are found in places where the probable leakage of water from the settling pond is identified. In the context of the background levels and pollution criteria, significantly increased concentrations of arsenic, cadmium, and an increased level of copper was found in investigated samples at location Loei.

6.4.2.2 Khon Kaen

Based on the measured data, increased levels mainly of arsenic and cadmium were found in sediment samples in the Khon Kaen hot spot area. One sample (KK 8) also has an increased concentration of mercury (0.46 mg/kg). Few sediment samples exceeded three times the threshold of sediment quality criteria

for protection of benthic animals from arsenic and cadmium. The highest concentrations of arsenic (47.84 mg/kg) and cadmium (2.99 mg/kg) were found in the sediment samples KK 10 and KK 11, respectively. In the context of the backrgound levels and pollution criteria, increased concentrations of arsenic, mercury, and cadmium were found in investigated samples at location Khon Kaen.

6.4.2.3 Map Ta Phut

Based on the measured data, an increased average concentration of most of heavy metals, mainly arsenic, mercury, zinc, copper, and chromium was found in downstream sediments in comparison to upstream sediments in the Map Ta Phut hot spot area. Several sediment samples exceeded three times the threshold of sediment quality criteria for the protection of benthic animals from mercury, zinc, cadmium, and copper. The highest concentration of mercury (1.48 mg/kg) was found in the sediment sample MTP 2-6 (1). The highest concentrations of zinc (1062.24 mg/kg), cadmium (2.95 mg/kg), and copper (23.56 mg/kg) were found in the sediment sample MTP 1-17. In relation to the backrgound levels and pollution criteria, increased concentrations of arsenic, cadmium and zinc (and also mercury in several cases) were found in investigated samples at location Map Ta Phut mainly in downstream sediments.

6.4.2.4 Tha Tum

Based on the measured data, location Tha Tum shows increased concentrations mainly of arsenic, cadmium, and chromium. Some sediment samples exceeded three times the threshold of sediment quality criteria for protection of benthic animals from arsenic, cadmium, copper, and chromium. The highest concentrations of arsenic (47.77 mg/kg) and copper (82.42 mg/kg) were found in the sediment samples TT 2-1 and TT 1-2, respectively. The highest concentrations of cadmium (12.17 mg/kg) and chromium (402.55 mg/kg) were found in the sediment sample TT 1-7. In regard to the background levels and pollution criteria, increased concentrations of arsenic, cadmium and chromium were found in investigated samples in the Tha Tum hot spot area.

6.4.2.5 Samut Sakhon

Based on the measured data, high levels of all measured heavy metals were found mainly in sediments from the channels around factories in the Samut Sakhon hot spot area. A high concentration of mercury was also found in a fishing pond nearby a smelting plant. Many sediment samples exceeded three times the threshold of sediment quality criteria for protection of benthic animals from one of the traced metals (arsenic, mercury, zinc, cadmium, copper, chromium, and lead). Two soil samples (A3, SMS 1-2) exceeded soil quality standards of soils for other purposes for arsenic, chromium, or lead. The highest concentrations of arsenic (40.35 mg/kg), chromium (1701.75 mg/kg), and lead (18990 mg/kg) were found in the sediment samples SMS 2-7, SMS 2-1 and A3, respectively. The highest concentrations of mercury (2.39 mg/kg), zinc (1650.5 mg/kg), cadmium (18.65 mg/kg), and copper (792.62 mg/kg) were found in the sediment sample SMS 2-6. In the context of the background levels and pollution criteria, increased concentrations of all traced metals (arsenic, mercury, zinc, cadmium, copper, chromium, and lead) were found in investigated samples in the Samut Sakhon hot spot area.

6.4.2.6 Praeksa

Based on the measured data, the location around the landfill in the Praeksa hot spot area shows increased concentrations, mainly of arsenic, zinc, and cadmium and copper. The highest concentrations of heavy metals were found in a canal along the landfill wall and delete then along the fish pond. Many sediment samples exceeded three times of the threshold of sediment quality criteria for protection of benthic animals from arsenic, zinc, cadmium, or copper. The highest concentrations of arsenic (51.94 mg/kg) and cadmium (4.42 mg/kg) were found in the sediment sample PR 1. The highest concentrations of zinc (1087.38 mg/kg) and copper (99.39 mg/kg) were found in the sediment sample PR 8. In the context of the background levels and pollution criteria, significantly increased concentrations of arsenic, cadmium, zinc and copper were found in investigated samples in Praeksa. The highest risk on the locality is the leakage of hazardous leachate from the landfill. The highest concentrations of heavy metals were found in a channel where water flows in the direction to the dump site in high tide and rainy season, and water flows naturally out from the dump site in low tide and dry season. Ongoing research should be carried out to detect the spread of contamination resulting in any toxic threats to human health and the environment in the future. In general, landfill leachates represent a risk to the environment due to their

composition. A leachate collection and treatment system should be installed on any landfill site for hazardous or municipal solid waste.

6.4.2.7 Chachoengsao

Based on the measured data, high levels of arsenic, cadmium, and chromium were found in sediment collected at the effluent discharge point. Increased levels of arsenic and mercury were found in wetlands used for agriculture, which are expected to receive effluent from the eucalyptus plantation. Several sediment samples exceeded three times the threshold of sediment quality criteria for protection of benthic animals from arsenic, cadmium, copper, or chromium. The highest concentration of copper (51.94 mg/kg) was found in the sediment sample KHS 5. The highest concentrations of arsenic (136.39 mg/kg), cadmium (26.7 mg/kg) and chromium (437.02 mg/kg) were found in the sediment sample KHS 4. In the context of the backrgound levels and pollution criteria, increased concentrations of arsenic, cadmium, copper, and chromium were found in investigated samples in the Chachoengsao hot spot area. Further attention should be focused on the effluent discharge drainage near the industrial park.

6.4.2.8 Rayong River Estuary

Based on the measured data, locations around the IRPC Industrial Zone in Rayong Province show increased concentrations mainly of cadmium. All three sediment samples exceeded three times the threshold of sediment quality criteria for protection of benthic animals from cadmium. The highest concentration of cadmium (1.96 mg/kg) was found in the sediment sample IRPC 2. In the context of the background levels and pollution criteria, increased concentrations of cadmium were found in investigated samples on the Rayong River Estuary hot spot area. Ongoing research should be carried out to detect any threats resulting from this content of cadmium.

6.4.3 HEALTH RISK ASSESSMENT

Health risk assessments assume that, under certain specified conditions, there is a risk of damage to human health, while the risk rate from zero to maximum is determined by the type of activity, respectively staying at the location and conditions of the environment. Zero health risk is not really possible; however, the risk of damage must be minimized to an acceptable level in terms of health and environmental risks. To determine the risk, it is necessary to clarify the most important transport routes, and then, specify exposure scenarios to potentially threatened recipients. There are two approaches to evaluate the dose effects, for substances with threshold (non-carcinogenic) ,and non-threshold (carcinogenic) effect [130].

For substances with a non-carcinogenic effect, it is anticipated that in the body repair processes, which are able to successfully cope with exposure to a toxic substance, but only to a certain dose, the effect is already apparent. Threshold, known as the NOAEL (No Observed Adverse Effect Level), is the exposure level at which no adverse effects are observed. Alternatively, values LOAEL (Lowest Observed Adverse Effect Level) values can be used. They correspond to the lowest dose levels at which the negative health effects are observed. ADI (Acceptable Daily Intake) or RfD (Reference Dose) are derived using NOAEL or LOAEL values and relevant UF (Uncertainty Factors) or MF (Modifying Factors). These factors have to compensate for all the uncertainty and variability in determining the NOAEL and LOAEL values. The results of calculations (ADI or RfD) are usually much lower than NOAEL or LOAEL and represent the estimation of daily exposure to the human population (including sensitive population groups), which is very likely to pose no risk of adverse effects to human health, even if it lasts throughout a lifetime. In the case of carcinogenic substances, it is assumed that there is no such a dose that would not cause modifications at the molecular level, and subsequently, lead to the formation of malignant disease. Evaluation of the dose-effect relationship uses parameter SF (Slope Factor), which indicates the possible top edge of the probability of malignant disease per unit of the average daily dose received throughout a lifetime [131].

For the calculation of risk exposure to substances with a non-carcinogenic effect, a received and absorbed dose with acceptable toxicological intake of the substance is compared (i.e. RfD – Reference Dose). The risk level then represents Hazard Quotient HQ. The calculation is performed according to the equation:

$$HQ = \frac{E}{RfD}$$

E – parameter Average Daily Dose (ADD) or Lifetime Average Daily Dose (LADD), respectively Chronic Daily Intake (CDI) (mg/kg.day);
RfD – Reference Dose (mg/kg.day).

The calculation method for substances with a carcinogenic effect uses the parameter, ELCR - Excess Lifetime Cancer Risk (dimensionless indicator corresponding to the probability of developing cancer with lifetime exposure), which can be described by the following equation:

$$ELCR = CDI \cdot SF$$
$$ELCR = LADD \cdot SF$$

CDI – parameter Chronic Daily Intake, respectively Lifetime Average Daily Dose (LADD) relative to lifetime exposure of 70 years (mg/kg.day);
SF – Slope Factor (mg/kg.day). [131]

Table 2: *Agents classified by the IARC monographs.*

Group 1	Carcinogenic to humans
Group 2A	Probably carcinogenic to humans
Group 2B	Possibly carcinogenic to humans
Group 3	Not classifiable as to its carcinogenicity to humans
Group 4	Probably not carcinogenic to humans

The International Agency for Research on Cancer (IARC) recognizes: arsenic and inorganic arsenic compounds as Group 1 – carcinogenic to humans, lead as Group 2B - possibly carcinogenic to humans, inorganic compounds of lead as Group 2A - probably carcinogenic to humans, and organic compounds of lead as Group 3 - not classifiable as to its carcinogenicity to humans. [132, 133]

6.4.4 RISC MODEL

Risk-Integrated Software for Cleanups (RISC) is software developed to assess human health risks in contaminated areas. It can integrate up to 14 possible exposure pathways, and calculate the risks associated with them, both carcinogenic and non-carcinogenic.

If the carcinogenic risk (ELCR) is $<10^{-6}$, there are not significant adverse health effects. If it is between 10^{-6} and 10^{-4}, adverse effects may occur in the future, thus factors need to be taken into consideration. Finally, if it is $>10^{-4}$, the risk is unacceptable and serious measures must be taken immediately. If a hazard quotient (HQ) is <1, it implies that there are not significant adverse health effects, whereas a HQ >1 implies that potential adverse health effects exist. More research must be done in order to determine any toxic threats. Results are based on standard calculation coefficients defined in Risk-Integrated Software for Cleanups (RISC). Results are related to the average population. Samples collected in the hot spot areas were used to perform human health risk assessments. On the basis of the toxicological data risk assessment, RISC software was used for four heavy metals: arsenic, mercury, cadmium, and lead. Results of the calculation of human health risks which exceeded 10^{-6} for ELCR and 1 for HQ are presented in Tables 3 to 8.

Table 3: *Results of the calculation of human health risks for adults associated with arsenic in selected samples - carcinogenic risk (ELCR).*

Hot spot area	Sample	Concentration (mg/kg)	Exposition pathway			
			Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 7	39.18	4.7E-07	1.4E-07	1.3E-05	1.4E-05
	LOE 8	162.17	1.9E-06	6.0E-07	5.5E-05	5.8E-05
	LOE 1 D	42.23	5.1E-07	1.6E-07	1.4E-05	1.5E-05
Khon Kaen	KK 10	47.84	5.7E-07	1.8E-07	1.6E-05	1.7E-05
Tha Tum	TT 1-3	38.00	4.6E-07	1.4E-07	1.3E-05	1.4E-05
	TT 1-4	42.37	5.1E-07	1.6E-07	1.4E-05	1.5E-05
	TT 1-6	45.89	5.5E-07	1.7E-07	1.6E-05	1.6E-05
	TT 2-1	47.77	5.7E-07	1.8E-07	1.6E-05	1.7E-05
Samut Sakhon	SMS 1-8	31.93	3.8E-07	1.2E-07	1.1E-05	1.1E-05
	SMS 1-9	32.39	3.9E-07	1.2E-07	1.1E-05	1.2E-05
	SMS 2-2	117.96	1.4E-06	4.4E-07	4.0E-05	4.2E-05
	SMS 2-7	40.35	4.8E-07	1.5E-07	1.4E-05	1.4E-05
	SMS 2-12	35.28	4.2E-07	1.3E-07	1.2E-05	1.3E-05
	A3	28.200	3.4E-07	1.0E-07	9.6E-06	1.0E-05
Praeksa	PR 1	51.94	6.2E-07	1.9E-07	1.8E-05	1.8E-05
	PR 2	39.79	4.8E-07	1.5E-07	1.4E-05	1.4E-05
	PR 4	41.38	5.0E-07	1.5E-07	1.4E-05	1.5E-05
	PR 8	45.66	5.5E-07	1.7E-07	1.6E-05	1.6E-05
Chachoengsao	KHS 4	136.39	1.6E-06	5.0E-07	4.6E-05	4.9E-05

Table 4: *Results of the calculation of human health risks for children associated with arsenic in selected samples - carcinogenic risk (ELCR).*

Hot spot area	Sample	Concentration (mg/kg)	Exposition pathway			
			Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 4	12.91	3.5E-06	2.1E-07	6.6E-06	1.0E-05
	LOE 5	25.69	6.9E-06	4.1E-07	1.3E-05	2.0E-05
	LOE 6	19.21	5.2E-06	3.1E-07	9.8E-06	1.5E-05
	LOE 7	39.18	1.1E-05	6.3E-07	2.0E-05	3.1E-05
	LOE 8	162.17	4.4E-05	2.6E-06	8.3E-05	1.3E-04
	LOE 24	22.13	6.0E-06	3.5E-07	1.1E-05	1.8E-05
	LOE 1 D	42.23	1.1E-05	6.8E-07	2.2E-05	3.4E-05
Khon Kaen	KK 10	47.84	1.3E-05	7.7E-07	2.4E-05	3.8E-05
	KK 11	25.96	7.0E-06	4.2E-07	1.3E-05	2.1E-05
Map Ta Phut	MTP 1-7	27.72	7.5E-06	4.4E-07	1.4E-05	2.2E-05
Tha Tum	TT 1-2	25.82	7.0E-06	4.1E-07	1.3E-05	2.1E-05
	TT 1-3	38.00	1.0E-05	6.1E-07	1.9E-05	3.0E-05
	TT 1-4	42.37	1.1E-05	6.8E-07	2.2E-05	3.4E-05
	TT 1-6	45.89	1.2E-05	7.3E-07	2.3E-05	3.7E-05
	TT 1-9	25.90	7.0E-06	4.1E-07	1.3E-05	2.1E-05
	TT 2-1	47.77	1.3E-05	7.6E-07	2.4E-05	3.8E-05

