Developments in Ecosystems, volume 1
Edited by M.H. Wong

Chapter 8

Assessment of Risks to the Mai Po/Inner Deep Bay Ramsar Site due to Environmental Contaminants

P.K.S. Lam and M.H.W. Lam

Centre for Coastal Pollution and Conservation, Department of Biology and Chemistry, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong SAR, People's Republic of China

Abstract. Within the Mai Po/Inner Deep Bay Ramsar site of Hong Kong, relatively high levels of trace metals and persistent organic contaminants were found in the sediments and biota. Levels of polychlorinated dibenzodioxins and dibenzofurans in the sediments from the Mai Po Marshes Nature Reserve were measured. When expressed on a toxicity equivalency basis, the concentrations ranged from 11 to 16 pg I-TEQ/g dry wt. Ecological risks to the Mai Po/Inner Deep Bay area due to environmental contaminants were assessed and some recommendations are made to elucidate the fate and environmental effects of these contaminants.

8.1. Background

Pollution of marine waters reduces the quantity and quality of available marine resources and, where toxic pollutants are involved, may also have a deleterious impact on human health via the consumption of contaminated seafoods. Due to its proximity to one of the most densely populated areas and busiest ports in the world, the coastal environment of Hong Kong has come under severe stress. Discharges of largely untreated domestic and industrial wastewater and the disposal of contaminated mud into Hong Kong's coastal waters have resulted in high levels of toxic contaminants in the water column, biota and bottom sediment (Wu, 1988; Blackmore, 1998; Connell et al., 1998a). In addition, the multi-billion dollar Harbour Area Treatment Scheme (HATS) (currently under construction) will discharge the wastewater from over 3 million people into surrounding waters, even though the impact of this release on the coastal environment is largely unknown. Previous studies of toxic contaminants in Hong Kong have tended to focus on monitoring heavy metal concentrations, while less attention has been given to persistent organic contaminants (POC).

DOI: 10.1016/S1572-7785(04)01008-1

In a recent review, Connell et al. (1998a) investigated the occurrence of POC, based upon previous monitoring at a total of 66 sites in Hong Kong waters over the past 10 years. They concluded that the contaminants concerned, including petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticides, were likely derived from a combination of industrial discharges, stormwater runoff, sewage and combustion (Connell et al., 1998a; and references therein). Further assessment of risks associated with the above POC in the Victoria Harbour was also performed using the routine monitoring data (1996–1999) from the Hong Kong Environmental Protection Department. Fugacity modeling was employed to calculate the aqueous and biotic concentrations (from POC concentrations in sediments), and the estimated levels were then compared with relevant guidelines. Based on this analysis, it was concluded that POC (e.g. PAHs and PCBs) were at levels which might pose a risk to local marine ecosystems and seafood consumers (Connell et al., 1998b). They also noted that the risks posed by other contaminants, including total alkanes, non-aromatic hydrocarbons, linear alkyl benzenes and chlorohydrocarbons, were likely to be additive to those of other POC present, and required further investigation to elucidate their distribution and ubiquity in local waters.

8.2. The Mai Po and Inner Deep Bay Ramsar Site

The Mai Po and Inner Deep Bay wetland, the largest remaining system of its type in Hong Kong, was listed as a Wetland of International Importance under the Ramsar Convention in September 1995 (Fig. 1). The Mai Po Marshes, occupying an important area for biodiversity conservation within the Ramsar site, were originally designated as a Site of Special Scientific Interest in 1976, and have been managed as a nature reserve by the World Wide Fund for Nature Hong Kong since 1984. Based on the bird list of Mai Po, records accumulated over several decades, there are over 380 bird species recorded in the area. Specifically, Mai Po supports the second largest known group in the world of Saunders' gulls (*Larus saundersi*) and one fourth of the world population of the Black-faced spoonbill (*Platalea minor*). Indeed, records from regular ringing exercises carried out at the Mai Po Marshes since 1979 show that the Deep Bay and Mai Po area is becoming increasingly important as a staging ground for migrant birds, especially shorebirds, to build up fat stores to provide fuel for the next stage of their migration.

