CONTAMINATED MUD DISPOSAL AT EAST SHA CHAU : COMPARATIVE INTEGRATED RISK ASSESSMENT

GEO REPORT No. 82

EVS Environment Consultants

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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This report was prepared by EVS Environment Consultants in September 1996 under Consultancy Agreement No. CE 68/94 for the sole and specific use of the Government of the Hong Kong Special Administrative Region

First published, January 1999

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This publication is available from:

Government Publications Centre,
Ground Floor, Low Block,
Queensway Government Offices,
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Overseas orders should be placed with:

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Hong Kong.

Price in Hong Kong: HK$52
Price overseas: US$12 (including surface postage)

An additional bank charge of **HK$50** or **US$6.50** is required per cheque made in currencies other than Hong Kong dollars.

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PREFACE

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R.K.S. Chan
Principal Government Geotechnical Engineer
January 1999

FOREWORD

This report presents the findings of a study using comparative integrated risk assessment to address public health and ecological concerns associated with the disposal of contaminated mud at East of Sha Chau.

The study was carried out by EVS Environment Consultants of Canada for Geotechnical Engineering Office (GEO) of the Civil Engineering Department under Agreement No. CE 68/94. Dr. K.C.Ng of GEO coordinated the study and reviewed the report.

D.C.H. Chang
Chief Geotechnical Engineer/Fill Management (Ag)

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LIST OF ACRONYMS

AFD	(Hong Kong) Agriculture and Fisheries Department
CED	(Hong Kong) Civil Engineering Department
CITES	Convention on International Trade in Endangered Species
COC	Contaminant of Concern
CSF	Cancer Slope Factor
CSMS	Contaminated Spoil Management Study (Mott MacDonald, 1991)
CT	Central Tendency
DL	Detection Limit
ELCR	Excess Lifetime Cancer Risk
EPA	(U.S.) Environmental Protection Agency
EPD	(Hong Kong) Environmental Protection Department
ERA	Ecological Risk Assessment
ERH	Effects range high
ERL	Effects range low
ERM	Effects range median
ESC	East Sha Chau
FAO/WHO	Food and Agricultural Organization/World Health Organization
FAR	Food Adulteration Regulations
FMO	Fish Marketing Organization
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HQ	Hazard Quotient
IRIS	Integrated Risk Information System
LC	London Convention
LOAEL	Lowest Observed Adverse Effects Level
MATC	Maximum Allowable Toxicant Concentration

AFD	(Hong Kong) Agriculture and Fisheries Department
NOAEL	No Observed Adverse Effects Level
NRC	Negligible Risk Concentration
RfD	Reference Dose
RME	Reasonable Maximum Exposure
ROC	Receptor of Concern
SFS	Subsistence Fishers Subpopulation
TMW	Tai Mun Wan
TBT	Tributyltin
TRV	Toxicity Reference Value
VH	Victoria Harbour

GLOSSARY

NOTE: Explanations of glossary terms are provided here for guidance and may not be universally definitive.

Acute	With reference to toxicity, having a sudden onset, lasting a short time. Of a stimulus, severe enough to induce a response rapidly. Can be used to define either the exposure or the response to an exposure (effect). The duration of an acute aquatic toxicity test is generally 4 days or less and mortality is generally the response measured.
Additive Toxicity	The toxicity of a mixture of chemicals which is approximately equivalent to that expected from a simple summation of the known toxicities of the individual chemicals present in the mixture (i.e., algebraic summation of effects).
Adsorption	The adhesion of a thin layer of one substance on the surface of another.
Allometry	The measurement of the relative growth of a part of an organism in comparison with the whole.
Antagonism	A phenomenon in which the toxicity of a mixture of chemicals is less than that which would be expected from a simple summation of the toxicities of the individual chemicals present in the mixture (i.e., algebraic subtraction of effects).
Assessment Endpoint	An explicit expression of the environmental value to be protected.
Background Concentration	Value which indicates the pre-anthropogenic concentration of a contaminant, occurs in deeper or offshore sediment layers (from Mott MacDonald, 1991).
Benchmark Concentration	Specific concentrations at which some level of effects are expected.
Benthic	Referring to organisms living in or on sediments.