Hot spot area	Sample	Concentration (mg/kg)	Exposition pathway			
			Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Samut Sakhon	SMS 1-1	22.09	6.0E-06	3.5E-07	1.1E-05	1.8E-05
	SMS 1-3	27.59	7.4E-06	4.4E-07	1.4E-05	2.2E-05
	SMS 1-5	24.57	6.6E-06	3.9E-07	1.3E-05	2.0E-05
	SMS 1-6	24.87	6.7E-06	4.0E-07	1.3E-05	2.0E-05
	SMS 1-8	31.93	8.6E-06	5.1E-07	1.6E-05	2.5E-05
	SMS 1-8	24.01	6.5E-06	3.8E-07	1.2E-05	1.9E-05
	SMS 1-9	32.39	8.7E-06	5.2E-07	1.7E-05	2.6E-05
	SMS 1-10	23.55	6.4E-06	3.8E-07	1.2E-05	1.9E-05
	SMS 2-2	117.96	3.2E-05	1.9E-06	6.0E-05	9.4E-05
	SMS 2-7	40.35	1.1E-05	6.5E-07	2.1E-05	3.2E-05
	SMS 2-12	35.28	9.5E-06	5.6E-07	1.8E-05	2.8E-05
	A3	28.200	7.6E-06	4.5E-07	1.4E-05	2.2E-05
Praeksa	PRE 1-1	19.65	5.3E-06	3.1E-07	1.0E-05	1.6E-05
	PR 1	51.94	1.4E-05	8.3E-07	2.6E-05	4.1E-05
	PR 2	39.79	1.1E-05	6.4E-07	2.0E-05	3.2E-05
	PR 4	41.38	1.1E-05	6.6E-07	2.1E-05	3.3E-05
	PR 5	23.67	6.4E-06	3.8E-07	1.2E-05	1.9E-05
	PR 8	45.66	1.2E-05	7.3E-07	2.3E-05	3.6E-05
Chachoengsao	KHS 2	21.87	5.9E-06	3.5E-07	1.1E-05	1.7E-05
	KHS 4	136.39	3.7E-05	2.2E-06	7.0E-05	1.1E-04

Table 5: *Results of the calculation of human health risks associated with arsenic in selected samples – hazard quotients (HQ).*

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 8	162.17	A	3.4E-02	1.0E-02	9.6E-01	1.0
			C	1.2E+00	6.8E-02	2.1E+00	3.3
Samut Sakhon	SMS 2-2	117.96	C	8.4E-01	5.0E-02	1.5E+00	2.4
Praeksa	PR 1	51.94	C	3.7E-01	2.2E-02	6.8E-01	1.1
Chachoengsao	KHS 4	136.39	C	9.7E-01	5.7E-02	1.8E+00	2.8

Table 6: *Results of the calculation of human health risks associated with mercury in selected samples – hazard quotients (HQ).*

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Samut Sakhon	SMS 2-10	10.32	A	7.3E-02	1.4E-03	3.1E+00	3.2
			C	2.2E-03	2.2E-03	1.3E+00	1.3

Table 7: *Results of the calculation of human health risks for adults associated with cadmium in selected samples – hazard quotients (HQ).*

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Loei	LOE 7	15.33	C	6.6E-02	9.8E-05	1.7E+00	1.8
	LOE 8	39.25	C	1.7E-01	2.5E-04	4.3E+00	4.5
			A	5.1E-03	5.1E-05	1.8E+00	1.8
	LOE 1 C	9.92	C	4.3E-02	6.3E-05	1.1E+00	1.1
	LOE 1 D	19.71	C	8.5E-02	1.3E-04	2.2E+00	2.3
Tha Tum	TT 1-7	12.17	C	5.2E-02	7.8E-05	1.3E+00	1.4
Samut Sakhon	SMS 2-6	18.65	C	8.0E-02	1.2E-04	2.1E+00	2.1
	SMS 2-1	19.67	C	8.5E-02	1.3E-04	2.2E+00	2.2
Chachoengsao	KHS 4	26.70	C	1.1E-01	1.7E-04	2.9E+00	3.1
			A	3.5E-03	3.5E-05	1.2E+00	1.2
	KHS 4a	22.73	C	9.8E-02	1.5E-04	2.5E+00	2.6
			A	3.0E-03	3.0E-05	1.0E+00	1.0

Table 8: *Results of the calculation of human health risks associated with lead in selected samples – hazard quotients (HQ).*

Hot spot area	Sample	Concentration (mg/kg)	Child/adult	Exposition pathway			
				Ingestion of soil	Dermal contact of soil	Ingestion of vegetable	Total
Samut Sakhon	A1	2197	C	1.3E+00	2.6E-02	0.0E+00	1.3
	A3	18990	C	1.1E+01	2.3E-01	0.0E+00	11.4

The carcinogenic and non-carcinogenic risks from arsenic for local residents from several exposure pathways were evaluated in all the hot spot areas. This included assessing exposure to heavy metals by ingestion of soil (including dust ingestion), dermal contact, and crops (vegetable) consumption. Values of arsenic Excess Lifetime Cancer Risk are between 10^-6 and 10^-4 for 19 and 36 samples for adults and children respectively. In these cases, adverse effects may occur in the future; thus, factors need to be taken into consideration on relevant locations. Arsenic hazard quotients (HQ), which represent non-carcinogenic risk have exceeded value 1 in four and one sediment samples (from Loei, Samut Sakhon, Praeksa, Chachoengsao) for children and adults respectively. Arsenic health quotients in these sediment samples could inflict adverse health effects for children and adults.

The non-carcinogenic risks of mercury, cadmium, and lead for local residents from several exposure pathways were also evaluated for sediment and soil samples collected on the hot spot areas. Unacceptable risks (HQ >1) have been identified in one sediment sample for mercury (SMS 2-10) and in two samples for lead (ash A1 and soil A2), all from the Samut Sakhon hot spot area. Cadmium hazard quotients for children have exceeded value 1 in nine sediment samples from four hot spot areas (Loei, Tha Tum, Samut Sakhon, and Chachoengsao). Three samples have also exceeded cadmium hazard quotients for adults (one from Loei and two from Chachoengsao). These results make cadmium the second most risky heavy metal for human health in the hot spot areas.

6.5 CONCLUSIONS

This study focused on monitoring and the evaluation of concentrations of heavy metals in sediments, soils, and ashes at eight industrial hot spot areas in Thailand. A series of samples were taken at contaminated sites and compared with the legal pollution criteria.

There are several spots where hazardous levels of arsenic, mercury, lead, and cadmium were found in soils and sediments. These levels of pollutants represent significant threats to the environment and human health. The high levels of heavy metals were observed in sediments and soils in all the hot spot areas (especially arsenic and cadmium). Concentrations of heavy metals exceed not only levels of sediment quality criteria for protection of benthic animals drafted for Thailand, but, in some cases, also levels of pollution limits for industrial or general use based on the US EPA.

An analysis using the Risk-Integrated Software for Cleanups (RISC) indicated the following results. The riskiest heavy metal on the hot spot areas was arsenic, followed by cadmium. Several samples polluted with arsenic showed that adverse carcinogenic effects may occur in the long term. Moreover, some of the samples polluted with arsenic and cadmium exceeded the hazard quotient (HQ). Potential adverse health effects exist in this case. More research should be done in order to determine these toxic threats at the studied sites.

The severity of the risks identified on the hot spot areas depends on the particular use of the local site. On some hot spots with a metallurgical industry, improved assessments for better environmental practices are recommended. In the case of the most contaminated samples, materials should be excavated and removed. Ongoing research should be carried out to detect the spread of contamination resulting in any toxic threats to human health and environment in the future.

7. Mercury in fish from industrial sites in Thailand

Ing. Jana Tremlová, PhD.

7.1 INTRODUCTION

The main objective of this study is to interpret a data set obtained from an environmental sampling in different parts of Thailand that was carried out in February and March 2016 and February 2017. Samples originated from various sites, some of which served as control areas without any known sources of pollution, and some samples originated from highly industrialized areas. Collected samples of fish and sediments were analyzed for content of mercury and methylmercury, and also for the content of some selected risk elements. Data was further discussed and compared to national and international legal standards.

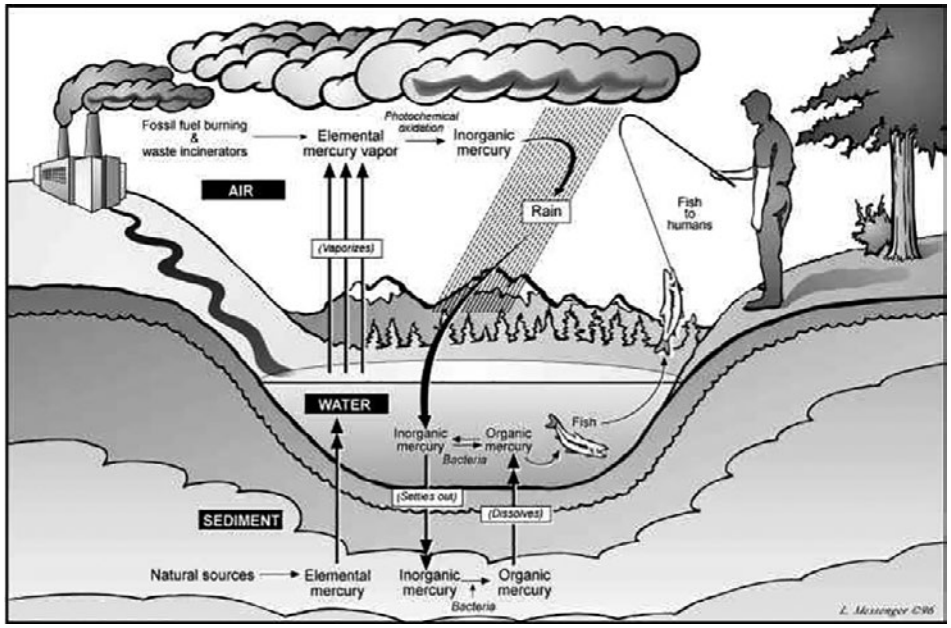
This sampling campaign is a part of the "Increasing Transparency in Industrial Pollution Management through Citizen Science" project, and was conducted by the non-profit organization, Arnika Association, Czech Republic and Ecological Alert and Recovery – Thailand (EARTH) Association.

7.2 MERCURY CONTAMINATION

Mercury is a well-known toxin that has damaging effects on human health, affecting mostly the nervous system and other body systems, including cardiovascular, respiratory, gastrointestinal, hematologic, immune and reproductive systems [134]. Its neurotoxicity is most damaging for developing organisms and therefore, pregnant women. Fetuses are the most sensitive group when exposed to mercury in the environment of the mother [135]. A unique first-ever peer-reviewed study on the economic burdens of mercury exposure by Transande et al. [136] states that mercury contamination that causes a significant IQ reduction costs 77.4 – 130 million dollars per year in lost income potential. In the case of Thailand, these costs to the community were enumerated in 278,000 – 480,000 dollars per year, just for the Tha Tum industrial area. The earning losses on mercury can be summed up as follows: higher mercury contamination = lower IQ = lower economical potential = higher community costs [137].

Sources of mercury contamination in the environment can be either natural or anthropogenic. Natural sources of mercury include volcanoes, forest fires, or leaching of mercury (which contains minerals and rocks). Anthropogenic sources are mainly connected with industrial activities and levels of mercury in the environment that are increasing due to discharge from hydroelectric, mining, smelting, cement and alkali, pulp and paper industries. Incineration of municipal and medical waste and emissions from coal power plants and the use of fossil fuels also contribute to high levels of mercury. A problem with mercury is that it is able to travel long distances in the air and therefore, able to contaminate places remote from an initial source of pollution. Airborne mercury is then deposited into water and becomes accessible for bacterias

Figure 1: *Biochemical cycle of mercury [139].*



in lakes, streams and ocean sediments that convert elemental mercury into highly bioavailable organic compounds, such as methylmercury. The conversion of inorganic mercury to methylmercury is important for two reasons: i) it is much more toxic than inorganic mercury compounds, ii) organisms require a long time to eliminate it and therefore, it leads to bioaccumulation.

Bioaccumulation of mercury is a process where methylmercury-producing bacterias may be consumed by the next highest organism in the food chain, or the bacterias may release the methylmercury into the water where it can be adsorbed by plankton, which can also be consumed by the organisms of the higher trophic level. This pattern continues as small fish and organisms get eaten by progressively bigger and bigger fish until the fish are finally consumed by a human or another animal. It is called biomagnification and it means that mercury levels are gradually higher in the food chain, e.g. levels in carnivorous fish are usually higher than levels in lower segments of the food chain, like in omnivorous and herbivorous species. Once it is in the fish's body, it binds to the fish's tissues, including fat and muscles, and is eliminated very slowly and persists in the body for a very long time [138].

Mercury in the environment is constantly cycled and recycled through a biochemical cycle shown in Figure 1 [139].

7.3 SAMPLING AND ANALYTICAL METHODS

Analytical procedures for sediments were as follows: after transport to the laboratory, samples were homogenized, and a representative part (50 g) was used for the determination of dry matter by a gravimetric method. Another representative part was taken for the analysis of heavy metals (cadmium, copper, chromium, lead, zinc and arsenic) by a mineralization procedure. The analytical procedure of mineralization was as follows: 5 g of a sample was placed into a beaker together with 30 ml of distilled water and 10 ml of concentrated nitric acid. The sample was boiled for a period of two hours. Then, it was filtered through a fluted filter paper. Metals and arsenic were determined in the mineralizates by atomic absorption and emission spectrometer SensAA. Mercury was measured directly in solid samples by Advanced Mercury Analyzer (AMA 254, Altec). Analyses were conducted using standard operating procedures (SOP) established at the University of Chemical Technology, Prague, Czech Republic.

Analyses of mercury and methylmercury in fish were conducted using standard operating procedures (SOP): 70.4 (AAS-AMA and AAS-CZL;S), 70.4.1 (AAS-CZL 2/13;S), respectively. Other risk elements were determined as follows: using SOP 70.3, AAS-hydrides; other elements using SOP 70.2, AAS-flame and GF-AAS. All procedures were established at the State Veterinary Institute, Prague, Czech Republic.

7.4 RESULTS

The results of the analytical measurements of mercury, methylmercury and, marginally, other risk elements in collected samples are presented in the following tables (Table 1 – Table 2) and figures (Figure 2 – 7).

Table 1: *Content of risk elements in analyzed fish and sediment samples. The content of elements is given in mg kg^{-1} of dry matter. NA: not analyzed. Contents of Zn, Cd, Sr, Ba, Cu, Co, Ni, Cr, Pb, Mo in fish that were below detection limits are not further mentioned in this table.*

Fish Samples					Area Relevant Sediments			
Sample code	**Mercury mg kg^{-1}**	**Methylmercury mg kg^{-1}**	**Arsenic mg kg^{-1}**	**Other elements**	**Sample code**	**Mercury mg kg^{-1}**	**Arsenic mg kg^{-1}**	**Other elements**
CHA3	NA	NA	NA		CHA1	0.02	0.06	1.99 Cd/ 3.98 Cr
CHA4	0.316	0.226	<0.010	0.014 Cd/ 0.07 Cr/ 0.04 Pb				
KHS6	NA	NA	NA		KHS7	0.03	4.08	
KHS10	0.283	0.267	0.010					
KK-2017-2	0.024	0.0177	NA		KK4	<0.01	0.47	
KK-2017-5	0.269	0.202	NA		KK9	0.03	1.12	
KK-2017-6	0.00960.120	<0.0150.105	NA					
KK12	0.0091	<0.015	NA					
KK14-1	0.0356	0.0318	NA					
KK14-2	0.120	0.105	NA					
KLO1-3/1-3	0.197	0.18	0.240		KLO1-4	0.07	31.87	2.81 Cd/ 72.18 Cr
KLO1-3/4-6	NA	NA	NA					
KLO1-2	0.06	<0.015	0.98	0.018 Cd/ 0.57 Cr/ 0.22 Pb				