There is increasing evidence that the high levels of environmental contaminants in the marine sediments around the Deep Bay area may be attributed largely to contamination sources in the Chinese mainland (Richardson & Zheng, 1999;

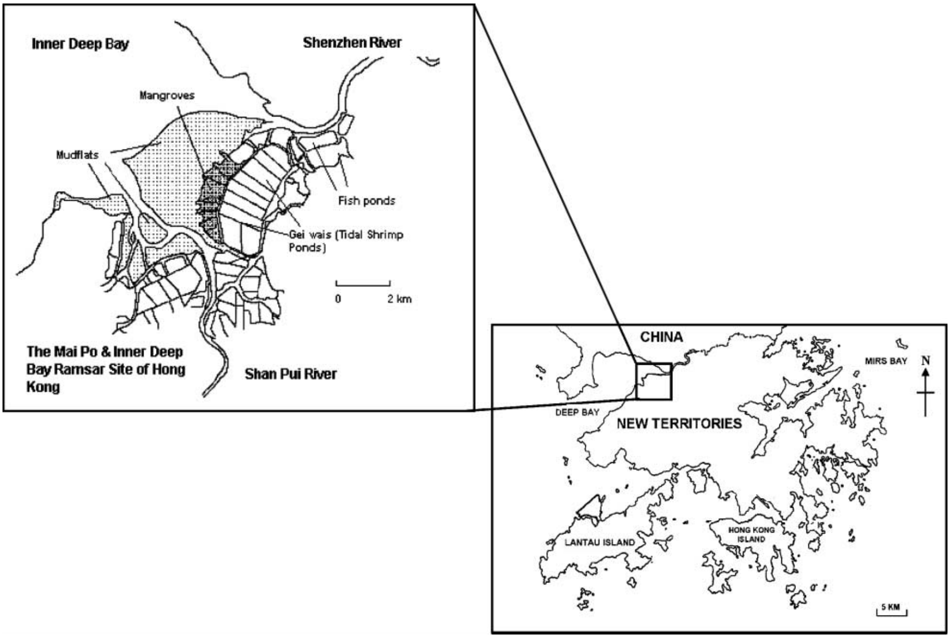

Figure 1: The Mai Po and Inner Deep Bay Ramsar Site of Hong Kong.

Richardson et al., 2000). The lower reaches of the Pearl River, receiving 2 million tonnes of various types of wastes and wastewater annually, are heavily polluted by domestic, industrial and livestock waste, and also by agrochemicals. Indeed, the annual discharge of the Pearl River (340 billion m^3), with an average sediment

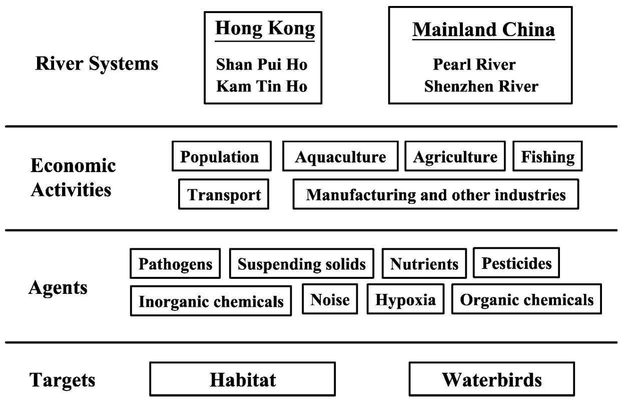

Figure 2: A simplified environmental profile of the Mai Po/Inner Deep Bay Ramsar Site showing major river systems, economic activities, and potential agents and targets.

load of 84 million tonnes, accounts for over 85% of the total nutrient input to the local waters of Hong Kong. This, together with inputs from the nearby polluted Shenzhen River and local streams, have been of major concern to maintenance of the long-term sustainability of the Mai Po and Inner Deep Bay ecosystem. A simplified environmental profile of the Mai Po/Inner Deep Bay area is given in Fig. 2. This report attempts to summarize results from recent studies on environmental contaminants in the Mai Po and Inner Deep Bay area, and assess the ecological risks to the Ramsar site due to these contaminants.

8.3. Levels and Risks of Environmental Contaminants in Sediments

Trace metals in Hong Kong's coastal waters, sediments and biota have been the subject of a number of studies spanning the 1970s to the 1990s, and the resultant data have been extensively reviewed by Blackmore (1998). Despite the existence of a large dataset on sediment trace metal contents and some information on the tissue metal content of certain marine organisms, their ecotoxicological significance has not been thoroughly investigated. A study, commissioned by the Agriculture and Fisheries Department (now Agriculture, Fisheries and Conservation Department, AFCD), examined the vertical profile of key inorganic (Cd, Cr, Cu, Hg, Ni, Pb, Zn, Fe and Mn) pollutants in porewater at selected sampling stations on the Mai Po mudflat and mangrove areas (Lam & Lam, 2000). Concentrations of cadmium, chromium, copper, lead and zinc in the sediment porewater of the Mai Po mudflat were found to vary in the range <1.1 ng/l–6.2 μg/l, <0.52 ng/l–20.8 μg/l, 0.6 ng/l–212.1 μg/l, <2.1 ng/l–24.0 μg/l, <0.7 ng/l–1,151.0 μg/l, respectively. For [Cd], [Cu], [Pb] and [Zn], remobilisation of trace metals from sediment to porewater occurred in the oxic layer close to the sediment–water interface, while the remobilisation of [Cr] occurred at the oxic/sub-oxic boundary. Metals in the porewater may be absorbed and accumulate in the tissues of benthic organisms, and may have an influence on predatory birds via the food chain.