Bioaccumulation

A general term, meaning that an organism stores within its body a higher concentration of a substance than is found in its environment. Includes uptake of substances from water (=bioconcentration) and from food. This phenomenon is not necessarily harmful. For example, freshwater fish must bioaccumulate common salt if they are to live because the water in which they swim dissolves the salts out of their bodies. Many toxicants, such as arsenic, can be excreted by aquatic organisms, and are not included among the bioaccumulative substances (e.g., certain chemicals in food eaten by a fish tend to accumulate in its liver or other tissues).

Bioavailability

The degree to which the total chemical in the surrounding environment can be taken up by organisms. The environment may include water, sediment, suspended particles, and food items.

Bioconcentration

Accumulation of a chemical by an aquatic organism directly from the water, to a higher concentration than is found in the water. The bioconcentration results from simultaneous processes of uptake and elimination.

Biomagnification

The result of processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through the food chain. The term implies an efficient transfer of chemical from food to consumer, so that residue concentrations increase systematically from one trophic level to the next.

Chronic

Involving a stimulus that continues for a long time or a response that is lingering; generally signifies periods from weeks to years, depending on the reproductive life cycle of the aquatic species. Can be used to define either the exposure or the response to an exposure (effect). Chronic exposure can induce a biological response of relatively slow progress and long continuance, or rapid progress once the response is triggered.

Contaminant Of Concern (COC)	A chemical at a site that may cause risks to exposed organisms at the site.
Dose (Intake)	The quantifiable amount of a material introduced into an organism by injection or ingestion.
Intake (dose)	The quantifiable amount of a material introduced into an organism by injection or ingestion.
Ecotoxicity	The study of toxic effects on nonhuman organisms, populations, or communities.
Endpoint	The variable(s) (e.g., time, the organisms reaction) that indicate(s) the termination of a test or the value derived that characterizes the results of the test (e.g., EC50, LC50).
Epibenthic	Referring to organisms that live at the surface of (on, and not in) the sediments of aquatic/marine habitats.
Exposure	Co-occurrence of or contact between a stressor and an ecological component.
Exposure Assessment	The process of estimating the dose received by an organism, population or ecosystem. The exposure assessment may be prospective, in which case estimates of the chemical concentrations and forms in various media or habitats are combined with estimates of the organism's behaviour to predict dose. The exposure assessment may also be retrospective, in which case dose is estimated from body burdens of the chemical or changes in the organism caused by the chemical (biomarkers).
Exposure Pathway	The course a chemical takes from a source to an exposed organism.
Exposure Scenario	A set of assumptions concerning how an exposure may take place.
Food Chain	The process by which organisms in higher trophic levels gain energy by consuming organisms at lower trophic levels; the dependence for food of organisms upon others in a series beginning with plants and ending with the largest carnivores.

Hazard Index (HI)	Summation of hazard quotients of COCs with like toxic mechanisms.
Hazard Quotient (HQ)	The ratio of a single-substance exposure level to a toxicity value selected for the risk assessment.
Ingestion Rate	The rate at which an organism consumes food, water, or other materials (e.g., sediment).
LC50	The median lethal concentration; the concentration of material in water to which test organisms are exposed that is estimated to be lethal to 50% of the test organisms. The LC50 is usually expressed as a time-dependent value (e.g., 24-h or 96-h LC50; the concentration estimated to be lethal to 50% of the test organisms after 24 or 96 h of exposure).
Lethal	Causing death, or sufficient to cause death.
Lowest Observable Adverse Effect Level (LOAEL)	The lowest concentration of a material used in a toxicity test that has a statistically significant adverse effect on the exposed population of test organisms as compared with the controls.
Lipophilicity	The measure of a substance's relative solubility in an oil-like matrix. Lipophilic compounds are those which have a high affinity for (dissolve in) lipids.
Measurement Endpoint	A measurable environmental characteristic that is related to the valued characteristic chosen as the assessment endpoint.
No Observable Adverse Effect Level (NOAEL)	The highest concentration of a stressor in a test that has no statistically significant adverse effect on the exposed population of test organisms as compared with the controls.
Open Sea Floor Ocean Disposal	Open ocean disposal for sediments which are considered noncontaminated and pose minimal or no toxicity risk to the marine environment.
Oxidation State	A number which indicates the electrical characteristics of an atom.
Piscivorous	Fish eating.