Fish Samples					Area Relevant Sediments			
Sample code	Mercury mg kg^{-1}	Methylmercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements	Sample code	Mercury mg kg^{-1}	Arsenic mg kg^{-1}	Other elements
LOE14	0.016	<0.015	NA		LOE12	0.04	3.80	
LOE15	0.020	<0.015	0.080					
LOE19	0.229	0.22	0.010		LOE27	0.05	1.49	
LOE29	NA	NA	NA					
MTP-2017-1	0.103	0.096	NA		MTP1-14	0.35	19.86	
MTP-2017-2	0.143	0.112	NA					
MTP-2017-3	0.500	0.483	NA					
MTP-2017-5	0.353	0.334	NA					
MTP-2017-8	0.168	0.144	NA		MTP1-1	0.03	1.53	
MTP1-4	0.042	0.016	1.510	0.011 Cd/ 0.29 Cr/ 0.20 Pb	MTP1-6	0.13	6.82	13.63 Cd
MTP1-10/1	1.027	0.988	NA		MTP1-8	0.03	2.30	
MTP1-10/2	0.119	0.112	NA					
MTP2-1/1	0.507	0.487	NA		MTP2-2	0.05	3.03	
MTP2-1/2	NA	NA	NA					
MTP2-8	0.124	0.112	0.020		MTP2-6	0.08	0.30	
MTP2-9	0.173	0.141	0.060					
PR3	0.021	<0.015	0.020		PR2	0.04	39.79	
PR7	NA	NA	NA		PR5	0.04	23.67	

Fish Samples					Area Relevant Sediments			
Sample code	**Mercury mg kg^{-1}**	**Methylmercury mg kg^{-1}**	**Arsenic mg kg^{-1}**	**Other elements**	**Sample code**	**Mercury mg kg^{-1}**	**Arsenic mg kg^{-1}**	**Other elements**
IRPC7	0.028	<0.015	6.720		IRPC6	0.01	2.03	1.92 Cd/ 4.79 Cr
PRN-2017-1	0.561	0.499	NA					
PRN-2017-2	0.177	0.158	NA		-	-	-	
PRN-2017-3A+3B	0.129	0.115	NA					
SMS1-12/1	0.145	0.109	0.470					
SMS1-12/2	0.054	0.038	0.740		SMS1-9	0.04	32.39	3.94 Cd/ 54.14 Cd
SMS1-12/3	0.012	<0.015	0.680	0.071 Cd/ 0.33 Cd/ 0.11 Pb				
SMS1-2	0.020	<0.015	0.680		SMS1-3	0.04	27.59	
SMS1F	0.009	<0.015	NA		SMS2-11	0.15	11.02	
SMS2F	0.017	<0.015	NA					
TT-2017-1	0.517	0.455	NA		TT1-9	0.04	25.90	
TT2-8	NA	NA	NA					
TT1-1F	0.450	0.376	NA		TT1-7	0.04	2.06	
TT2-6	0.006	<0.015	0.030		TT1-5	0.08	0.22	
TT2-7	0.009	<0.015	0.45	0.65 Cr/ 0.04 Pb				

Table 2: *Correlation analysis between total mercury content and other measured parameters. Length 1 – Weight befits polynomic correlation. Methylmercury content befits linear correlation.*

Parameter	Correlation coefficient (R)
Length 1 (with tail fin)	0.854
Length 2 (without tail fin)	0.851
Weight	0.671
Methylmercury content	0.998

Figure 2: *Graph shows the relationship between total mercury content and fish length.*

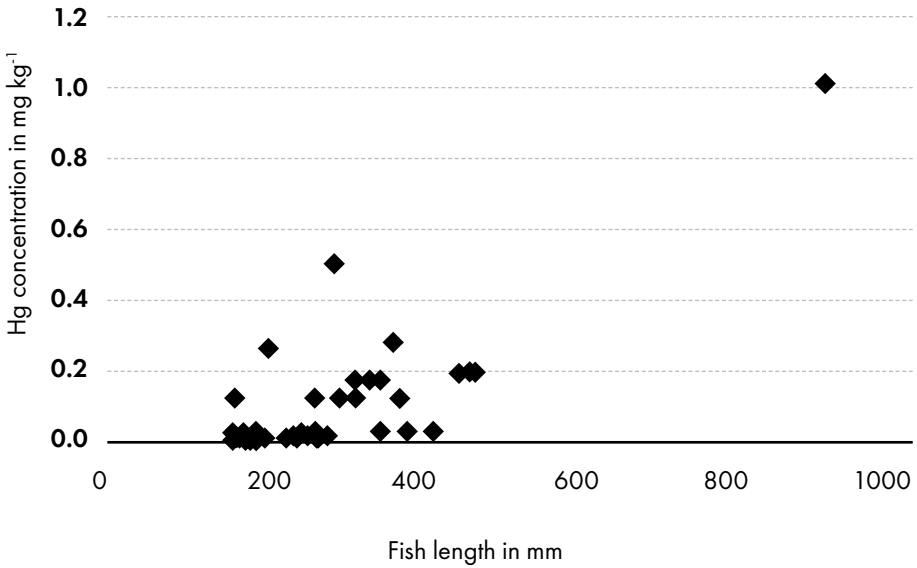


Figure 3: *Graph shows the relationship between methylmercury content and total mercury.*

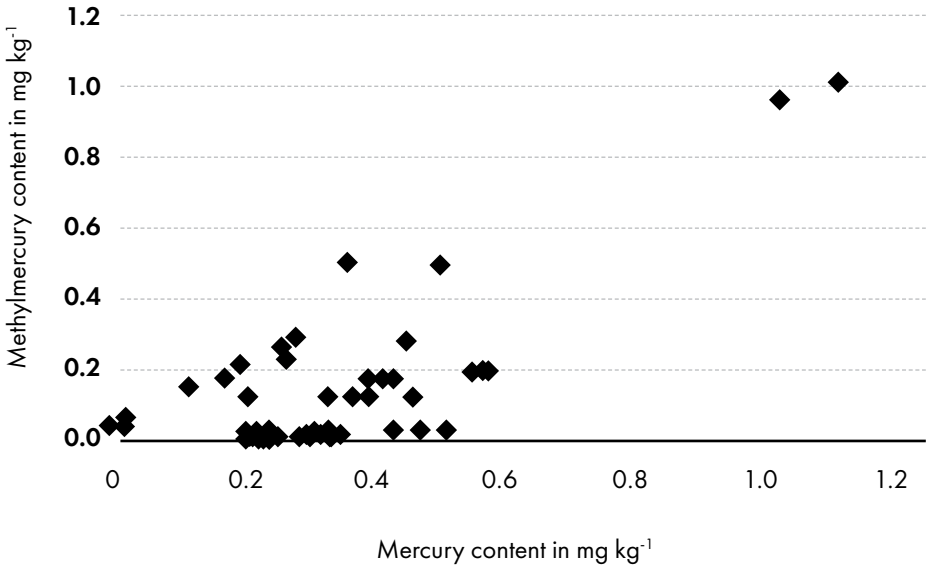


Figure 4: *An average concentration of total mercury in individual fish species including standard deviation if available.*

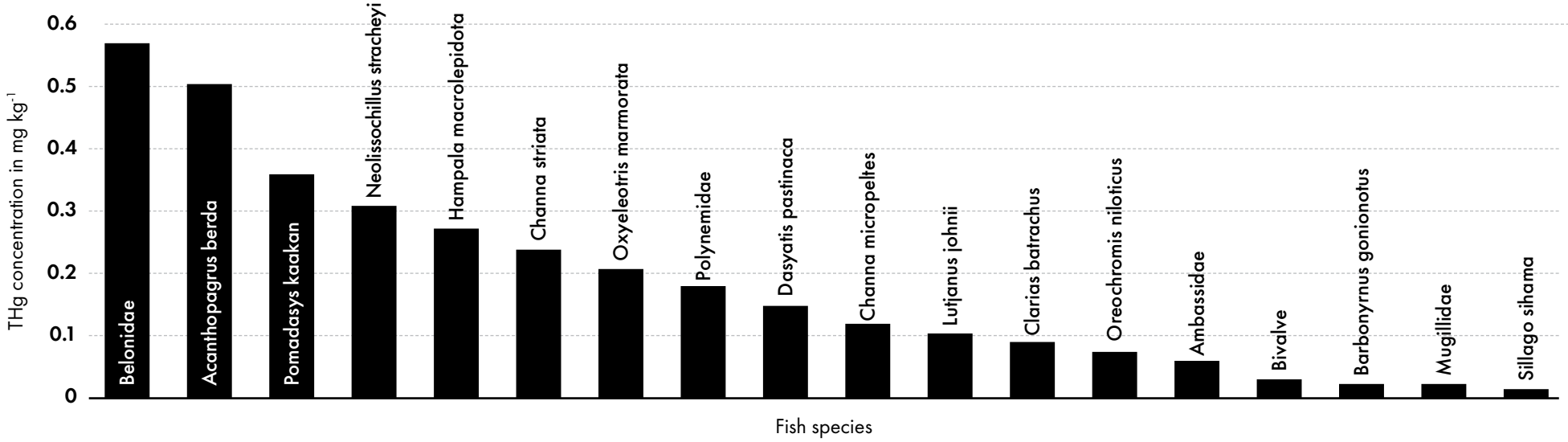


Figure 5: *Concentration of total mercury in fish originating from different areas.*

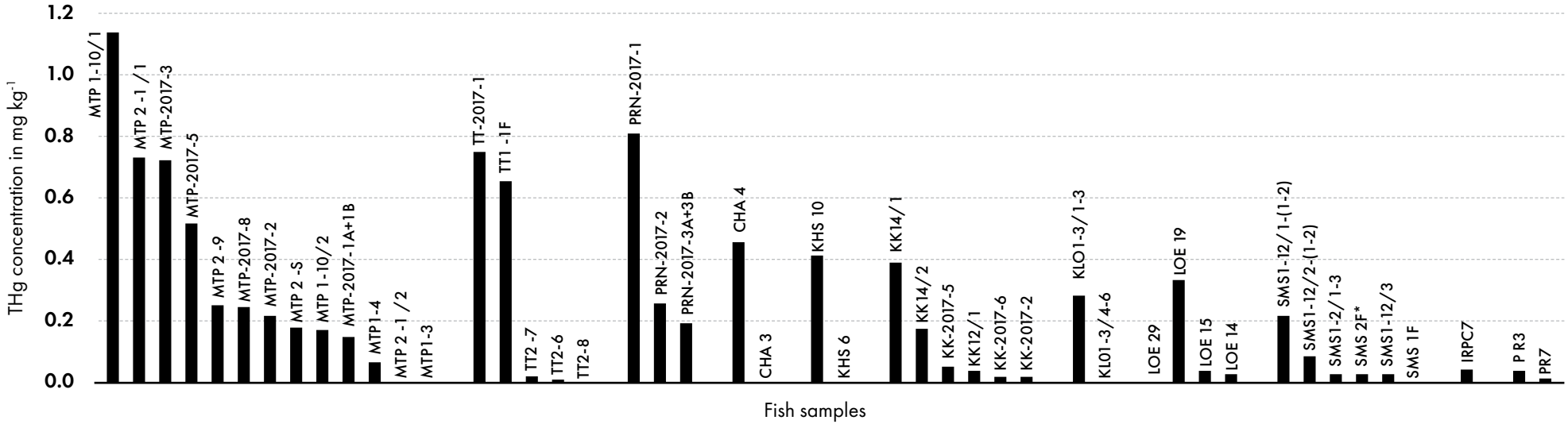


Figure 6: *Graph shows a mercury content in fish originating from different sites of Map Ta Phut area.*

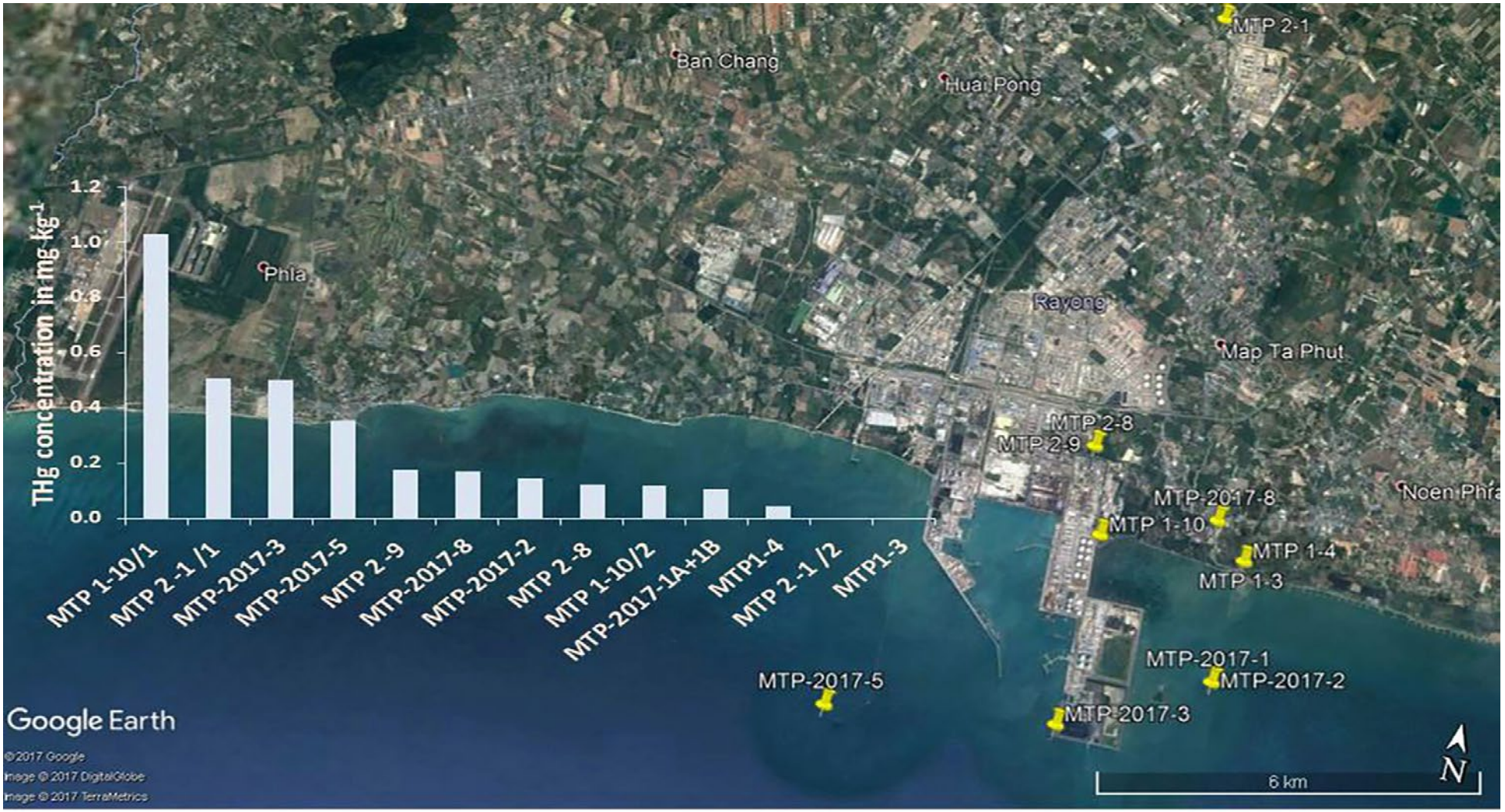
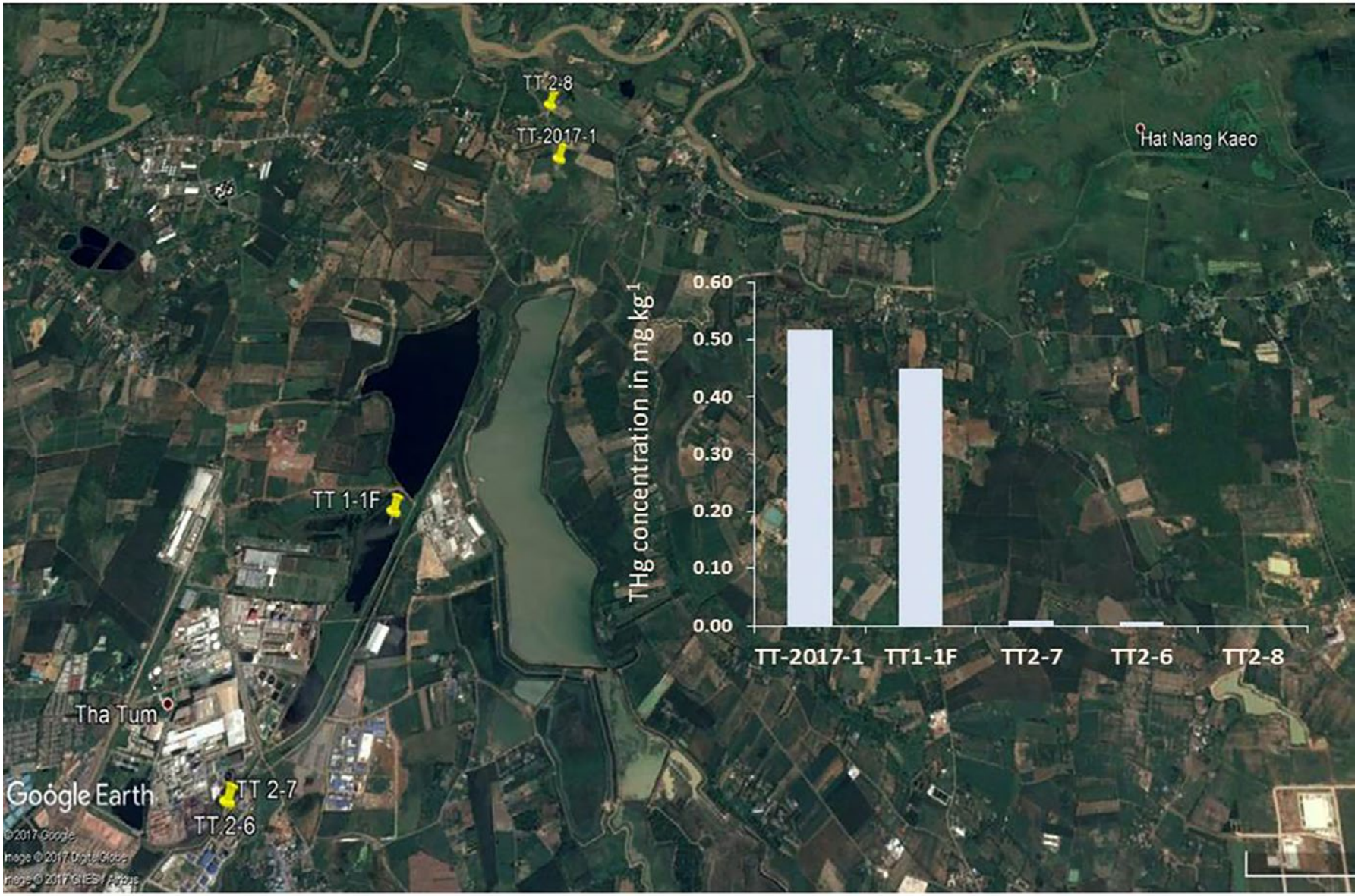