Within the Ramsar area, total PAH concentrations in sediments collected from within the mangrove zone ranged between 666 and 1,042 ng/g dry weight. Zheng & Richardson (1999) reported a slightly lower level of total PAHs (558 ng/g) in sediments collected on a mudflat off Tsim Bei Tsui, Deep Bay. Naphthalene contents were high in the mangrove sediments, but mostly undetectable on the mudflat. There was a marked decline in total PAH levels from the landward end (about 800 ng/g near the mangrove fringe) towards the seaward end (212–355 ng/g) of the mudflat. The high total PAH concentrations in mudflat sediment collected near the mangrove fringe were partly attributed to the relatively high levels of specific PAH congeners, including benzo[a]pyrene and dibenzo(1,2,5,6)anthracene, which are potential carcinogens. In general, levels of total PHCs ranged from 267 to 363 μg/g dry weight, and did not show marked variations across different sampling stations in the Mai Po Nature Reserve. Total PCB concentrations in the Mai Po sediments were comparable to levels recorded elsewhere in Hong Kong (Richardson & Zheng, 1999). Levels of individual chlorinated pesticides were relatively stable (generally between 1 and 10 ng/g dry weight) across the mangrove and the open mudflat, except towards the seaward end where there was an apparent increase in chlorinated pesticide levels (Zheng et al., 2000). There is now increasing evidence that the high levels of OC pesticides in the marine sediments around the Deep Bay area, including compounds that have been banned in Hong Kong (e.g. DDT), are largely attributed to contamination sources in the Chinese mainland.

Tam et al. (2001) found that the PAH profiles of surface sediment samples from the Mai Po mangrove swamps had higher percentages of low-molecular-weight PAHs, and suggested that the PAHs might have originated from petrogenic sources. Zheng et al. (2002) analysed sediment cores (0–35 cm below surface) retrieved from 12 sampling stations in the Mai Po Marshes Nature Reserve of Hong Kong in 1999, and the vertical profiles of 15 priority PAHs in each sediment core were determined. On the mudflats, vertical profiles of the PAHs were quite uniform. At the fringe of the Mai Po mangroves, significantly higher concentrations of all PAHs were observed at the upper 0 to −8 cm layer. No significant difference in the distribution patterns of the 15 priority PAHs in summer and winter was observed, indicating that distribution of PAHs in the sediment of the Mai Po Marshes was not sensitive to sub-tropical climatic changes of the region. Two PAH isomer ratios, [Phenanthrene]/([Phenanthrene] + [Anthracene]) and [Pyrene]/([Pyrene] + [Fluoranthene]), were used to identify potential sources of PAH contamination in the wetland. The results suggested that local deposition might be a more important source than long-range atmospheric transportation.

There have been very few studies on PCDD and PCDF in Hong Kong. Müller et al. (2002) determined the concentrations of 2,3,7,8-substituted PCDDs and PCDFs in 14 sediment samples collected from four sampling stations in the Mai Po Marshes Nature Reserve and from another six sites in Victoria Harbour and along the Hong Kong coastline. Concentrations of PCDD/Fs were detected in all samples collected in the Mai Po Marshes and other sites from Hong Kong. In the Mai Po Marshes the mean concentrations of the $\sum$2,3,7,8-PCDD/Fs ranged from 5,000 to 6,900 pg/g dry wt in surface sediments and from 5,300 to 7,000 pg/g dry wt in sediments from various core depths. When expressed on a toxicity equivalency basis the concentrations in the sediments from the Mai Po Marshes ranged from 11 to 16 pg I-TEQ/g dry wt. The PCDD/F congener profiles in all samples are dominated by OCDD which contributed 94–97% to the $\sum$2,3,7,8-PCDD/F concentration in the samples. PCDD/F levels and congener profiles in the samples from the Mai Po Marshes Nature Reserve suggest that these contaminants have nonanthropogenic sources.