Receptor Of Concern	The organism of interest that might be adversely affected by contact with or exposure to a COC.
Risk Assessment	The process that evaluates the likelihood that adverse effects may occur or are occurring as a result of exposure to one or more stressors.
Risk Characterization	The evaluation of the likelihood that adverse ecological effects may occur as a result of exposure to a stressor, including an evaluation of the consequences of these effects.
Sensitivity Analysis	The process of examining the relative influence of model parameters by sequentially varying individual parameters and tracking the overall results.
Stressor	Any physical, chemical, or biological entity that can induce an adverse effect.
Sublethal	Involving a stimulus/concentration below the level that causes death. Exposure to sublethal concentrations of a material may produce less obvious effects on behaviour, reproduction, biochemical and/or physiological function, and histology of organisms.
Teratogen	A substance that causes alteration in the developing cells, tissues, or organs at the embryonic stage of development. An agent that increases the incidence of congenital malformations.
Tiered Approach	The application of sequentially more sophisticated and complex evaluations or testing procedures.
Toxic Mechanism	Mode of action of a chemical stressor on an organism.
Toxicity Reference Value (TRV)	Toxicity value chosen in a risk assessment for the denominator in the hazard quotient calculation.
Uncertainty Analysis	Assessment of potential sources of error in a risk assessment in which data may not be sufficient.

ACKNOWLEDGEMENTS

EVS Environment Consultants gratefully acknowledge the assistance and cooperation of the Civil Engineering Department. This risk assessment was conducted by Gary Mann and Patrick Allard. Literature searches were conducted by Michael Z'Graggen. Technical review was provided by Beth Power (entire document), Gary Vigers (entire document), and Brenda Shaw (public health sections). Technical advice was received from Drs. Thomas Jefferson (Research Scientist, Ocean Park Conservation Foundation, Hong Kong), David Lincoln (Public health risk assessment expert, Decision Risk Management, Bellevue, Washington, USA), and Brad Sample (Wildlife risk assessment expert, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA), and from Ms. Brenda Shaw (Hong Kong public health risk assessment specialist, Hong Kong). The document was wordprocessed by Jackie Gelling, Kristen Ramsden and Shannon Scott and produced by Rhea Sichani.

Citation:

EVS Environment Consultants. 1996. Contaminated Mud Disposal at East Sha Chau: Comparative Integrated Risk Assessment. Report to the Civil Engineering Department, Government of Hong Kong, prepared by EVS Environment Consultants, North Vancouver, BC.

EXECUTIVE SUMMARY

A screening-level comparative integrated risk assessment was commissioned by the Hong Kong Civil Engineering Department to address public health and ecological concerns associated with the disposal of metals-contaminated mud at East Sha Chau. All seven target metals (cadmium, chromium, copper, lead, mercury, nickel and zinc) were included as contaminants of concern (data on organic contaminants in target fishery species is currently being incorporated into routine monitoring of target fishery species at East Sha Chau). The risk assessment integrated fishes, Chinese white dolphins and human receptors to provide a consistent framework within which to address potential environmental risks associated with disposal activities at East Sha Chau. The assessment endpoints (i.e., those values to be protected) for this assessment were:

(1) Abundance of commercially-exploited fisheries species.

(2) Viability of Chinese white dolphin populations feeding in the vicinity of the East Sha Chau mud disposal area.

(3) Health of individual Chinese white dolphins feeding in the vicinity of the East Sha Chau mud disposal area.

(4) Health of human seafood consumers in Hong Kong.