Figure 7: *Graph shows a mercury content in fish originating from different sites of Tha Tum area. Sample TT2-8 was not analyzed.*



7.5 DISCUSSION

The main part of this chapter is an interpretation of data obtained from the conducted survey and their comparison to national and international standards, as well as drawing conclusions of what the results mean for people living around these areas and how it can affect their health. This chapter also tries to outline available options on how to reduce risks associated with consumption of fish and fishery products originating from mercury polluted areas.

7.5.1 LEGAL STANDARDS AND RESULTS OF COMPARABLE STUDIES

Content of pollutants in collected samples of fish and sediments was compared to the maximum, allowed, or recommended levels of these pollutants as defined in national and international decrees, norms and laws (Table 3 – Table 6). Table 7 shows results of other comparable studies that have been conducted in the region of Thailand since the 1970s.

The sediment quality guideline for surface water by the Thai Pollution Control Department (PCD) [140] gives the maximum recommended levels of risk elements in surface water sediments.

Supplementary guidance for developing soil screening levels by the United States Environmental Protection Agency (US EPA) [141] sets regulatory standards of maximum contaminant levels in agricultural soils.

Because sediments may be washed out on surrounding land and its suitable physico-chemical properties can be used as fertilizers or soil improvers, there is Czech Decree No. 257/2009 [142] that regulates sediment application on agricultural soils. It defines the maximum possible content of selected risk elements in sediments that are intended to be used as soil improvers on agricultural soils.

Table 3: *Legal standards and recommendations for heavy metals in sediments and soils. The content of elements is given in mg kg^{-1} of dry matter.*

	Mercury	Arsenic
Sediment quality guideline (based on Thai PCD)	0.18	-
Regulatory standards in soils (based on US EPA)	1	0.11
Usage of sediments on agricultural soils (based on CZ Decree)	0.8	30

On the basis of the US EPA, Regional Screening Levels was created as an edited version of Methodological guidelines of the Czech Ministry of Environment on Risk assessment of soil, soil, air and underground water [143] that gives criteria for industrial and other use areas that are not legally binding, however, often applied on a voluntary basis.

Table 4: *Auxiliary criteria for soils. The content of elements is given in mg kg-1 of dry matter.*

Criterion	Mercury	Arsenic
Industrial areas	43	2.4
Other areas	10	0.61

US EPA [144], Commission Regulation (EC) No. 1881/2006 [145], an advisory for consumers by Health Canada [146] and Ministerial Notification No. 98 of B.E. 2529/1986 [147] and its later issue No. 273 of B.E. 2546/2003 [148] limit the maximum levels of mercury in fish and fishery products in the European Union, respectively Thailand.

Table 5: *Maximum allowable levels of mercury and arsenic in fish and seafood.*

Foodstuffs	Maximum level of mercury (mg kg^{-1} of fresh weight)	Maximum level of arsenic (mg kg^{-1} of fresh weight)
Fishery products and muscle meat of fish (excluding species listed below)	0.5	Not set
Selected fishery products and muscle meat of fish: Lophius spp., Anarhichas lupus, Sarda sarda, Anguilla spp., Hoplostethus spp., Coryphaenoides rupestris, Hippoglossus hippoglossus, Genypterus capensis, Makaira spp., Lepidorhombus spp., Mullus spp., Genypterus blacodes, Esox ivipa, Orcynopsis unicolor, Trisopterus minutus, Centroscymnes coelolepis, Raja spp., Sebastes marinus, S. mentella, S. iviparous, Istiophorus platypterus, Lepidopus caudatus, Aphanopus carbo, Pagellus spp., Carcharodon spp., Lepidocybium flavobrunneum, Ruvettus pretiosus, Gempylus serpens, Acipenser spp., Xiphias gladius, Thunnus, Euthynnus, Katsuwonus pelamis. **(based on Commission Regulation (EC) No. 1881/2006)**	1.0	Not set
Fish and Seafood **(based on US EPA Fact Sheet No. 823-R-01-001/2001)**	0.3 (total per week) 0.2 (methylmercury per week)	Not set
Level requiring special fish advisory for consumers **(based on Health Canada 2007: Human Health Risk Assessment)**	0.2 (total mercury)	-
Marine fish and Seafood **(based on Thai Ministerial Notification No. 98 of B.E. 2529/1986 and No. 273 of B.E. 2546/2003)**	0.5	2 (inorganic)
Other food (including freshwater fish) **(based on No. 98 of B.E. 2529/1986and Thai Ministerial Notification No. 273 of B.E. 2546/2003**	0.02	2 (total)

Table 6: *Summary of average intakes from individual fish samples. For calculations was used an average daily intake of fish in Thailand of 0.061 kg and an average body weight of 60 kg [149].*

Limit US EPA			**RfD 0.3 mg THg kg^{-1}**	**RfD 0.2 mg MeHg kg^{-1}**	**0.006 mg MeHg-day***	
Sample	**THg**	**MeHg**	**Weekly THg intake [A]**	**Weekly MeHg intake [B]**	**Daily MeHg intake [C]**	**g of fish to reach daily limit[D]**
CHA 4	0.316	0.226	0.135	0.097	0.014	26.5
IRPC7	0.028	<0.015	0.012			
KHS 10	0.283	0.267	0.121	0.114	0.016	22.5
KK12/1	0.024	0.018	0.010	0.008	0.001	339.0
KK14/1	0.269	0.202	0.115	0.086	0.012	29.7
KK14/2	0.120	0.105	0.051	0.045	0.006	57.1
KK-2017-2	0.009	<0.015	0.004			
KK-2017-5	0.036	0.032	0.015	0.014	0.002	188.7
KK-2017-6	0.010	<0.015	0.004			
KLO1-3/1-3	0.197	0.180	0.084	0.077	0.011	33.3
LOE 14	0.016	<0.015	0.007			
LOE 15	0.020	<0.015	0.009			
LOE 19	0.229	0.220	0.098	0.094	0.013	27.3
MTP 1-10/1	1.027	0.988	0.439	0.422	0.060	6.1

Limit US EPA			RfD 0.3 mg THg kg^{-1}	RfD 0.2 mg MeHg kg^{-1}	0.006 mg MeHg-day*	
Sample	**THg**	**MeHg**	**Weekly THg intake [A]**	**Weekly MeHg intake [B]**	**Daily MeHg intake [C]**	**g of fish to reach daily limit[D]**
MTP 1-10/2	0.119	0.112	0.051	0.048	0.007	53.6
MTP 2 -1 /1	0.507	0.487	0.216	0.208	0.030	12.3
MTP 2 -8	0.124	0.112	0.053	0.048	0.007	53.6
MTP 2 -9	0.173	0.141	0.074	0.060	0.009	42.6
MTP1-4	0.042	0.016	0.018	0.007	0.001	375.0
MTP-2017-1A+1B	0.103	0.096	0.044	0.041	0.006	62.5
MTP-2017-2	0.143	0.112	0.061	0.048	0.007	53.6
MTP-2017-3	0.500	0.483	0.214	0.206	0.029	12.4
MTP-2017-5	0.353	0.334	0.151	0.143	0.020	18.0
Limit US EPA			RfD 0.3 mg THg kg^{-1}	RfD 0.2 mg MeHg kg^{-1}	0.006 mg MeHg-day*	
Sample	THg	MeHg	Weekly THg intake [A]	Weekly MeHg intake [B]	Daily MeHg intake [C]	g of fish to reach daily limit[D]
MTP-2017-8	0.168	0.144	0.072	0.061	0.009	41.7
PR3	0.021	<0.015	0.009			
PRN-2017-1	0.561	0.499	0.240	0.213	0.030	12.0
PRN-2017-2	0.177	0.158	0.076	0.067	0.010	38.0

Limit US EPA			RfD 0.3 mg THg kg^{-1}	RfD 0.2 mg MeHg kg^{-1}	0.006 mg MeHg-day*	
Sample	**THg**	**MeHg**	**Weekly THg intake [A]**	**Weekly MeHg intake [B]**	**Daily MeHg intake [C]**	**g of fish to reach daily limit[D]**
PRN-2017-3A+3B	0.129	0.115	0.055	0.049	0.007	52.2
SMS 2F*	0.017	<0.015	0.007			
SMS1-12/1-(1-2)	0.145	0.109	0.062	0.047	0.007	55.0
SMS1-12/2-(1-2)	0.054	0.038	0.023	0.016	0.002	157.9
SMS1-12/3	0.012	<0.015	0.005			
SMS1-2/1-3	0.020	<0.015	0.009			
TT1 -1F	0.450	0.376	0.192	0.161	0.023	16.0
TT-2017-1	0.517	0.455	0.221	0.194	0.028	13.2
TT2-6	0.006	<0.015	0.003			
TT2-7	0.009	<0.015	0.004			

***** limit was calculated as US EPA limit 0.0001 mg MeHg kg-1 body weight per day times average body weight of 60 kg. Values of THg and MeHg intakes and g of fish to reach daily limit were calculated as follows: [A] 7 (days of the week) times an average fish consumption per person times total mercury content in individual fish samples. [B] 7 (days of the week) times an average fish consumption per person times methylmercury content in individual fish samples. [C] An average fish consumption per person times methylmercury content in individual fish samples. [D] US EPA limit related to an average body weight of 0.006 (see * note above) times 1000 (grams in one kilogram) divided by methylmercury content in individual fish samples.

The results of this study are similar to the results obtained from studies previously carried out in the region of Thailand, pointing to long-term mercury contamination of this area and its continuance.

Table 7: *Overview of mercury content in fish of Thailand.*

Study period	Location	Biota	Total mercury (mg kg^{-1})	Reference
1974	Bang Pra coast	3rd trophic level fish 4th trophic level fish	0.003 – 0.010 0.02 – 0.057	Menasveta (1976)
1976	Chao Phraya estuary	Fish and shellfish	0.009 – 0.205	Menasveta (1978)
1976 - 1977	Inner Gulf	3rd trophic level fish 4th trophic level fish	0.002 0.130 0.002 – 0.650	Cheevaparanapiwat and Menasveta (1979)
1977 - 1980	Inner Gulf	Fish and shellfish	0.002 – 0.206	Sivarak and co. (1981)
1979 - 1981	Inner Gulf	Fish and shellfish	0.012 – 0.051	Sidhichaikasem and Chernbamrung (1983)
1980	Mekong Ta Chin Chao Phraya Bang Prakong	Mullets	0.04±0.03 0.07±0.03 0.15±0.06 0.08±0.03	Menasveta and Cheevaparanapiwat (1981)
1990	Sichang Island Map Ta Phut Offshore (Erawan)	Fish	0.012 – 0.032 0.013 – 0.049 0.055 – 0.324	Menasveta (1990)
1997	Outer Gulf of Thailand	Demersal Fish	0.003 – 0.930	ARRI (1998)
2000	Offshore (Erawan)	Fish	0.045 – 0.892	Menasveta and Piyatiratitivorakul (2000)
Study period	Location	Biota	Total mercury (mg kg^{-1})	Reference
2008	Offshore (Erawan)	Fish	0.005 – 0.840	Menasveta and Piyatiratitivorakul (2008)
2013	Shalongwaeng Canal	Snakehead Fish	0.067 – 0.526	IPEN (2013)
2016 – 2017	Various sites	Fish	0.006 – 1.027	Results of this study

7.5.2 EVALUATION OF POLLUTANT LEVELS

The aim of this chapter is to evaluate data obtained from analyzing fish and sediment samples that originate from different parts of Thailand and determine the degree of environmental and health burdens it can cause. The following text is also a summary of results from each studied area and other generalizations resulting from analysis outcomes.

7.5.2.1 Chanthaburi

The mercury content in samples from Chanthaburi, in the case of CHA3, is below Thai legal standards for freshwater fish (0.02 mg kg^{-1}), but in the case of omnivorous Masheer Barb (CHA4), it exceeds this limit almost 16 times. It also exceeds the US EPA limit 0.0001 mg MeHg kg^{-1} body weight per day by eating just 26.5 g of this Masheer Barb a day. Elevated content of mercury was found, in spite of the fact that the content of the measured risk elements in sediment samples were below legal standard levels in all of them, including mercury and arsenic. The measured arsenic content in fish was below the Thai legal threshold limit that is set for freshwater fish at 2 mg total arsenic kg^{-1}. Chanthaburi site was chosen as a control site; however, it is obvious that biomagnification of mercury can be a problem even in unpolluted areas. In this case, it may be caused by a long transport deposition of mercury, likely from Map Tha Put industrial area that is about 70 km far away. Figure 9 (Appendix 2) shows that prevailing winds from October to January blow from Map Tha Put in the direction of Chantaburi, which supports the theory of the long-range transport of mercury depositions.

7.5.2.2 Khao Hin Sorn

In the case of Khao Hin Sorn, both mercury and methylmercury reached the maximum allowable levels in tissues of the analyzed omninivorous Snakehead fish. Arsenic content, on the contrary, was within the Thai legal standard, although arsenic in sediments exceeded the auxiliary criteria for industrial and other areas given by the Czech Ministry of Environment (2.4 and 0.61 mg arsenic kg^{1}, respectively). Hazardous waste dumping grounds, outflows of wastewater, and smelting factories are placed in the vicinity of the sampling sites, which can all be sources of the elevated content of arsenic in the environment.