8.4. Levels and Risks of Environmental Contaminants in Biota

Liang et al. (1999) measured the PCB levels in fish and shrimps collected from tidal ponds at the Mai Po Marshes Nature Reserve, and concluded that PCB levels in the Grey Mullet exceeded the guideline value for human consumption, but the PCB concentrations in the aquatic organisms posed no hazard to fish-eating birds. In 2000, AFCD commissioned a study on the tissue contaminant levels of selected faunal groups in the Mai Po and Inner Deep Bay Ramsar Site (Lam & Lam, 2001). The study was mainly designed to provide data for an assessment of risks to predatory waterbirds due to consumption of potential food items in the area. A list of the eight faunal groups/species selected for analysis is given in Table 1. Tissue concentrations of trace metals and persistent organic pollutants (PHCs, OC pesticides, PCBs and PAHs) were analysed, and the results are summarised in Tables 2 and 3.

The potential risks of environmental contaminants to wildlife in Mai Po were assessed by comparing environmental conditions (e.g. environmental concentrations of toxic chemicals) with threshold values likely to cause adverse effects in the targets under consideration. In the type of risk assessment undertaken in this project, this was made explicit as a risk quotient (RQ) that is the ratio of an environmental concentration (either predicted (PEC) or measured (MEC)) with

Table 1: The eight faunal groups/species selected for analysis of persistent toxic substances in the Mai Po Marshes Nature Reserve.

Faunal group	**Common name**	**Scientific names**	**Sampling site**
Shrimps	*Gei wai* shrimp	*Metapenaeus ensis*	*Gei wais*
		Exopalaemon styliferus	*Gei wais*
Fish	Grey Mullet	*Mugil cephalus*	*Gei wais*
	Tilapia	*Tilapia mossambicus*	*Gei wais*
	Mudskipper	*Boleophthalmus pectinirostris*	Mudflat
Crabs	Fiddler crab	*Uca arcuata*	Mangroves
		Varuna litterata	*Gei wais*
Polychaetes			Mudflat

Table 2: Summary of mean tissue levels of metals in the eight faunal groups.

	Tissue concentration (μg/g)							
	Zn	**Fe**	**Mn**	**Cu**	**Hg**	**Cd**	**Cr**	**Pb**
Boleophthalmus pectinirostris	84.61	197.78	12.56	2.08	0.02	0.012	1.104	1.56
	(7.06)	(60.30)	(4.32)	(0.37)	(0.03)	(0.009)	(0.35)	(0.88)
Metapenaeus ensis	55.16	132.85	80.91	48.00	0.02	0.017	0.748	0.204
	(5.43)	(38.36)	(23.89)	(6.19)	(0.001)	(0.007)	(0.218)	(0.0082)
Uca arcuata	88.75	2340.20	385.40	70.11	0.07	0.49	2.555	5.985
	(8.48)	(732.67)	(182.74)	(19.65)	(0.03)	(0.22)	(0.93)	(1.923)
Mugil cephalus	75.50	969.84	67.63	3.24	0.0084	0.0071	1.326	0.58
	(10.169)	(1030.35)	(24.10)	(1.65)	(0.0036)	(0.0026)	(1.314)	(0.44)
Tilapia mossambicus	100.03	1480.00	122.25	5.76	0.015	0.010	1.40	0.74
	(12.42)	(840.00)	(81.02)	(1.37)	(0.0034)	(0.0038)	(0.43)	(0.38)
Exopalaemon styliferus	63.41	75.27	110.15	55.16	0.0065	0.0052	0.17	0.044
	(5.73)	(19.95)	(34.97)	(2.51)	(0.0021)	(0.0024)	(0.068)	(0.012)
Varuna litterata	75.24	947.46	371.99	54.98	0.016	0.017	0.25	0.16
	(9.61)	(112.04)	(92.25)	(7.17)	(0.0054)	(0.018)	(0.083)	(0.033)
Polychaetes	129.89	2795.35	38.36	20.17	0.0094	0.018	1.85	1.48
	(3.92)	(40.27)	(0.69)	(0.41)	(0.0038)	(0.0049)	(0.11)	(0.052)

Standard deviations are given in parentheses.

Table 3: Summary of mean tissue levels of persistent organic pollutants in the eight faunal groups.