A comparative approach was used to estimate the relative risks predicted for East Sha Chau compared to an uncontaminated area (Tai Mun Wan) and a contaminated area (Victoria Harbour). Relative risk estimates were calculated for East Sha Chau, Tai Mun Wan and Victoria Harbour using data collected during the fall of 1995. Absolute risk estimates were calculated for East Sha Chau using data collected during the period of 1993-1995. Relative risk estimates are useful to interpret the significance of absolute risk estimates (i.e., those estimated for East Sha Chau) in terms of ecological and public health. The major conclusions of the risk assessment are summarized below.

Fishes

- Commercially important fishery species, based on an analysis of the benthic flatfish *Cynoglossus* spp., are not at risk from metals in sediments disposed of at East Sha Chau.

Chinese White Dolphin

- Cadmium was the only Contaminant of Concern predicted to pose potentially unacceptable risks to the Chinese white dolphin; risks associated with other Contaminants of Concern ranged from slightly below acceptable (mercury) to negligible (other five metals).

- Predicted risks due to consumption of cadmium in prey were slightly elevated but may not be related to mud disposal activities at East Sha Chau as similar risks were predicted for Victoria Harbour and Tai Mun Wan.

- In this screening-level risk assessment, predicted risk for cadmium was a consequence of the moderately conservative approach used which may result in an overestimation of risk. However, due to current uncertainty regarding the general health of the local Chinese white dolphin population, further effort is needed to confirm the conclusion.

Humans

- The general population of Hong Kong is not at risk through the consumption of seafood from East Sha Chau.

- The subsection of the general population exposed to reasonable maximum levels of seafood from East Sha Chau is also not at risk.

- The subsistence fishing subpopulation may be at risk from the consumption of mercury and lead in seafood. However, those risks could not be related to disposal activities at East Sha Chau and similar risks were predicted for Victoria Harbour and Tai Mun Wan.

- Predicted risks for lead and mercury are likely a result of the moderately conservative approach used in this screening-level risk assessment. However, further effort would be necessary to confirm this conclusion.

1.0
INTRODUCTION

1.1 BACKGROUND

Many of Hong Kong's seabed areas have been contaminated as a result of inadequate treatment of domestic and industrial wastes over many decades (CED, 1996). As part of the infrastructure development and harbour maintenance activities initiated in the early 1990s, an estimated 30M m^3 of contaminated mud will require disposal by the year 2000. The disposal management option selected for contaminated mud was confined aquatic disposal (i.e., disposal in seabed pits and capping with inert materials). After evaluation of several prospective disposal sites, East Sha Chau (ESC) was chosen mainly because of its shallow water depth and relatively low current velocities.

In compliance with the Dumping at Sea Ordinance (Chapter 466), the disposal program required the establishment of disposal and monitoring protocols which would ensure that mobilization, dispersion, and uptake of trace metals and organic contaminants into the food chain were minimized (CES and Binnie, 1994). The ESC environmental monitoring program was initiated prior to commencement of disposal activities and now covers sediment and water quality, aquatic biota and ecotoxicology. This monitoring program is designed to provide continuous feed-back to the Hong Kong Civil Engineering Department (CED) with regard to the status of the environment in the ESC area to support management of disposal activities. Not withstanding this monitoring program which has not identified any adverse trends in the parameters being monitored, some concerns have been raised about the potential risks of disposal activities to public health, the Chinese white dolphin, and to commercial fishery species inhabiting the area.

1.2 OBJECTIVES

This risk assessment was commissioned by the CED to address public health and ecological concerns associated with the disposal of contaminated mud at ESC. Specifically, this risk assessment addresses whether the disposal of metals-contaminated mud at ESC is likely to result in adverse effects to the following:

- Public health through the consumption of seafood from ESC.
- Chinese white dolphin through the consumption of seafood from ESC.
- Commercial fishery species through the accumulation of toxic quantities of contaminants from ESC.

A comparative risk assessment approach was used to meet these objectives; this approach (described in Section 1.3) compares risk estimates for ESC to two other sites outside the influence of contaminated mud disposal activities.