7.5.2.3 Khon Kaen

Samples of fish (Cat fish, Snakehead fish, Silver Barb, Hampala Barb, Giant Snakehead fish) were taken from an outflow of a near paper and pulp factory and a coal power plant. Therefore, the results show elevated levels of mercury in the samples, except samples of Catfish (KK-2017-2, KK-2017-6). Methylmercury reaches the US EPA legal standard for daily methylmercury consumption in samples of carnivorous Giant Snakehead fish and omnivorous Hampala Barb. Consumation of only 29.7 g and 57.1 g of the fish, respectively, would reach the US EPA daily limit of 0.0001 mg MeHg kg^{-1}-day. On the contrary, the content of arsenic in fish tissues were within the legal standards in all analyzed samples from Khon Kaen area.

7.5.2.4 Klong Dan

Analysis of mussel, Threadfin, and Mullet samples showed elevated levels of mercury and methylmercury only in the Threadfins (KLO1-3/1-3). Content of methylmercury in this sample exceeded the US EPA daily limit almost two times and total mercury content exceeded Thai legal standard for freshwater fish almost 10 times. Content of arsenic reached approximately one half of the legal standard in mussels and about one tenth in the case of Threadfins, although the measured amount of arsenic in sediments was above the maximum allowable arsenic content in sediments according to the Czech decree (30 mg arsenic kg^{-1}). The Thai PCD sediment quality guideline, on the other hand, does not set any maximum levels of arsenic in sediments.

7.5.2.5 Loei

Samples of carnivorous Marble Goby that were caught in the area of Loei gold mine show elevated levels of mercury and methylmercury as well. Only in the case of omnivorous Snakehead fish (LOE29), the mercury content did not reach the Thai legal standard. On the other hand, Marble Goby (LOE19) exceeded the US EPA daily limit of methylmercury more than two times and consumption of just 27.3 g of this fish would be enough to exceed the daily allowable intake of methylmercury according to the US EPA limit. Arsenic content in fish did not reach the regulatory limits; although, sediments from this area exceed the US EPA regulatory standards for agricultural soils and the Czech auxiliary criteria too.

7.5.2.6 Map Ta Phut

The heavy industrialized area of Map Ta Phut shows elevated levels of mercury and methylmercury in tissues of collected fish samples (Goldsilk Seabream, Javelin Grunter, Needle fish, Snakehead fish) that belong mostly to the carnivorous type of fish. The amount of mercury in the samples varied between 0.042 – 1.027 mg total mercury kg^{-1} and 0.016 – 0.998 mg methylmercury kg^{-1}, respectively, and reaches the legal standard in all of them regardless of their type of diet. The place of origin and measured concentration of total mercury in the samples is shown in Figure 6. Daily intake of methylmercury is exceeded by all fish species, but not by mussels. Amount of fish or mussels to reach the US EPA daily intake of methylmercury limit varies between 6.1 – 375 g depending on the species. The most toxic is carnivorous Needlefish and the least toxic are mussels that feed on plankton and other microscopic organisms which are free-floating in the water. Arsenic content in some sediments exceeded the US EPA regulatory standard more than 180 times, although this fact did not reflect on arsenic content in fish samples, as arsenic in the samples did not reach the regulatory limits for arsenic in food.

7.5.2.7 Rayong IRPC industrial zone

Although the sample of mussels was taken near an industrial complex, the result of 0.028 mg THg kg^{-1} exceeded the Thai mercury limit for food only slightly. However, the legal standard for arsenic was, in this case, exceeded more than three times.

7.5.2.8 Praeksa

Samples from Praeksa come from the surrounding of a large municipal and hazardous waste landfill; therefore, the collected samples show elevated levels of mercury, but only slightly (0.021 mg THg kg^{-1} for PR3). All samples are within a range of the allowable weekly average intake of mercury and contents of methylmercury were below detection limits in all analyzed samples, and therefore, within the legal standard of US EPA as well. Arsenic content in fish was below Thai legal standard for food.

7.5.2.9 Prachinburi

Samples originated from Thap Lan National Park and Klong Yang Canal should have served as controls, being industry and pollution-free areas with expected low mercury levels; however, the results show otherwise. High contents of mercury and methylmercury, both higher than maximum allowable levels, were found in all samples (Snakehead fish, Marble Goby, Nile Tilapia) exceeding the Thai legal standards for food 6 – 28 times and the US EPA daily methylmercury intake standard 1.16 – 5 times. The highest concentration of both mercury and metylmercury was found in omnivorous Snakehead fish (PRN-2017-1) reaching 0.561 mg kg^{-1} and 499 mg kg^{-1}, respectively. Almost 90% of the mercury in the tissue of the Snakehead fish occurs as highly toxic methylmercury, which is consistent with the results of US EPA [144]. The source of pollution remains unknown, although a possible long-range transport and atmospheric deposition and accumulation of the mercury from neighboring polluted areas, like Prachinburi large Rojana industrial park, can be discussed.

7.5.2.10 Samut Sakhon

The content of measured elements in Samut Sakhon fish samples is generally low, although some of the fish species are carnivores. Threadfin, Asiatic Glassfish and the omnivorous Mullet species reached the Thai legal standard for total mercury in food. Threadfins also exceeded the US EPA daily intake limit for metylmercury 1.16 times. Arsenic in the fish tissues was present at levels about one fourth to one third of the legal standard, even though elevated levels of this element were found in some sediments.

7.5.2.11 Tha Tum

Although Tha Tum area is highly industrialized, the results of mercury in fish tissues are ambiguous and results are affected by the place of origin (see Figure 7). The content of total mercury varies between 0.006 – 0.517 mg mercury kg^{-1}, i.e. from levels close to the detection limit (Nile Tilapia, Shellfish) to levels exceeding legal standards for fish and seafood given by the US EPA, EU and Thai legal standards (Snakehead fish). All analyzed Snakehead fish samples were above regulatory standards for both total mercury and methylmercury as well. Thai legal standard for total mercury was exceeded more than 24 times and the US EPA daily mercury intake limit more than four times. Sediment samples do not show exceeded levels, except slightly

elevated levels of arsenic in TT1-7 sample (2.06 mg arsenic kg^{-1}) and significantly elevated levels of arsenic in the sample TT1-9 (25.9 mg arsenic kg^{-1}); although, this fact does not reflect on the content of arsenic in fish samples.

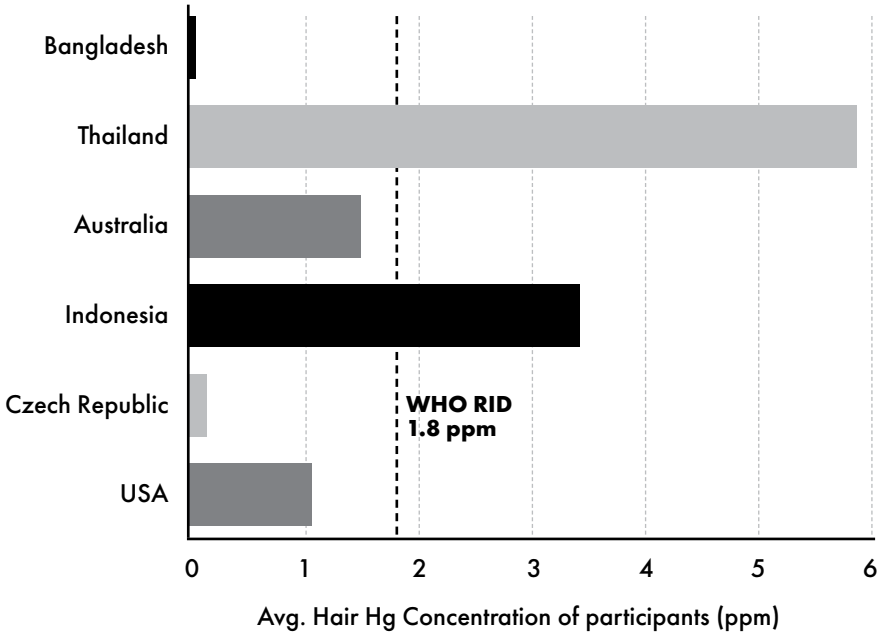
Figure 4 shows an average concentration of total mercury in individual fish species that reaches 0.573±0.454 mg kg^{-1} for carnivorous Needlefish (*Belonidae*) to 0.0090±0.0002 mg kg^{-1} for Catfish (*Clarias batrachus*). The most often represented fish was a Snakehead fish (n=13) that occurs in nine of the 11 studied areas and for its frequent occurrence, can be considered as one of the most frequently eaten fish. An average content of mercury in the Snakehead fish is 0.235±0.222 mg kg^{-1}; the median value of 0.168 mg kg^{-1}. 82% of the Snakehead fish samples exceed the Thai legal standard for mercury in food, which together with its frequent occurrence, may cause serious health effects.

The concentration of the total mercury in fish originating from different studied areas (Figure 5) shows that most toxic fish samples come from the highly industrialized Map Ta Phut area and Tha Tum area, but also from the area of Thap Lan National Park and Klong Yang Canal. The source of pollution in the case of Map Ta Phut and Tha Tum is obvious but in the case of the Thap Lan National Park and Klong Yang Canal, the source remains unknown. A possible long-range transport and atmospheric deposition and accumulation of the mercury from polluted areas, like Tha Tum industrial area, can be discussed. Figure 10 (Appendix 2) shows that prevailing winds in this area from October to February blow from Tha Tum in the direction of the Thap Lan National Park, which is about 50 km far away. Therefore, it may be the possible source of pollution in the National Park and its surroundings.

High content of mercury in the environment also results in a higher concentration of this element in hair. Analyses of mercury in the hair of Thais that were conducted by EARTH Association, and that will be separately published in the fall of 2017 (data given in Appendix 3), show that mercury in human hair samples originating from Tha Tum and Map Ta Phut are generally high. 65% of Map Ta Phut hair samples and 79% of Tha Tum hair samples have mercury content above US EPA standard for safe mercury level in hair that is set at 1 mg kg^{-1}. The content of mercury in hair from Map Ta Phut reaches 0.562 – 35.929 mg kg^{-1}, with mean and median values of 4.339±7.496 mg kg^{-1}, 1.598 mg kg^{-1}. In the case of Tha Tup, the content reaches 0.625 – 10.093 mg kg^{-1}, 1.815±1.695 mg kg^{-1} and 1.367 mg kg^{-1}, respectively. This fact is also supported by a chart below that is using data on mercury concentration in hair previously published by the Arnika Association (Figure 8) that, as a limit, uses converted WHO and the US EPA guidance values for mercury that are 1.8 mg kg^{-1} and 1.2 mg kg^{-1}, respectively [150].

The results of this study also confirm bioaccumulation and biomagnification of mercury higher in the food chain, resulting in the generally higher content of mercury in carnivorous fish. Correlation analyzes of mercury content with measured parameters (Table 2, Figure 2 – 3) show that fish length (both with and without tail fin) correlates significantly (0.854 and 0.851,

Figure 8: *Mercury concentration in hair. Complied by Amanda Giang and Julie van der Hoop [150].*



respectively) and weight of the fish correlates less (0.671). A strong correlation was found between total mercury content and methylmercury content (0.998), showing that methylation of mercury is one of the main biochemical pathways in studied fish species.

7.5.3 HEALTH RISK MANAGEMENT

Fish and other nutrient-rich foodstuff is recommended by the US EPA to be eaten two to three times per week, especially in the case of children and women of childbearing age. Although, the US EPA points out that it is essential to cautiously choose what kind of fish to consume. It is reported by many studies that mercury levels vary between different fish species and areas they come from. Big carnivorous fish from polluted areas are more likely to have much higher mercury levels compared to herbivorous fish from the same place. In general, King Mackerel, Shark, Tilefish, Marlin, swordfish, Orange Roughy and Big Eye Tuna belong to fish that should be avoided [151].

Mercury's high toxicity for humans and overall wildlife demands a worldwide initiative to reduce the mercury contamination of the environment. The results of this study show that mercury can contaminate even places with no sources of pollution nearby. In this case, the contamination pathway is most probably due to the long distance transport of atmospheric depositions and mercury persistence and accumulation in the environment [152, 153].

Within the EU, emissions of mercury are controlled by the Convention on Long-Range Transboundary Air Pollution (CLRTAP). However, it is aimed exclusively at airborne mercury. In order to really eliminate the negative impact of the use and release of mercury worldwide, an international convention has to be applied.

In February 2009, at the 25th meeting of the United Nations Environment Program (UNEP) Steering Committee, representatives from more than 140 countries agreed to the launch of a new Global Mercury Convention. Negotiations began in the fall of 2009; in October of 2013, the Minamata convention was signed at a diplomatic conference in Japan. Its purpose is to limit mercury inputs in production processes, international mercury trade, mercury emissions, secure storage, and address old environmental and mercury waste. Likewise, it should prevent not only the use of this toxic metal in the production of chlorine, but also in a wide range of medical devices. It should also contribute to the decrease of mercury emissions from coal power plants, waste incinerators and other sources using the best available technologies and procedures [154].

7.6 CONCLUSIONS

The main objective of this study is the evaluation of the contamination in different parts of Thailand by mercury and other elements (As, Zn, Cd, Sr, Ba, Cu, Co, Ni, Cr, Pb, Mo). These elements were determined in a set of fish and sediment samples taken during February and March of 2016 and February 2017. In collected samples only, mercury and arsenic were found at significant levels. Although arsenic in sediments exceeded legal standards quite often, its content in fish was elevated only in a few samples. Also, the occurrence of arsenic in water and especially marine organisms is not that crucial because most of the inorganic arsenic from the environment is transformed by the organisms into much less harmful organic compounds, like arsenobetaine and arsenocholine, that are often considered harmless. On the contrary, a main product of mercury methylation by organisms is highly toxic methylmercury. Another problem is high background concentrations of mercury in samples originating from unpolluted areas, which can be caused by a long-distance transport of mercury and its bioaccumulation and biomagnification further away from the original source of contamination. When it is counted with Thai average daily fish consumption per person of 0.061 kg and an average body weight of 60 kg, then the amount of methylmercury in almost all fish samples was above the US EPA oral reference dose for methylmercury, which is set at 0.0001 mg methylmercury per kg body weight-day (see Table 6 ^{*,C}). The most contaminated samples originated from Tha Tum and Map Ta Phut areas. The situation is all the more serious when we take into consideration that such contaminated fish are sometimes eaten up to two to three times a day, and are eaten even by children, pregnant women and are intended for the local market. Use of mercury in the industry and subsequent mercury contamination causes health, ecological, economical and ethical burdens and should be further regulated on a national and international level.

8. General conclusions

This series of reports demonstrates some emerging problems of pollution by POPs, VOCs and heavy metals in relation to the growing industry in Thailand. Some sites with a large concentration of industrial facilities create a broad and exhaustive picture of POPs and heavy metals pollution. Detailed descriptions of detected pollution for particular hot spot areas are presented below.

8.1 ORGANOCHLORINE PESTICIDES AND TECHNICAL PCBs – GENERAL CONCLUSION FOR ALL HOT SPOTS

Levels of organochlorine pesticides and indicator PCBs were generally low in most of the samples; therefore, we don't highlight this observation in conclusions for specific localities. The origin of most of the PCB congeners is related to their unintentional production in industrial processes and improper waste management. Mirex residue was measured in one sediment sample from Tha Tum at a level slightly above LOQ. The occurrence of mirex is surprising because this pesticide has never been imported or used in Thailand according to the National Implementation Plan of the Stockholm Convention on POPs. It can be a consequence of long-range transport of this pollutant.