	Tissue concentration (μg/g)							
	Total PAHs	**Total PHCs**	**Total HCHs**	**Heptachlor**	**Chlordane**	**DDE**	**DDT**	**Total PCBs**
Boleophthalmus	0.854	175.35	0.021	0.007	0.082	0.063	0.015	0.77
pectinirostris	(0.58)	(30.64)	(0.014)	(0.0026)	(0.11)	(0.040)	(0.022)	(0.30)
Metapenaeus ensis	0.93	91.25	0.015	0.0012	0.0015	0.014	0.0010	0.069
	(0.31)	(36.62)	(0.024)	(0.00038)	(0.00057)	(0.0074)	(0.0006)	(0.036)
Uca arcuata	0.75	151.84	0.0037	0.0039	0.00055	0.00048	0.0010	0.011
	(0.33)	(62.53)	(0.0051)	(0.0024)	(0.00021)	(0.00038)	(0.00044)	(0.009)
Mugil cephalus	0.98	574.35	0.0060	0.0018	0.0020	0.0011	0.0013	0.200
	(0.19)	(110.11)	(0.0014)	(0.0011)	(0.0011)	(0.0005)	(0.0007)	(0.050)
Tilapia mossambicus	1.443	672.0	0.019	0.0009	0.0041	0.0018	0.0028	0.086
	(0.214)	(84.6)	(0.022)	(0.0007)	(0.0010)	(0.0005)	(0.0017)	(0.025)
Exopalaemon styliferus	0.99	679.93	0.011	0.0022	0.0020	0.0014	0.0012	0.239
	(0.159)	(82.16)	(0.0033)	(0.0009)	(0.0010)	(0.0011)	(0.0010)	(0.080)
Varuna litterata	1.28	697.26	0.017	0.0023	0.0029	0.0005	0.0008	0.275
	(0.108)	(82.60)	(0.0097)	(0.0015)	(0.0010)	(0.0004)	(0.0009)	(0.033)
Polychaetes	1.49	1213.66	0.013	0.0016	0.0573	0.0066	0.0040	0.488
	(0.358)	(116.76)	(0.0018)	(0.0006)	(0.042)	(0.0018)	(0.0014)	(0.077)

Standard deviations are given in parentheses.

a predicted no-effect concentration (PNEC) for the target of concern (RQ = P(M)EC/PNEC), such that an RQ < 1 indicates a low, and thus acceptable risk, and an RQ ≥ 1 indicates a level of concern and possibly the deployment of management programmes.

Lam & Lam (2001) evaluated risks to faunal groups inhabiting the Mai Po mudflats and mangroves by comparing contaminant concentrations in the sediments with threshold effects levels (TELs) promulgated by the United States Environmental Protection Agency (USEPA, 1996). The TELs are defined as the concentrations below which toxic effects are rarely observed. These values were mainly derived from freshwater exposures of *Hyalella azteca* using 28-day survival, growth, and reproductive endpoints (USEPA, 1996). Where relevant data is available, RQs are calculated and tabulated in Table 4.

The risk assessment based on concentrations of various environmental contaminants in the sediments revealed that RQ values were all greater than one except for fluoranthene, chrysene and endrin in the mudflat; and benzo[a]pyrene and dibenzo(1,2,5,6)anthracene in the mangroves. RQ values for total PCBs were less than one. RQ values for copper and heptachlor epoxide were greater than 10. These results suggested that the levels of POC and certain metals in the Mai Po mudflats and mangroves might pose a substantial risk to aquatic organisms inhabiting the area. Results of this study further indicated that PCBs in the biota, except for *Uca arcuata*, posed a substantial risk to the waterbirds via food consumption (Lam & Lam, 2001). It was also observed that certain chlorinated pesticides (dieldrin and DDE, a metabolite of DDT) in the mudskippers (*Boleophthalmus pectinirostris*) were at levels that might cause harm to fish-eating birds (Lam & Lam, 2001). Tissue levels of PAHs were not directly relevant in this risk assessment process as many organisms, particularly fish, could rapidly metabolise and excrete PAH compounds.

In 2000, a second study, also commissioned by AFCD, was undertaken to examine the potential effects of waterborne pollutants on the breeding success of Ardeids in Hong Kong with special reference to the Mai Po/Inner Deep Bay areas (Lam et al., 2001). Possible exposure and effect pathways for bird populations in the Mai Po/Inner Deep Bay area are summarised in Fig. 3.

In this project, the feathers of two Ardeid species, the Little Egret (*Egretta garzetta*) and the Black-crowned Night Heron (*Nycticorax nycticorax*) were collected from six egretries and two egretries, respectively, located in different areas in the New Territories of Hong Kong, including the Mai Po Marshes. These feathers were digested and concentrations (μg/g dry weight) of copper (4.6–19.4), iron (8.1–641.3), manganese (0.4–19.4), zinc (51.3–183.5), lead (0.1–5.1), cadmium (0.01–0.15), chromium (0.06–1.7) and mercury (0.0–7.1) were determined by ICP-AES, ICP-MS and CVA-AS. A probabilistic risk assessment of the possible adverse effects on the breeding success of the Little Egret was

Table 4: Sediment threshold effects levels (TELs), maximum sediment concentrations, and calculated risk quotients (RQs) for the mudflat and mangroves in the Mai Po and Inner Deep Bay area.