1.3 COMPARATIVE RISK ASSESSMENT APPROACH

Risk assessments generally address excess risks of specific activities or situations (i.e., absolute risk that a specific adverse effect will occur). Uncertainty in risk assessments, particularly at the screening level, can sometimes lead to difficulties interpreting the significance of predicted risks. Uncertainty is defined as imperfect knowledge concerning the present or future state of the system in consideration (Suter, 1993). Uncertainties in risk assessments have three basic sources: (1) the inherent randomness of the world (i.e., stochasticity or variability); imperfect or incomplete knowledge of things that could be known (i.e., ignorance); and mistakes in execution of assessment activities (i.e., error) (Suter, 1993). A conservative approach is often used in risks assessment to avoid underestimating risk and to screen-out contaminants that do not warrant concern. However, compounding of conservative assumptions can lead to over-estimation of risks in some cases. As a result, when uncertainty is high, absolute risk estimates sometimes offer little useful information for risk managers to make sound environmental decisions. To overcome this potential problem, a comparative risk assessment approach was used to derive relative risks (i.e., comparisons were made between predicted risks ESC and other areas within Hong Kong's territorial waters).

The two areas selected for comparative purposes were Tai Mun Wan (TMW), a relatively uncontaminated area, and Victoria Harbour (VH), an area that receives boat wastes, effluent and storm water discharges, and which is presumably contaminated. Public health and ecological risks for these areas were not estimated in an absolute sense (i.e., using area-specific exposure assumptions), rather, the environmental conditions in these areas were applied to the exposure assumptions used for ESC (e.g., both humans and dolphins were assumed to consume seafood from VH to the same degree as ESC, when in reality consumption of seafood from VH is quite low). This approach served to place any predicted risks at ESC into the proper environmental context, which made interpretations of the significance of predicted public health and ecological risks more meaningful.

The risk assessment approach used herein integrates human and ecological receptors. Traditionally these types of receptors are addressed separately. More recently, however, risk assessors and risk managers have recognized the advantages of integrating the two to optimize the entire process (Pueuler et al., 1995; Clarkson, et al., 1995). For ESC, the integration of human health and ecological risk assessments has three key advantages:

- To streamline the risk assessment process.

- To ensure the highest degree of coordination and consistency between approaches.

- To facilitate decision-making and risk management.

This type of approach is particularly relevant to ESC since the primary ecological (i.e., Chinese white dolphin) and human receptors share primary exposure routes (i.e., consumption of seafood from ESC). The integrated risk assessment framework used in this study (see Figure 1) combines elements of the U.S. EPA's human health (U.S. EPA, 1989) and ecological (U.S. EPA, 1992a) frameworks.

2.0
PROBLEM FORMULATION

The problem formulation presents relevant information needed to set the stage for the rest of the assessment. Key subjects covered include:

- Ecological communities at potential risk
- Contaminants of concern
- Receptors of concern
- Assessment and Measurement Endpoints
- Conceptual model for the site

This section was taken largely from the Problem Formulation document which was presented to CED in May 1996 as an appendix of the report *Review of Contaminated Mud Disposal Strategy and Status Report on Contaminated Mud Disposal Facility at East Sha Chau* (EVS, 1996). The information has been repeated here to provide complete documentation of the information presented in this risk assessment.

2.1 ECOLOGICAL COMMUNITY POTENTIALLY AT RISK - EAST SHA CHAU

The ESC area lies within the dynamic estuarine waters of the Pearl River Delta, north of Lantau Island and approximately 1 km north of the new Chek Lap Kok Airport (Figure 2). In 1992, this area was selected for contaminated mud disposal in response to a need for the management of dredged sediments which have been contaminated by urban and industrial effluent discharges, polluted stormwater runoff, boat and ship wastes, and agricultural runoff.