8.2 MAP TA PHUT

Measurable, but relatively low concentrations of PCDD/Fs and DL PCBs were found in fish, molluscs, and crustaceans. Two fish samples have HCB and HCHs concentrations higher than the Thai maximum residue limits and HCB concentrations in all egg samples are higher than the maximum residue limit in Thailand. Two egg samples exceed the maximum levels of PCDD/Fs and sum of PCDD/Fs + DL PCBs in the European Union. Moreover, concentrations of PCDD/Fs and DL PCBs are relatively high in the other egg samples. Also, high levels of PAHs were observed in egg samples, one of the egg samples had the second highest level of PAHs measured in eggs in this study. Eggs were the most contaminated organic matrix in the hot spot area.

The occurrence of chlorinated unintentionally produced persistent organic pollutants (HCB, PeCB, HCBD, HCHs, DL PCBs, and PCDD/Fs) is most probably caused by industrial facilities operated in the hotspot area, particularly by several chlorine production plants. These chlorinated compounds can be formed as by-products of industrial processes involving chlorine compounds. Moreover, some unintentional POPs could be produced in power plants of the industrial complex as one sample collected from a tank containing ash from a power plant that has higher level of DL PCBs. This result indicates a potential source of PCB contamination from the energy industry in the area. Dioxins can be formed as an unintentional by-product in chlor-alkali and VCM plants, as well as in other chemical processes, and waste disposal [91]. This assumption is supported by the fact that the fish with measurable PCDD/Fs levels were caught in the Chak Mak Canal or in its mouth to the sea. The canal is flowing around two factories producing chlorine, whose waste waters are probably discharged into the canal. All the fish samples with measurable PCB levels in the hotspot area were also

caught in the Chak Mak Canal; therefore, there is probably a source of PCB pollution around the canal.

The concentration of benzene exceeded the limits for ambient air (air quality standards) given by European legislation in all samples from Map Ta Phut (up to three times). The concentration of benzene in the measured locations is also significantly higher than in similar urban or suburban locations elsewhere in the world today. Concentrations of toluene and heptane are close to concentrations in other urban and suburban areas. Concentrations of chlorinated volatile organic compounds are significantly higher than those found in other urban or suburban locations elsewhere in the world. Substances emitted from industrial plants and transport can participate in the measured values in the cases of benzene, toluene and heptane. The source of chlorinated volatile organics compounds and ethylacetate is most likely industrial plants. Also, PCDD/Fs were measured in passive air samples from Map Ta Phut area, although the levels were low in comparison with some other locations in the world (see Chapter 4). The northernmost sampling site at the Map Ta Phut Hospital exhibits the highest burden, i.e. the determined PCDD/Fs and DL PCBs levels are about a quarter higher than at the other two sites in Map Ta Phut.

Increased concentrations of arsenic, mercury, zinc, copper, and chromium were found in downstream sediments in comparison with upstream in the Map Ta Phut hot spot area. Several sediment samples exceed three times the threshold of the Thai sediment quality criteria for the protection of benthic animals from mercury, zinc, cadmium, and copper. Sediment samples collected in the Map Ta Phut area are the most mercury inorganic samples we took in Thailand. Moreover, a heavy industrialized area of Map Ta Phut shows elevated levels of mercury and methylmercury in tissues of the collected fish. The amount of mercury in the samples reaches the legal standard in all of them. The amount of fish or mussels to reach the US EPA daily intake of methylmercury limit varies between 6.1 – 375 g depending on the species. Use of mercury in the industry and subsequent mercury contamination causes health, ecological, economical and ethical burdens, and should be further regulated.

8.3 SAMUT SAKHON

Soil and ash samples collected from the hotspot area have increased concentrations of PCDD/Fs, PCBs, and PAHs, indicating contamination from potential industrial sources. The levels of benzo(a)pyrene in soil samples exceed the pollution criteria for soils in the United States. Fish samples from the Samut Sakhon hot spot area show a generally low level of residues of organochlorine pesticides, but there is little contamination of fish by PCBs and PCDD/Fs. Levels of all POPs in fish samples were below the maximal levels in the European Union. Egg samples collected in the Samut Sakhon hotspot area contain unsafe levels of unintentionally produced POPs. One of the two egg samples from Samut Sakhon has concentrations of PCDD/Fs and PCDD/Fs + DL PCBs that are 33 folds and 19 folds higher than the maximal levels in eggs tolerable for the European market. Moreover, his egg sample also contains a concentration of PBDD/Fs without the maximal tolerable levels at all, but the level of these chemicals measured in the egg sample was the second highest level ever measured in chicken eggs globally.

Detected PCBs and PCCD/Fs pollution could be explained by unintentional POPs production during the combustion process in metallurgical plants and open burning in small waste "recycling" facilities at some locations in the hot spot area. From these sources also originate contamination of soil and ash samples. The contamination of the egg samples by PCDD/Fs, DL PCBs, and other unintentionally produced POPs most probably originate from waste burning in small waste "recycling" facilities placed nearby a household where the hens are kept. These facilities are common sources of unintentional POPs, as well as brominated compounds. To prevent the release of these chemicals, Samut Sakhon would require better organization and regulation of such facilities. Existing facilities should be replaced by more appropriate recycling facilities that utilize clean technologies for waste recycling. It would require assistance from the authorities and potentially the state. It could be included among other actions into the updated NIP for the Stockholm Convention on POPs.

High levels of heavy metals were found in sediments from the channels and in fishing ponds around factories in the Samut Sakhon hot spot area. Many sediment samples exceed three times the threshold of the Thai sediment

quality criteria for the protection of benthic animals from one of the traced heavy metals. Soil samples exceed Thai soil quality standards of soils for other purposes for arsenic, chromium, or lead. Unacceptable human health risks have been identified in a sediment sample for mercury and in two samples for lead. The content of measured elements in Samut Sakhon fish samples is generally low. Some fish samples reached the Thai legal standard for total mercury in food. The heavy metal pollution in the area most probably originates from small metallurgical plants and small waste "recycling" facilities.

8.4 THA TUM

There is some contamination of inorganic samples by unintentionally produced POPs, such as HCB, PCBs, PCDD/Fs, and PAHs. Organic samples were also polluted by unintentionally produced POPs. The HCB concentration in a sample of mussels exceeds the maximum residue level in Thailand. The egg sample collected in the hot spot area contains dangerous levels of POPs. Concentrations of β-HCH and HCB in the egg sample are higher than the maximum residue limits in Thailand and the concentrations of PCDD/Fs and PCDD/Fs + DL PCBs are significantly higher than the maximal levels tolerable in the EU. The egg sample is unsafe for human consumption due to the content of PCDD/Fs and DL PCBs.

The presence of unintentionally produced POPs in inorganic and organic samples can be explained by the release of these compounds from the industrial facilities in the hotspot area. They are produced unintentionally in chemical processes (e.g. bleaching of paper in the pulp and paper plant) or during incineration of fuels containing chlorine (e.g. coal and other fuels in power plants).

The concentration of benzene exceeded the limits for ambient air (air quality standards) given by European legislation in two of the three samples from Tha Tum (up to 1.7 times). The concentration of benzene in the measured locations was also significantly higher than in similar urban or suburban locations elsewhere in the world today. Concentrations of toluene and heptane are close to concentrations in other urban and suburban areas. See Chapter 4 for more information.

Sediments from the Tha Tum hot spot area show increased levels of arsenic, cadmium, and chromium. Some sediment samples exceeded three times the threshold of Thai sediment quality criteria for the protection of benthic animals from arsenic, cadmium, copper, and chromium. Moreover, some fish samples from the hot spot area have very high mercury levels. Mercury levels in some fish exceed legal standards for fish and seafood given by the US EPA, EU, and Thailand. All analyzed Snakehead fish samples were above regulatory standards for both total mercury and methylmercury as well. Thai legal standard for total mercury was exceeded more than 24 times. A possible source of mercury contamination is the coal power plant in the hot spot area, but there is variety of factories in the industrial park that could also contribute.

8.5 KHON KAEN

On the other hand, the one ash sample from Khon Kaen has significant concentrations of PCDD/Fs, PCBs, and PAHs. This sample found nextto a road near the power plant is probably fly or bottom ash from the power plant or from another industrial plant. If this assumption is true, there is an unequivocal source of PCDD/Fs and PCBs in the industrial area. It is in accordance with significant levels of PCDD/Fs, PCBs, PAHs, and other unintentionally produced POPs found in egg samples. Egg samples from the hot spot area exceeded the Thai maximum residue limit of HCB.

The presence of PCDD/Fs, PCBs, PAHs, and HCB at the hotspot area may have been unintentionally created in chlorine production facilities and as by-products during chlorine bleaching in pulp and paper mills. The US EPA's national dioxins source assessment reported that bleached pulp and paper production was ranked fourth overall as a source of dioxins contamination [46]; although, it can be due to historic use of chlorine [43]. A historical scientific survey conducted around the pulp and paper plant near Khon Kaen found high PCDD/Fs concentrations in sediments in 2006. The highest concentration of PCDD/Fs was found in sediment from the discharge point of the pulp and paper plant, which indicated PCDD/F contamination from the plant's operations. Our results show that PCDD/F contamination

is still present in the food chain. For a better understanding of the PCDD/F contamination and its proliferation in the area, more measurements are needed.

Increased levels, mainly of arsenic and cadmium, were found in sediment samples in the Khon Kaen hot spot area. Few sediment samples exceed three times the threshold of Thai sediment quality criteria for the protection of benthic animals from arsenic and cadmium. One sediment sample has increased the concentration of mercury. Fish samples also show elevated mercury levels. Methylmercury in fish reaches the US EPA legal standard for daily methylmercury consumption in few samples. A potential source of mercury is a coal power plant in the hot spot area, which is corroborated by the fact that the fish samples were taken from an outflow of a paper and pulp factory and a coal power plant.

8.6 LOEI

The location below the dam of the settling pond in the Loei hot spot area shows increased concentrations of arsenic, cadmium, and copper. Several sediment samples exceeded three times the threshold of the Thai sediment quality criteria for the protection of benthic animals for arsenic, cadmium and copper. Increased concentrations of metals are found in places where the probable leakage of water from the settling pond is identified. Samples of carnivorous fish that were caught in the area of the Loei gold mine show elevated levels of mercury and methylmercury as well. One fish sample exceeded the US EPA daily limit of methylmercury more than two times. Consumption of just 27.3 g of this fish is enough to exceed the daily allowable intake of methylmercury according to the US EPA limit.

8.7 PRAEKSA

The first two sediment samples (PKS 1 and PKS 2) collected in the hotspot area in November 2015 were analyzed for the content of 16 PAHs only among POPs. Measured levels of 186 and 285 μg/kg DW of PAHs in two sediment samples from Praeksa were rather low in comparison with some other hot spots and none of the PAHs exceeded pollution criteria set in either Thailand or in the Czech Republic. Naphthalene had the highest concentrations among PAHs in both samples.

The most significant levels of POPs were measured in a pooled egg sample from Praeksa in which PCDD/Fs exceeded the EU standard set for eggs. Levels of PCDD/Fs and DL PCBs in an egg sample from Praeksa exceeded the EU standard for eggs almost twice.

Sediment samples collected around the landfill in the Praeksa hot spot area show increased concentrations of arsenic, zinc, cadmium, and copper. The highest concentrations of heavy metals were found in a canal along the landfill wall and then along the fish pond. Many sediment samples exceeded three times the threshold of Thai sediment quality criteria for the protection of benthic animals from arsenic, zinc, cadmium, or copper. Fish samples show slightly elevated levels of mercury. All fish samples are within a range of an allowable weekly average intake of mercury and methylmercury contents are below detection limits and within the legal standards of the US EPA in all analyzed samples.

The highest risk at the locality is the leakage of hazardous leachate from the landfill. The highest concentration of heavy metals were found in a channel where water flows in the direction to the dump site in high tide and rainy season; water flows naturally out from the dump site in low tide and dry season. Ongoing research should be carried out to detect the spread of contamination resulting in any toxic threats to human health and the environment in the future. In general, landfill leachates present a risk to the environment due to their composition. A leachate collection and treatment system should be installed at the landfill site.

8.8 KHAO HIN SORN

High levels of arsenic, cadmium, and chromium were found in sediment collected at the effluent discharge point from the industrial park. Increased levels of arsenic and mercury were found in wetlands used in agriculture,

which are expected to receive effluent from the eucalyptus plantation. Several sediment samples exceeded three times the threshold of Thai sediment quality criteria for the protection of benthic animals for arsenic, cadmium, copper, or chromium. Both mercury and methylmercury reached the maximum allowable levels in the tissue of analyzed omnivorous fish.

Smelting factories, dumping grounds of hazardous waste, or an outflow of wastewater have been placed in the vicinity of the sampling sites, all of which can be a source of elevated content of heavy metals in the environment. Further attention should be focused on the effluent discharge drainage near the industrial park.

8.9 KOH SAMUI

Two egg samples from the Koh Samui hot spot area have the lowest levels of PCDD/Fs and DL PCBs from all egg samples collected in Thailand. Our very limited investigation of this hot spot does not corroborate potential POP pollution from the large municipal solid waste landfill and an abandoned waste incinerator.

8.10 SARABURI

One egg sample from the Saraburi hot spot area has concentrations of PCDD/Fs and DL PCBs at a troubling level exceeding several times the maximal levels tolerable in the EU. This very limited result could indicate pollution of unintentionally produced POPs due to the operation of cement kilns in the hot spot area; however, it can also be the result of open burning of waste.

8.11 RAYONG IRPC INDUSTRIAL ZONE

Sediments around the IRPC Industrial Zone in Rayong Province show increased concentrations of cadmium. All sediment samples exceeded three times the threshold of Thai sediment quality criteria for the protection of benthic animals from cadmium. Ongoing research should be carried out to detect any threats resulting from the content of cadmium.

8.12 BACKGROUND LOCALITIES: KLONG DAN,CHANTHABURI, THAP LAN NATIONAL PARK AND KLONG YANG CANAL

Samples originated from Klong Dan, Chanthaburi, Thap Lan National Park and Klong Yang Canal should have served as control measurements, since these are industry and pollution-free areas with expected low mercury levels. However, the results show otherwise. Analyses of samples showed elevated levels of mercury and methylmercury in the sample of carnivorous fish collected at Klong Dan. Content of methylmercury in this sample exceeded the US EPA daily limit almost two times and total mercury content exceeded Thai legal standard for freshwater fish almost 10 times. The mercury content in the omnivorous fish sample from Chanthaburi exceeds Thai legal standards for freshwater fish almost 16 times. High content levels of mercury and methylmercury, both higher than maximum allowable levels, were found in all fish samples from the Thap Lan National Park and Klong Yang Canal exceeding the Thai legal standards for food 6 to 28 times and US EPA daily methylmercury intake standard 1.16 to 5 times. These localities were chosen as control sites; however, it is obvious that biomagnification of mercury can be a problem even in unpolluted areas. In these cases, it may be caused by a long transport deposition of mercury likely from industrial areas.