	TEL[a]	Maximum sediment concentrations on the mudflat (μg/g)	Maximum sediment concentration in the mangroves (μg/g)	RQ (mudflat)	RQ (mangrove)
Trace elements					
Cadmium	0.6	1.59	0.7	2.65	1.17
Chromium	36.3	198.95	40.0	5.48	1.10
Copper	28	652.71	75.8	23.31	2.71
Lead	34.2	80.91	300.0	2.37	8.77
Manganese	615	No data	No data		
Mercury	0.17	No data	No data		
Zinc	94.2	233.96	553.3	2.48	5.87
PAHs					
Phenanthrene	0.042	0.057	0.079	1.36	1.88
Fluoranthene	0.111	0.073	0.239	0.66	2.15
Pyrene	0.053	0.107	0.320	2.02	6.04
Chrysene	0.057	0.016	0.116	0.28	2.04
Benzo(a)pyrene	0.032	0.107	0.029	3.34	0.91
Dibenzo(1,2,5,6) anthracene	0.032	0.040	0.025	1.25	0.78
Total PAHs	0.264	0.849	1.042	3.22	3.95
PCBs					
Total PCBs	0.032	0.028	0.018	0.88	0.56
Pesticides					
Chlordane	0.0045	0.0068	0.0065	1.51	1.44
Dieldrin	0.0029	0.011	0.0075	3.79	2.59
Heptachlor epoxide	0.0006	0.011	0.0062	18.33	10.33
DDE	0.0014	0.010	0.0043	7.14	3.07
Total DDT	0.007	0.00821	0.0081	1.17	1.16
Endrin	0.0027	<0.00001	0.0028	<0.0037	1.037

[a] From USEPA (1996); Table from Lam & Lam (2001).

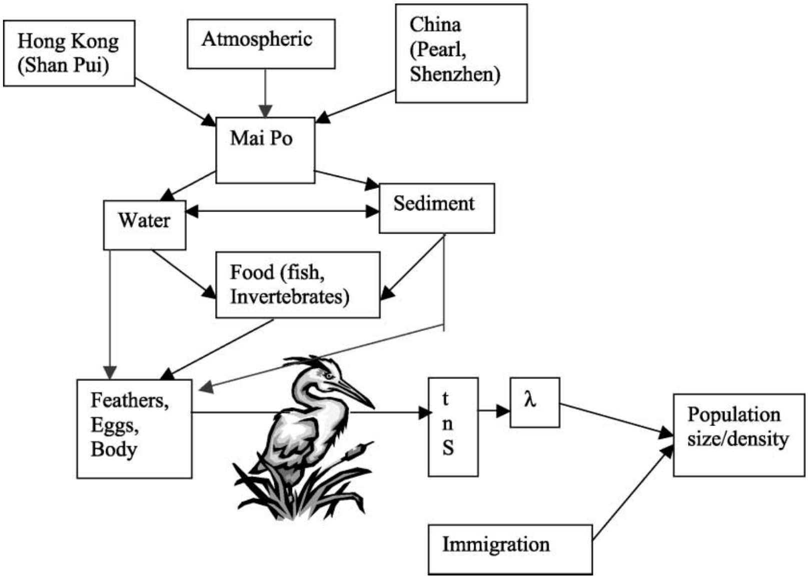

Figure 3: Possible exposure and effect pathways for bird populations in the Mai Po/Inner Deep Bay area. t is growth rate; n is fecundity; S is survivorship and λ is population growth rate.

carried out with respect to mercury, lead and cadmium. It was concluded that mercury (0.5–7.1 μg/g dry weight feathers) probably has had adverse effects at the Au Tau egretry of the Little Egrets, but no evidence of adverse effects at other egretries. Notwithstanding, the levels of lead and mercury were generally higher in the egretries close to the polluted Deep Bay. The probabilistic analysis also indicated a low likelihood of adverse effects of mercury on the breeding of the Black-crowned Night Herons at A Chau (0.3–1.2 μg/g) and Mai Po Village (0.0–1.4 μg/g). The evidence for the effects of lead and cadmium was limited but suggested there may possibly be adverse effects with lead but not cadmium. Details of this study are given in Connell et al. (2002).