The ESC area is generally shallow (< 6 m depth) characterized by low to moderate current velocities. Conditions at ESC are seasonally variable, reflecting normal estuarine conditions. However, these conditions are influenced considerably by discharges from the Pearl River. Approximately 310 billion m^3 of water and 8.6 million tonnes of sediment and organic material are discharged annually by the Pearl River. Approximately 80% of the flow occurs during the summer months. The highly variable flows from the Pearl River cause large fluctuations in salinity, temperature, and suspended solids in the water column at the ESC site. In the summer, a marked halocline occurs with waters of reduced salinities overlying denser marine waters. During the winter, turbulent mixing caused by the strong monsoon breaks down the stratification of the water column. Typically, the benthic fauna adjacent to the ESC area can be characterized as being adapted to a dynamic estuarine environment with highly variable temperature and salinity, and high sedimentation and turbidity (CES and Binnie, 1993).

The seabed at ESC is characterized as a 10-20 m layer of clay/silt ("mud") of the Hang Hau Formation overlying alluvial sands and clays of the Chek Lap Kok Formation (Binnie et al., 1992). The seabed is considered to be in a state of long-term equilibrium, with episodes of deposition alternating with periods of erosion. Although the sediments are relatively stable and will not be eroded by tidal currents alone, they may erode due to the combined action of waves and currents, or during extreme events such as typhoons (Premchitt and Evans, 1993). Most of the sediments in Hong Kong waters are anaerobic.

ESC is also located near environmentally sensitive areas. The contaminated mud disposal area is within the habitat range of the Chinese white dolphin (*Sousa chinensis*) and is also relatively close to a seabird roosting ground at Lung Kwu Chau. The waters north of Lantau Island are important fishing grounds.

2.2 COMPARATIVE AREAS - TAI MUN WAN AND VICTORIA HARBOUR

Two areas within Hong Kong's territorial waters were selected for comparative purposes to place the absolute public health and ecological risks estimated for ESC into perspective. The areas were selected by the CED to represent relatively uncontaminated, Tai Mun Wan (TMW), and contaminated, Victoria Harbour (VH), areas. TMW and VH, therefore, respectively serve as risk benchmarks for uncontaminated and contaminated areas against which the absolute risks predicted for ESC can be compared. This comparative approach will support interpretations of the significance of predicted risks for ESC.

TMW is located in the southeast portion of Hong Kong's territorial waters (see Figure 2). Based on sediment quality data summarized in Lam (1994), TMW is a relatively uncontaminated area, with all reported metals found at Class A (i.e., classified as inert or unpolluted) concentrations of the current Hong Kong sediment classification criteria (EPD, 1992; see Section 2.3). This supports the designation of TMW as a relatively uncontaminated area for the purposes of this comparative risk assessment.

VH is centrally located within Hong Kong's territorial waters (see Figure 2). Based on sediment quality data summarized in Lam (1994), VC as a whole is moderately contaminated, with reported metals found at concentrations ranging from Class A to Class C (i.e., classified as heavily contaminated; EPD, 1992). This supports the designation of VH as a contaminated area for the comparative risk assessment.

2.3 CONTAMINANTS OF CONCERN (COCS)

2.3.1 Source Material Characterization

Sediment quality criteria presently used to evaluate sediment contamination in Hong Kong are based upon recommendations from the Contaminated Spoil Management Study (CSMS; Mott MacDonald, 1991; EPD, 1992). Criteria for seven key metals (cadmium [Cd], chromium [Cr], copper [Cu], lead [Pb], nickel [Ni], and zinc [Zn]) were developed based on existing data and perceived environmental risks associated with concentrations of these metals previously recorded in Hong Kong sediments (CSMS; EPD, 1992):

- Background Values
- Target Values (Class A material) - inert or uncontaminated
- Trigger Values (Class B material) - moderately contaminated
- Action Values (Class C material) - heavily contaminated

At the present time, Class A and B materials are considered safe for open sea floor ocean disposal, whereas Class C materials are isolated from the surrounding environment through confined ocean disposal. To date, criteria have not yet been developed for Hong Kong sediments for any contaminants other than the above seven metals.