9. Annexes

9.1 ANNEX 1 – SUMMARIZED RESULTS OF ANALYSES FOR POPS

9.1.1 MAP TA PHUT

Tab. 1: *Complete results of inorganic samples from Map Ta Phut hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 7 PCBs[1)] [µg/kg DW]	HCB [µg/kg DW]	PeCB [µg/kg DW]	∑ 3 HCHs[2)] [µg/kg DW]	∑ DDTs[3)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[4)] [µg/kg DW]	Endosulfan[5)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ HBCDs[6)] [µg/kg DW]	∑ 16 PBDEs[7)] [µg/kg DW]]	Naphthalene [µg/kg DW]
MTP 1-1	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 1-2	ash	<LOD	**0.0042**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MTP 1-6	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 1-7	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 1-8	sediment	NA	NA	**0.258**	**0.079**	**0.075**	<LOD	**0.647**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
MTP 1-12	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 1-13	sediment	NA	NA	**0.167**	<LOD	**0.025**	<LOD	**0.326**	<LOD	<LOD	<LOD	<LOD	<LOD	**0.05**	<LOD	**0.5**

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 7 PCBs[1] [µg/kg DW]	HCB [µg/kg DW]	PeCB [µg/kg DW]	∑ 3 HCHs[2] [µg/kg DW]	∑ DDTs[3] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[4] [µg/kg DW]	Endosulfan[5] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ HBCDs[6] [µg/kg DW]	∑ 16 PBDEs[7] [µg/kg DW]]	Naphthalene [µg/kg DW]
MTP 1-14	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 1-15	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 1-16	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.5**
MTP 1-17	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**1.7**
MTP 2-2	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 2-3	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.6**
MTP 2-5	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.7**
MTP 2-6	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	**0.6**
MTP 2-6 (1)	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 2-14	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA
MTP 2-15	sediment	NA	NA	<LOD	<LOD	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA

1) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

2) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

3) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

4) Heptachlor epoxide is sum of isomers cis and trans.

5) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

6) ∑ HBCDs is sum of isomers α-HBCD, β-HBCD, and γ-HBCD.

7) ∑ 16 PBDEs is sum of BDE 28, BDE 47, BDE 49, BDE 66, BDE 85, BDE 99, BDE 100, BDE 153, BDE 154, BDE 183, BDE 196, BDE 197, BDE 203, BDE 206, BDE 207, and BDE 209.

9.1.2 SAMUT SAKHON

Tab. 2: *Complete results of inorganic samples from Samut Sakhon hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Endosulfan[6] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	Naphthalene [µg/kg DW]	∑ 16 PAHs[7] [µg/kg DW]
SMS 1-1	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-3	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-5	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-6	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-8	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-8	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-9	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-10	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 1-11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**1.4**	NA
SMS 1-14	sediment	**12**	**1.54**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.5**	NA
SMS 2-2	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-4	ash	**40.5**	**5.67**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SMS 2-6	sediment	**8.05**	**1.71**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Endosulfan[6] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	Napthalene [µg/kg DW]	∑ 16 PAHs[7] [µg/kg DW]
SMS 2-7	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-10	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
SMS 2-12	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA
A3	soil	**35.2**	**5.72**	**1.2**	**7.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1747**
A2	soil	**12.8**	**0.001**	**1.06**	**1.06**	NA	NA	NA	NA	NA	NA	NA	NA	NA	**488**
A1	ash	**1.9**	**0.27**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**3210**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) Heptachlor epoxide is sum of isomers cis and trans.

6) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

7) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

9.1.3 THA TUM

Tab. 3: *Complete results of inorganic samples from Tha Tum hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1] [µg/kg DW]	∑ 7 PCBs[2] [µg/kg DW]	HCB [µg/kg DW]	TeClB [µg/kg DW]	1,2,3,4-TeClB [µg/kg DW]	QClB [µg/kg DW]	∑ 3 HCHs[3] [µg/kg DW]	∑ DDTs[4] [µg/kg DW]	Heptachlor [µg/kg DW]	Aldrin [µg/kg DW]	Oktachlorstyren [µg/kg DW]	Heptachlor epoxide[5] [µg/kg DW]	Chlordan[6] [µg/kg DW]	Oxychlordan [µg/kg DW]	Metoxychlor [µg/kg DW]	Mirex [µg/kg DW]	Endosulfan[7] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[8] [µg/kg DW]
TT 1-1	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-2	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-3	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-4	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-5	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-6	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-7	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-8	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-9	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-10	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 1-11	sediment	NA	NA	**0.28**	**0.28**	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
TT 2-1	sediment	NA	NA	<LOD	<LOD	<LOD	NA	NA	NA	<LOD	<LOD	<LOD	NA	NA	<LOD	NA	NA	NA	NA	<LOD	<LOD	<LOD	NA
S1	sediment	**1.6**	**0.013**	<LOD	<LOD	**0.23**	<LOD	<LOD	<LOD	<LOD	**0.44**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**137**
S2	sediment	**1.27**	**0.026**	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**631**
S3	sediment	**3.76**	**0.022**	NA	NA	**0.22**	<LOD	<LOD	<LOD	<LOD	**0.14**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	**0.32**	NA	NA	NA	**576**
S4	sediment	**0.22**	**0.048**	NA	NA	**0.30**	<LOD	<LOD	<LOD	<LOD	**2.2**	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA	NA	NA	**85**
S5	ash	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**6683**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) Heptachlor epoxide is sum of isomers cis and trans.

6) Chlordan is sum of isomers cis and trans.

7) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

8) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

9.1.4 KHON KAEN

Tab. 4: *Complete results of inorganic samples from Khon Kaen hotspot area*

Name	Matrix	PCDD/Fs [ng WHO-TEQ/kg DW]	DL PCBs [ng WHO-TEQ/kg DW]	∑ 6 PCBs[1)] [µg/kg DW]	∑ 7 PCBs[2)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[3)] [µg/kg DW]	∑ DDTs[4)] [µg/kg DW]	Heptachlor [µg/kg DW]	Heptachlor epoxide[5)] [µg/kg DW]	Endosulfan[6)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[7)] [µg/kg DW]
KK 3	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 4	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 7	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 8	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 9	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 10	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 11	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 13	sediment	NA	NA	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
KK 5	ash	**0.9**	**1.04**	**0.29**	**0.33**	NA	NA	NA	NA	NA	NA	NA	NA	**310**

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 7 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, and PCB 180.

3) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

4) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

5) Heptachlor epoxide is sum of isomers cis and trans.

6) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

7) ∑ 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

9.1.5 PRAEKSA

Tab. 5: *Results of inorganic samples from Praeksa hotspot area. Complete results are listed in the annex.*

Name	Matrix	∑ 6 PCBs[1)] [µg/kg DW]	HCB [µg/kg DW]	∑ 3 HCHs[2)] [µg/kg DW]	∑ DDTs[3)] [µg/kg DW]	Hepta-chlor [µg/kg DW]	Hepta-chlor epoxide[4)] [µg/kg DW]	Endosul-fan[5)] [µg/kg DW]	Dieldrin [µg/kg DW]	Endrin [µg/kg DW]	∑ 16 PAHs[6)] [µg/kg DW]
PKS1	sediment	NA	NA	NA	NA	NA	NA	NA	NA	NA	**186**
PKS 2	sediment	NA	NA	NA	NA	NA	NA	NA	NA	NA	**285**
PRE 1-1	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
PR 1	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
PR 2	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
PR 4	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
PR 5	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA
PR 8	sediment	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	NA

1) ∑ 6 PCBs is sum of congeners PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, and PCB 180.

2) ∑ 3 HCHs is sum of isomers α-HCH, β-HCH, and γ-HCH.

3) ∑ DDTs is sum of residues p,p'-DDT, o,p'-DDT, p,p'-DDE, o,p'-DDE, p,p'-DDD, and o,p'-DDD.

4) Heptachlor epoxide is sum of isomers cis and trans.

5) Endosulfan is sum of isomers α-endosulfan and β-endosulfan.

6) 16 PAHs is sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd) pyrene, benzo(ghi)perylene, and dibenzo(a,h)anthracene.

9.1.6 RESULTS FOR ORGANIC SAMPLES – ALL HOT SPOTS

Results for all organic samples, like eggs, fish or mussels are summarized in the table included in chapters 2 and 3 as they were measured at levels above LOQ for all samples analyzed.

9.2. ANNEX 2 – RESULTS OF ANALYSES FOR HEAVY METALS

Table 1: *Results of a chemical analysis for the collected samples. The content of elements is given in mg/kg of dry matter. <LOD: analyte concentration was below limit of detection. NA: not analyzed.*

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
LOE 1	6.695	0.004	40.780	4.973	851.402	41.774	NA
LOE 2	2.136	0.035	41.739	0.971	32.033	21.355	NA
LOE 3	5.006	0.015	36.346	0.982	22.593	16.699	NA
LOE 4	12.915	0.029	30.494	2.951	149.518	18.690	NA
LOE 5	25.688	0.032	48.134	4.912	107.073	23.576	NA
LOE 6	19.215	0.029	52.279	4.932	99.625	17.755	NA
LOE 7	39.178	0.038	93.870	15.326	113.027	24.904	NA
LOE 8	162.166	<LOD	15.699	39.246	<LOD	<LOD	NA
LOE 9	10.960	0.022	51.813	1.993	121.562	36.867	NA
LOE 11	1.186	0.021	22.736	0.989	40.530	37.564	NA
LOE 12	3.801	0.042	36.845	0.996	62.737	38.837	NA
LOE 20	0.188	0.017	21.799	0.991	5.945	15.854	NA
LOE 21	0.500	0.038	54.967	<LOD	16.990	44.973	NA
LOE 22	0.499	0.013	21.965	0.998	9.984	15.974	NA
LOE 23	1.873	0.036	50.266	0.986	62.093	24.640	NA

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
LOE 24	22.129	0.022	59.988	7.998	73.985	48.990	NA
LOE 25	3.376	0.034	56.604	2.979	63.555	28.798	NA
LOE 26	0.825	0.020	33.811	0.994	13.922	13.922	NA
LOE 27	1.491	0.046	91.469	1.988	29.827	21.873	NA
LOE 28	0.795	0.030	65.554	0.993	137.068	30.791	NA
LOE 1 C	9.300	<LOD	168.617	9.919	10841.103	29.756	NA
LOE 1 D	42.231	0.002	14.781	19.708	847.458	17.737	NA
KK 3	0.139	0.017	9.901	<LOD	13.861	35.644	NA
KK 4	0.470	0.004	10.767	1.958	1.958	11.746	NA
KK 7	1.139	0.011	25.097	<LOD	7.722	16.409	NA
KK 8	0.233	0.461	44.643	0.970	14.557	25.233	NA
KK 9	1.123	0.027	19.656	0.936	12.168	19.656	NA
KK 10	47.842	0.036	46.194	1.848	12.010	20.325	NA
KK 11	25.958	0.037	38.938	2.995	14.976	31.949	NA
KK 13	0.850	NA	18.782	<LOD	5.931	15.817	NA
MTP 1-1	1.530	0.032	64.070	1.830	14.644	3.661	NA
MTP 1-6	6.817	0.128	53.564	<LOD	26.295	13.635	NA
MTP 1-7	27.719	0.534	742.004	2.132	22.388	33.049	NA
MTP 1-8	2.298	0.026	133.065	<LOD	5.744	5.744	NA

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
MTP 1-12	2.332	0.020	38.865	<LOD	3.887	7.773	NA
MTP 1-13	0.213	0.011	30.930	<LOD	9.666	5.799	NA
MTP 1-14	19.861	0.351	415.094	0.993	29.791	35.750	NA
MTP 1-15	3.072	0.052	59.642	1.807	<LOD	15.362	NA
MTP 1-16	0.680	0.017	33.042	<LOD	7.775	15.549	NA
MTP 1-17	1.571	0.963	1062.242	2.945	23.562	56.941	NA
MTP 2-2	3.033	0.049	41.706	1.896	14.218	7.583	NA
MTP 2-3	1.266	0.383	389.559	1.977	7.910	11.865	NA
MTP 2-5	0.555	0.038	21.795	1.981	7.926	9.907	NA
MTP 2-6	0.299	0.079	55.866	0.998	3.990	7.981	NA
MTP 2-6 (1)	10.025	1.479	349.913	0.964	16.387	24.099	NA
MTP 2-14	NA	0.004	8.652	<LOD	1.923	2.884	NA
MTP 2-15	8.296	0.010	2.894	1.929	0.965	0.965	NA
TT 1-1	3.562	0.070	42.541	0.989	43.530	89.038	3.880
TT 1-2	25.819	0.083	115.194	2.979	82.423	143.992	3.580
TT 1-3	38.000	0.035	60.000	4.000	42.000	141.000	1.780
TT 1-4	42.367	0.098	36.985	2.999	25.990	82.967	3.740
TT 1-5	0.216	0.082	92.429	5.900	49.164	316.618	5.200
TT 1-6	45.894	0.043	122.473	3.888	28.188	141.913	3.910

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
TT 1-7	2.060	0.043	38.382	12.170	44.935	402.546	5.730
TT 1-8	0.578	0.151	17.354	1.928	23.139	61.705	2.980
TT 1-9	25.902	0.038	31.879	1.992	12.951	31.879	NA
TT 1-10	0.137	0.007	5.877	1.959	7.835	11.753	NA
TT 1-11	0.292	0.024	17.520	1.947	11.680	21.413	NA
TT 2-1	47.772	0.035	18.943	4.510	23.453	128.992	NA
S1	NA	0.026	NA	NA	NA	NA	NA
S2	NA	0.018	NA	NA	NA	NA	NA
S3	NA	0.029	NA	NA	NA	NA	NA
S4	NA	0.020	NA	NA	NA	NA	NA
S5	3.990	0.069	NA	0.295	NA	NA	20.600
SMS 1-1	22.091	0.066	54.228	2.542	23.725	42.366	NA
SMS 1-3	27.586	0.041	82.759	2.956	23.645	40.394	NA
SMS 1-5	24.570	0.058	212.940	2.048	21.499	46.069	NA
SMS 1-6	24.866	0.052	843.535	1.913	19.128	35.386	NA
SMS 1-8	31.930	0.041	46.312	2.573	15.437	45.455	NA
SMS 1-8	24.014	0.044	57.873	3.991	20.954	68.849	NA
SMS 1-9	32.392	0.037	59.067	3.938	16.736	54.145	NA
SMS 1-10	23.548	0.055	53.964	2.943	17.661	45.133	NA

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
SMS 1-11	0.975	0.098	351.014	1.950	68.253	87.754	NA
SMS 1-14	0.430	1.327	767.575	1.793	426.829	30.488	16.141
SMS 2-2	117.958	0.048	189.022	3.204	37.377	50.192	NA
SMS 2-6	9.138	2.392	1650.504	18.650	792.615	65.274	484.894
SMS 2-7	40.353	0.070	544.991	3.921	133.307	48.030	NA
SMS 2-10	1.256	10.318	233.207	1.993	49.831	51.824	NA
SMS 2-11	11.017	0.155	NA	NA	NA	NA	NA
SMS 2-12	35.280	NA	371.423	2.940	100.941	203.842	NA
A1	5.220	0.098	NA	4.060	NA	NA	2197.000
A2	1.890	0.046	NA	<LOD	NA	NA	58.500
A3	28.200	0.245	NA	3.980	NA	NA	18990
SMS 2-1	NA	NA	6088.924	19.673	1760.771	1701.751	373.795
PRE 1-1	19.650	0.026	68.776	3.930	16.703	38.318	NA
PR 1	51.944	0.031	69.923	4.924	26.591	69.923	NA
PR 2	39.790	0.042	96.042	3.880	44.626	48.506	NA
PR 4	41.377	0.023	62.905	4.625	18.501	59.204	NA
PR 5	23.666	0.036	121.063	3.641	25.487	77.371	NA
PR 8	45.660	0.087	1087.384	3.936	99.390	66.916	NA
KHS 1	4.314	0.031	32.821	1.875	14.066	30.945	NA