In addition, POC, including PAHs, PHCs, PCBs and OC pesticides, were also analysed in bird eggs. Results of this study concluded that both species of Ardeid had concentrations of total DDTs present in the eggs sufficient to initiate adverse effects on the breeding success of these species (Connell et al., 2003). Some individuals in the populations were at higher risk due to the higher concentration of total DDTs present with maximum RQ of 9.0 for the Little Egret and 6.0 for the Black-crowned Night Heron. The Little Egret was at greater risk of adverse effects than the Black-crowned Night Heron since it had higher concentrations of the total DDTs present reflected in a higher RQ, i.e. 4.8 and 2.1 for the Little Egret and the Black-crowned Night Heron, respectively. The total PCBs present in eggs were at threshold levels where adverse effects could be initiated with the Little Egret. On the other hand, no effects would be expected with the Black-crowned Night Heron population. In addition, chlordane was at levels where adverse effects were possible, while the total hexachlorocyclohexanes (total HCHs) were at levels where no adverse effects on the breeding success of the Ardeids at Mai Po would be expected.

The above risk assessments are performed on a contaminant-by-contaminant basis. However, when target populations are exposed to a complex environmental mix (as is likely to be the situation for targets in the Mai Po/Inner Deep Bay area), it will be desirable to consider possible combined effects of contaminants and to take into account the possibility of interactions (additive, antagonistic, synergistic) in these combinations. If the total DDTs, total PCBs and mercury have additive effects the total effect on breeding success would be substantial for both the Little Egret and the Black-crowned Night Heron. Also, for complex mixes it may be possible that the most influential contaminant(s) has not been identified and hence not included in the risk assessment. This is an important area of research that deserves consideration for future investigation. It was clear from the results that the western waters were, in general, more affected by contamination of persistent toxic substances as compared to the eastern waters of Hong Kong (Lam et al., 2001).

8.5. Recommendations

Based on the risk assessment results available to date, a number of recommendations can be made to further elucidate the fate and environmental effects of contaminants in the Mai Po and Inner Deep Bay area.

(1) Regular monitoring of mercury and DDTs in the Ardeid tissues and in key environmental compartments (e.g. water and sediments) of the Mai Po and Inner Deep Bay system should be undertaken by relevant authorities to provide an early warning of potential adverse effects due to increase in concentrations of these contaminants.
(2) Since there is some evidence that Ardeids inhabiting the eastern and western parts of Hong Kong may be exposed to different levels of contamination, a strategic monitoring of concentrations of specific toxicants in Ardeids inhabiting the eastern and western waters will provide additional information on the potential effect of water pollution on the Ardeids.
(3) Although there is no clear evidence to date to suggest that the breeding success of Ardeids in Hong Kong is impaired by environmental contaminants, the breeding success of Ardeids from major nesting sites in Hong Kong should be

regularly monitored. In the event that a significant decrease in the breeding success of a specific Ardeid population is associated with an increase in the concentrations of the key contaminants (e.g. DDTs and Hg), an inventory of the usage and occurrence of these compounds in the Deep Bay and Mai Po area should be developed. This is particularly important given that there is no reliable information on the source of specific contaminants in Hong Kong.

(4) As a precautionary measure, levels of cadmium, chlordane and lead should also be monitored regularly, and the possible effects of these chemicals on the breeding success of waterbirds carefully evaluated.

(5) Policies, methods and procedures for the management of important toxicants in the Mai Po system should be developed. Information collected from above should be synthesised and used to recommend practical measures to reduce the impacts of toxic pollutant residues on the Ardeids in the event that a significant effect due to environmental contaminant is clearly demonstrated. The aim here is to formulate a management plan that is cost-effective and practical. To this end, relevant government officials, non-government organisations, green groups, and other stakeholders should be widely consulted.

8.6. Overall Conclusion

Environmental pollution has long been considered a major threat to the long-term sustainability of our coastal environment, including areas of high ecological importance and conservation value. Specifically, it is apparent that PAHs, OCs as well as certain trace metals may pose a risk not only to the marine ecosystem, but also primary and secondary consumers of marine organisms. Although there are now considerable data on the levels of common environmental contaminants in the marine sediments and, to a lesser extent, other environmental compartments, such as biota, there is still a general paucity of information on the sources of these chemicals and their precise effects on biological systems in Hong Kong waters.

In regard to sources of environmental contaminants in Hong Kong, there is evidence that the marine sediments around the Mai Po/Inner Deep Bay area are contaminated by high levels of metals and certain persistent organic pollutants, including banned compounds, such as DDT. The sources of these contaminants are still not clearly known. Particularly, the importance of atmospheric input to the western waters of Hong Kong from the industrial areas in the Pearl River Estuary will need to be examined. Further investigations should focus on identifying the sources of important environmental contaminants in Hong Kong waters, and elucidating the effects of these chemicals on local biological/ecological systems.

Acknowledgements

This work was supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (No. CityU1112/02M).

References

Blackmore, G. R. (1998). An overview of the trace metal pollution in coastal waters of Hong Kong. *Science of the Total Environment*, **214**, 21–48.