Large amounts of copper, chromium and other metals associated with industrial processes such as electro-plating (CED, 1995) have likely contributed to the contamination of Hong Kong sediments by trace metals. However, other chemical substances, including pesticides, herbicides, tributyltin (TBT), and halogenated substances, may pose a potential risk to aquatic biota, wildlife and to humans as a result of the release, uptake, metabolism, and transformation of contaminants from the sediment matrix. For example, the presence of TBT has been identified in marinas and shipyards (CES, 1995) and certain pesticides, herbicides and fungicides currently used in Hong Kong have also been identified in inland waters, although their presence in marine sediment remains to be assessed (Axis, 1995).

The ESC disposal site environmental monitoring program has indicated low but detectable levels of substances other than regulated metals (e.g., polyaromatic hydrocarbons [PAHs], polychlorinated hydrocarbons [PCBs], arsenic, barium, cobalt, tin, molybdenum, selenium, and silver). Such non-regulated contaminants may be transferred from dredged materials to the ESC contaminated mud disposal area and thus may have some potential to pose public health and ecological risks.

2.3.2 Selection of COCs

The initial step in a risk assessment is to identify the contaminants of concern (COCs) to be evaluated in the assessment. The COCs and the rationale for their selection are presented in this section. The inclusion of a chemical as a COC does not imply that the chemical is posing risk to human or ecological receptors in the ESC contaminated mud disposal area, but only that it has the potential to do so.

This assessment considers public health and ecological risks posed by the seven metals currently regulated in the disposal of sediments in Hong Kong. Although the presence of several contaminants (e.g., trace metals, pesticides, herbicides, TBT, other halogenated substances) has been identified in potential source materials from Hong Kong waters (inland and marine), site-specific information was only available for contaminants measured as part of the ESC environmental monitoring program. EVS (1996) reported that overall sediment concentrations of metal and organic contaminants at ESC were considered low. Exceedances of sediment classification criteria (EPD, 1992) or sediment guidelines (Long et al., 1995) for sediments collected at all compliance and cumulative impact stations were rare and limited to a very small percentage of the overall data set (less than 1% of all metals out of approximately 860 samples collected in 1994-1995). While sediment concentrations of all contaminants measured were relatively low, the presence of bioaccumulative compounds still means that risks to biota are a possibility.

Routine monitoring of muscle tissue chemistry in eight target fishery organisms (*Charibdis cruciata* [crab], *Cynoglossus* sp. [fish]), *Leiognathus brevirostris* [fish], *Trypauchen vagina* [fish], *Metapenaeus affinis* [shrimp], *Metapenaeus ensis* [shrimp], *Oratosquilla oratoria* [stomatopod], and *Turitella* sp. [mollusc]) has been conducted as part of the ESC cumulative impact monitoring program. A separate sampling program was carried out in September, October and November 1995 to collect consistent data for the two comparative areas (i.e., TMW and VH). So far, all analyses have been restricted to seven metals (i.e., Cadmium, Chromium, Copper, Lead, Mercury, Nickel, and Zinc; distribution information for each metal/target species combination for the three areas is presented in Appendix A). The current list of parameters for routine monitoring of target fishery organisms at ESC is in the process of being expanded (e.g., addition of PAHs and PCBs); risks associated with these contaminants will be evaluated upon collection of sufficient data.

As a conservative approach is prescribed for screening-level risk assessments, all contaminants routinely measured in target fishery organisms in the ESC environmental monitoring program were included as COCs for this risk assessment. These included the following chemicals:

- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Zinc

2.3.3 Environmental Transport and Fate of COCs

The general transport and fate behaviour of COCs after their discharge to the environment is summarized in Table 1; details are provided in Appendix B. Due to the potential influence of the Pearl River on conditions at the site, transport and fate are discussed in general terms (i.e., not specifically for the marine environment). The chemical and physical characteristics of the COCs and those of the surrounding environment will determine their fate in the environment and their availability to receptor organisms.

2.3.4 COC Toxicity Profile

A summary of the possible toxicological effects of the contaminants of concern to fish and mammals is presented in Table 2; details are provided in Appendix C. This information was collected from literature sources as general information to support the risk assessment and is not intended to imply these effects are occurring at ESC.