Sample code	Arsenic	Mercury	Zinc	Cadmium	Copper	Chromium (total)	Lead
KHS 2	21.869	0.250	28.827	0.994	11.928	15.905	NA
KHS 3	2.048	0.014	7.803	3.902	11.705	37.066	NA
KHS 4	136.389	NA	58.335	26.696	55.369	437.018	NA
KHS 4a	0.455	0.095	22.727	22.727	68.182	45.455	NA
KHS 5	5.021	0.029	13.519	0.966	206.643	67.594	NA
KHS 7	4.077	0.029	29.121	1.941	10.678	28.150	NA
KHS 8	0.858	0.017	10.148	2.768	33.210	105.166	NA
KHS 9	0.410	0.025	6.841	0.977	5.864	22.478	NA
KHS 2-2	1.285	0.029	9.046	1.809	23.521	4.523	NA
KHS 2-5	1.381	0.159	77.661	1.918	199.425	29.722	NA
KHS 2-7	NA	0.017	21.743	2.836	4.727	4.727	NA
KHS 2-8	0.996	0.019	30.268	<LOD	13.669	61.511	NA
IRPC 2	3.928	0.073	56.952	1.964	7.855	9.819	NA
IRPC 3	2.148	0.034	163.054	1.953	5.858	10.740	NA
IRPC 6	2.300	0.009	18.206	1.916	5.749	4.791	NA
CHA 1	0.060	0.022	31.834	1.990	23.876	3.979	NA

9.3 ANNEXES TO THE MERCURY IN FISH REPORT

9.3.1 MAPS: PROVINCES

Figure 1: Chachoengsao Province

Figure 2: Khon Kaen Province

Picture 3: Loei Province

Figure 4: Prachinburi Province

Figure 5: Rayong Province

Figure 6: Samut Prakan Province

Figure 7: Samut Sakhon Province

Figure 8: Chanthaburi Province

Figures 1 – 8: Maps by NordNordWest WikiMedia

9.3.2 FISH SPECIES (PHOTOS)

Figure 9: Asiatic Glassfish

Figure 10: Climbing Perch

Figure 11: Giant Snakehead

Figure 12: Hampala Barb

Figure 13: Mullet

Figure 14: Needle Fish

Figure 15: Silver Barb

Figure 16: Snakehead Fish

Figure 17: Snakeskin Gourami

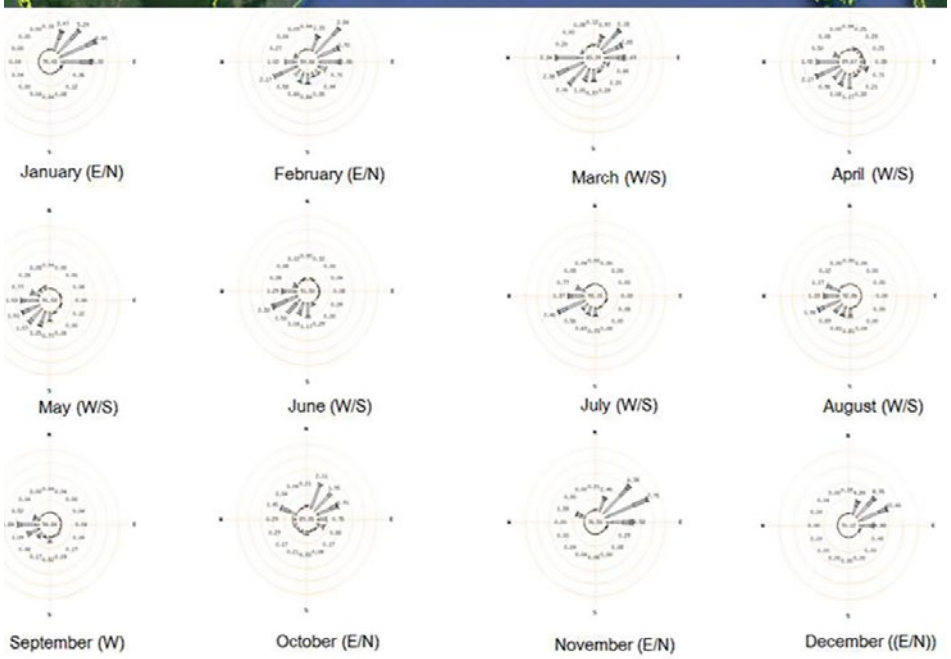
Figure 18: Threadfins

Figure 19: Walking Catfish

Figures 9 – 19: Photos by Arnika Association and EARTH 2016/2017.

9.3.3 MAPS AND WIND ROSES

Figure 9: *Comparison of windrose graphs (Rayong, Huay Pong Station) of the area with mutual geographical location of Map Tha Put and Chantaburi.*



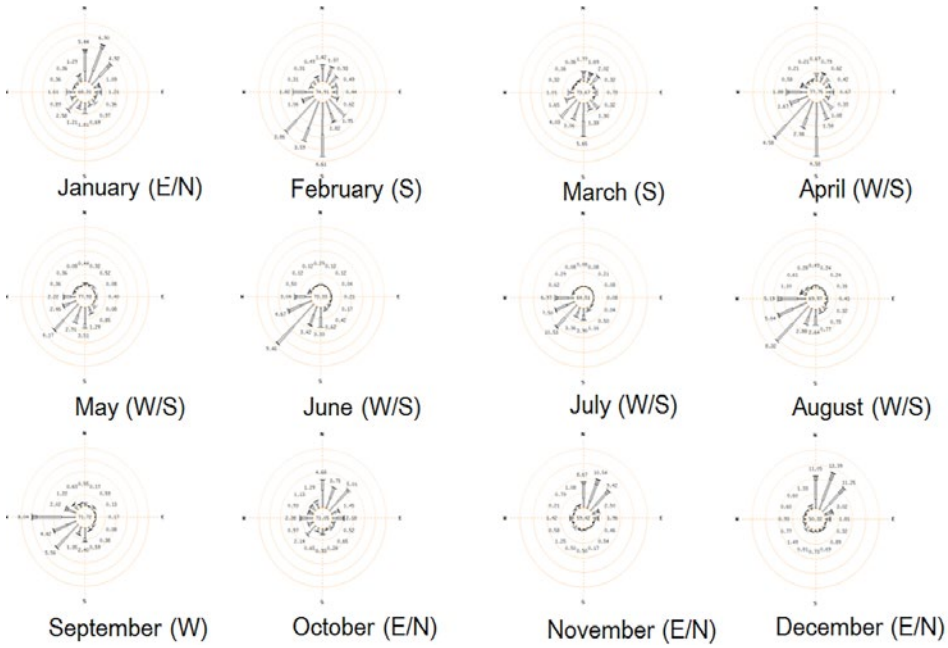
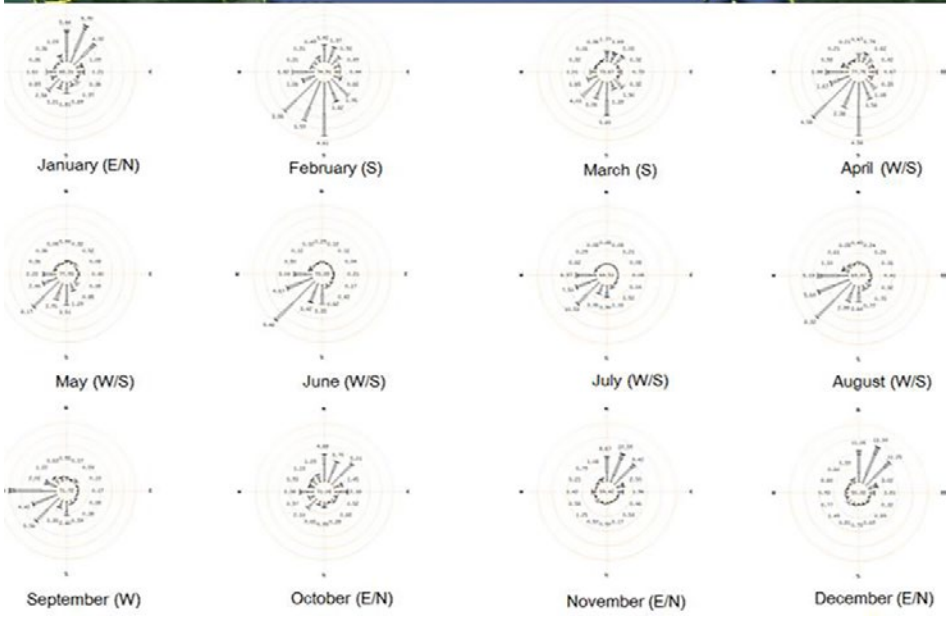
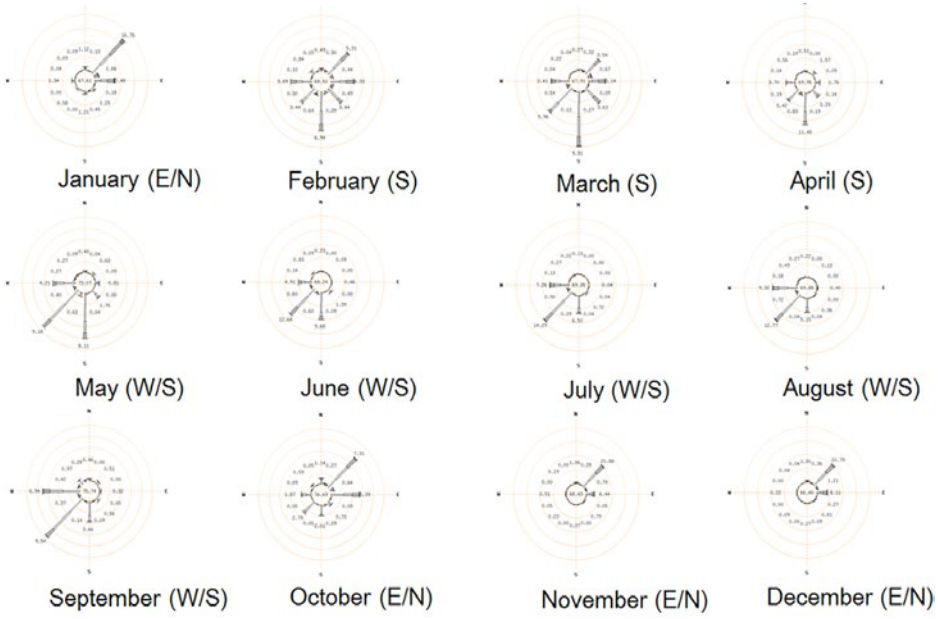


Figure 10: *Comparison of windrose graphs (Kabinburi district, Prachinburi province) of the area with mutual geographical location of Tha Tum and Thap Lap National Park.*





9.3.4 THE MERCURY CONTENT IN HUMAN HAIR COLLECTED FROM DIFFERENT COMMUNITIES IN THAILAND

The mercury content in human hair collected from different communities in Thailand. Research was conducted by EARTH Association and will be published separately in September 2017. THA1 samples originating from Map Ta Phut area, THA2 from Tha Tum area.

Sample Code	Community	Mercury mg kg^{-1}	Sample Code	Community	Mercury mg kg^{-1}
THA-1-Hair-01	Krok Yai Cha	1.144	THA-2-Hair-01	Moo 1, Ban Tha Tum	4.472
THA-1-Hair-02	Wat Maptaphut	29.070	THA-2-Hair-02	Moo 1, Ban Tha Tum	1.393
THA-1-Hair-03	Wat Maptaphut	0.696	THA-2-Hair-03	Moo 4, Ban Hua Loh	1.346
THA-1-Hair-04	Wat Maptaphut	0.596	THA-2-Hair-04	Moo 3, Ban Lang Thum	1.026
THA-1-Hair-05	Soi Prapa 2	1.610	THA-2-Hair-05	Moo 3, Ban Lang Thum	2.636
THA-1-Hair-06	Soi Prapa 2	6.196	THA-2-Hair-06	Moo 4, Ban Hua Loh	1.805
THA-1-Hair-07	Soi Prapa 2	0.893	THA-2-Hair-07	Moo 4, Ban Hua Loh	0.725
THA-1-Hair-08	Wat Maptaphut	4.132	THA-2-Hair-08	Moo 3, Ban Lang Thum	0.776
THA-1-Hair-09	Wat Maptaphut	12.512	THA-2-Hair-09	Moo 4, Ban Tha Bung Kan, Haad Nang Kaew	2.399
THA-1-Hair-10	Wat Maptaphut	0.956	THA-2-Hair-10	Moo 2, Ban Haad Sung, Haad Nang Kaew	1.328
THA-1-Hair-11	Wat Maptaphut	7.414	THA-2-Hair-11	Moo 6, Ban Wang Ka Pong	1.656
THA-1-Hair-12	Noen Phra	0.687	THA-2-Hair-12	Moo 6, Ban Haad Ma Kok	1.231
THA-1-Hair-13	Laem Sa Nguan	1.892	THA-2-Hair-13	Moo 7, Ban Haad Ma Kok	1.855
THA-1-Hair-14	Laem Sa Nguan	1.328	THA-2-Hair-14	Moo 7, Ban Haad Ma Kok	1.085
THA-1-Hair-15	Takuan-Ao-pradoo	1.196	THA-2-Hair-15	Moo 7, Ban Haad Ma Kok	1.082

Sample Code	Community	Mercury mg kg^{-1}	Sample Code	Community	Mercury mg kg^{-1}
THA-1-Hair-16	Takuan-Ao-pradoo	2.839	THA-2-Hair-16	Moo 6, Ban Wang Ka Pong	4.564
THA-1-Hair-17	Takuan-Ao-pradoo	1.120	THA-2-Hair-17	Moo 6, Ban Wang Ka Pong	1.076
THA-1-Hair-18	Takuan-Ao-pradoo	4.287	THA-2-Hair-18	Moo 3, Ban Lang Thum	1.412
THA-1-Hair-19	Takuan-Ao-pradoo	0.906	THA-2-Hair-19	Moo 3, Ban Lang Thum	1.387
THA-1-Hair-20	Takuan-Ao-pradoo	1.278	THA-2-Hair-20	Moo 3, Ban Lang Thum	10.093
THA-1-Hair-21	Takuan-Ao-pradoo	1.828	THA-2-Hair-21	Moo 5, Ban Taam	0.668
THA-1-Hair-22	Takuan-Ao-pradoo	35.292	THA-2-Hair-22	Moo 5, Ban Taam	1.579
THA-1-Hair-23	Takuan-Ao-pradoo	0.883	THA-2-Hair-23	Moo 5, Ban Wung Bua Tong	1.723
THA-1-Hair-24	Takuan-Ao-pradoo	1.762	THA-2-Hair-24	Moo 4, Ban Wung Bua Tong	1.097
THA-1-Hair-25	Nong Tungmay	2.193	THA-2-Hair-25	Moo 4, Ban Wung Bua Tong	0.836
THA-1-Hair-26	Lao Market	1.892	THA-2-Hair-26	Moo 4, Ban Wung Bua Tong	1.155
THA-1-Hair-27	Lao Market	1.100	THA-2-Hair-27	Moo 4, Ban Wung Bua Tong	1.920
THA-1-Hair-28	Lao Market	0.562	THA-2-Hair-28	Moo 4, Ban Wung Bua Tong	1.604
THA-1-Hair-29	Lao Market	0.874	THA-2-Hair-29	Moo 4, Ban Wung Bua Tong	0.964
THA-1-Hair-30	Lao Market	1.585	THA-2-Hair-30	Moo 4, Ban Wung Bua Tong	0.643
THA-1-Hair-31	Lao Market	1.325	THA-2-Hair-31	Moo 4, Ban Wung Bua Tong	2.227
THA-1-Hair-32	Lao Market	9.914	THA-2-Hair-32	Moo 4, Ban Wung Bua Tong	1.130
THA-1-Hair-33	The mouth of the Takuan Canal	3.550	THA-2-Hair-33	Moo 4, Ban Wung Bua Tong	2.176
THA-1-Hair-34	Krok Yai Cha	4.007	THA-2-Hair-34	Moo 5, Ban Taam	0.625

9.3.5 ADVISORY CHART AND RECOMMENDATIONS OF US EPA FOR FISH CONSUMPTION

Source of the advisory chart: [151].

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PHOTOS


MAP TA PHUT


KATO
TSK
60


SAMUT SAKHON


LONGLITE


RAYONG IRPC


THA TUM


SARABURI


LOEI


KHAO HIN SORN


PRAEKSA


KHON KAEN


KLONG DAN

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