Connell, D. W., Wu, R. S. S., Richardson, B. J., Leung, K., Lam, P. K. S., & Connell, P. A. (1998a). Occurrence of persistent organic contaminants and related substances in Hong Kong marine areas: an overview. *Marine Pollution Bulletin*, **36**, 376–384.

Connell, D. W., Wu, R. S. S., Richardson, B. J., Leung, K., Lam, P. K. S., & Connell, P. A. (1998b). Fate and risk evaluation of persistent organic contaminants and related compounds in Victoria Harbour, Hong Kong. *Chemosphere*, **36**, 2019–2030.

Connell, D. W., Wong, B. S. F., Lam, P. K. S., Poon, K. F., Lam, M. H. W., Wu, R. S. S., Richardson, B. J., & Yen, Y. F. (2002). Risk to breeding success of Ardeids by contaminants in Hong Kong: evidence from trace metals in feathers. *Ecotoxicology*, **11**, 49–59.

Connell, D. W., Fung, C. N., Minh, T. B., Tanabe, S., Lam, P. K. S., Wong, B. S. F., Lam, M. H. W., Wong, L. C., Wu, R. S. S., & Richardson, B. J. (2003). Risk to breeding success of fish-eating Ardeids due to persistent organic contaminants in Hong Kong: evidence from organochlorine compounds in eggs. *Water Research*, **37**, 459–467.

Lam, M. H. W., & Lam, P. K. S. (2000). *Study on the impact of sediment porewater quality on the benthic infauna of Mai Po Mudflats*. Final Report. Submitted to the Agriculture, Fisheries and Conservation Department Hong Kong SAR Government.

Lam, P. K. S., & Lam, M. H. W. (2001). *Analysis of tissue contaminant levels for selected fauna in the intertidal mudflat of the Mai Po Inner Deep Bay Ramsar Site*. Final Report. Submitted to the Agriculture, Fisheries and Conservation Department, Hong Kong SAR Government.

Lam, P. K. S., Connell, D. W., & Lam, M. H. W. (2001). *Study on the effect of water pollution on the breeding success of Ardeids*. Final Report. Submitted to the Agriculture, Fisheries and Conservation Department, Hong Kong SAR Government.

Liang, Y., Wong, M. H., Shutes, R. B. E., & Revitt, D. M. (1999). Ecological risk assessment of polychlorinated biphenyl contamination in the Mai Po Marshes Nature Reserve, Hong Kong. *Water Research*, **33**, 1337–1346.

Müller, J. F., Gaus, C., Prange, J. A., Paepke, O., Poon, K. F., Lam, M. H. W., & Lam, P. K. S. (2002). Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans in sediments from Hong Kong. *Marine Pollution Bulletin*, **45**, 372–378.

Richardson, B. J., & Zheng, G. J. (1999). Chlorinated hydrocarbon contaminants in Hong Kong surficial sediments. *Chemosphere*, **39**, 61–71.

Richardson, B. J., Lam, P. K. S., & Wu, R. S. S. (2000). The coast of Hong Kong. In: C. Sheppard (Ed.), *Seas at the millennium: an environmental evaluation* (Vol. II, pp. 535–547). Elsevier Science, Amsterdam.

Tam, N. F. Y., Ke, L., Wang, X. H., & Wong, Y. S. (2001). Contamination of polycyclic aromatic hydrocarbons in surface sediments of mangrove swamps. *Environmental Pollution*, **114**, 255–263.

USEPA. (1996). *Assessment and remediation of contaminated sediments (ARCS) program: calculation and evaluation of sediment effect concentrations for the amphipod Hyalella azteca and the midge Chironomus riparius*, EPA 905-R96-008. U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL, USA.

Wu, R. S. S. (1988). Marine pollution in Hong Kong: a review. *Asian Marine Biology*, **5**, 1–23.

Zheng, G. J., & Richardson, B. J. (1999). Petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) in Hong Kong marine sediments. *Chemosphere*, **38**, 2625–2632.

Zheng, G. J., Lam, M. H. W., Lam, P. K. S., Richardson, B. J., Man, B. K. W., & Li, A. M. Y. (2000). Concentrations of persistent organic pollutants in surface sediments of the mudflat and mangroves at Mai Po Marshes Nature Reserve, Hong Kong. *Marine Pollution Bulletin*, **40**, 1210–1214.

Zheng, G. J., Man, B. K. W., Lam, J. C. W., Lam, M. H. W., & Lam, P. K. S. (2002). Distribution and sources of polycyclic aromatic hydrocarbons in the sediment of a subtropical coastal wetland. *Water Research*, **36**, 1457–1468.