2.4 RECEPTORS OF CONCERN (ROCS)

2.4.1 Selection Criteria

The term receptor refers to a component of the ecosystem that has the potential to be adversely affected by pollutants or other stresses. Three receptors of concern (ROCs) were selected for this preliminary risk assessment of ESC: a resident fin fish (*Cynoglossus* spp.), the Chinese white dolphin (*Sousa chinensis*), and the human population of Hong Kong. These receptors were identified because they are important ecologically, socially or economically, and may be impacted by COCs from the ESC site either through direct exposure to contaminants in water and sediments, or through consumption of contaminated seafood from the area.

2.4.2 Life-history Characteristics of Selected ROCs

Fish — A large number of fish species are found at ESC, and many of the species are important commercially (1991 AFD Port Survey cited in Parsons, 1994b) (Table 3). The ESC region is likely to be of high ecological importance because estuarine waters are often breeding grounds and habitat for adults and juveniles of many species. Many oceanic fish species migrate to shallow coastal waters to spawn.

Fish were included as a receptor of concern because the health of fish populations could be adversely affected through exposure to COCs in water, sediments, and food sources at ESC. Exposure to COCs are of particular concern to all fish, but in particular to juvenile life stages. Exposure to COCs could increase mortality rates and depress population growth rates and ultimately decrease fish abundance. A reduction in fish abundance would harm the local fishery and adversely affect the economic well-being of people dependent on the resource. Fisheries closures due to anthropogenic sources of pollution have occurred in jurisdictions throughout the world (e.g., mercury and PCB closures).

The local fishery exploits both bottom dwelling and pelagic fin fish that thrive in the nutrient rich waters of the estuary. The high economic value species include sea breams, yellow croaker, slate cod croaker, Japanese sea perch, threadfin, soles, and white promfret (Wilson, pers. comm. 1995a). Of the fish species found at ESC, *Cynoglossus* spp. (sole) was selected as a ROC that represents fisheries in general. This fish species was chosen because it is a benthic species in intimate contact with the sediment, therefore probably at higher risk from sediment-associated contaminants. *Cynoglossus* spp. consumes primarily benthic invertebrates such as molluscs, crustaceans, and worms present in or on the surface of the bottom sediments. Exposure to COCs can occur either through direct contact with water and sediments or through the consumption of contaminated prey. This species was also considered a suitable receptor because it is a commercially valuable species, and trace metal concentrations in tissues have been a routine component of the ESC environmental monitoring program since January 1993.

Chinese White Dolphin — Chinese white dolphins (*Sousa chinensis*) frequent the waters of the ESC area. This marine mammal was selected as a receptor of concern because it is a protected species, and these dolphins are known to feed at ESC. The dolphins could be at risk if the food source for the dolphins is contaminated. Exposures to elevated levels of contaminants could negatively impact the health and reproductive capability of the dolphins, and ultimately threaten the viability of the population. Hoffmann (1995) reported 25 strandings in the past three years, which suggests that population viability may already be threatened for unknown reasons. Morton (1995a) provides an overview of current status of the Chinese white dolphin in Hong Kong. In addition, the development of a management strategy for the Chinese white dolphin was the subject of a recent coloquium (July 1996) which was attended by local and international experts.

Of the 14 species of cetaceans frequenting Hong Kong territorial waters, only two species remain year round: the Chinese white dolphin and the finless porpoise. A resident population of Chinese white dolphin is found in waters north of Lantau Island; including Sha Chau, Lung Kwu Chau and Chek Lap Kok (Parsons 1994a; Porter, 1994a). Although exact numbers are unknown, the population is thought to consist of approximately 200 individuals (Jefferson, 1996). The highest numbers have been observed in the Lung Kwu Chau and Sha Chau areas (Parsons, 1995).

The dolphin prefers shallow coastal and estuarine waters (Hoffmann, 1995). The unique ecological niche that these dolphins occupy may confine them to a limited geographic range in Hong Kong territorial waters. The Chinese white dolphin is currently protected under the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) and under Chinese state law and Hong Kong law (Hoffmann, 1995). The dolphins are currently threatened by increasing development in the area, and for these reasons the Hong Kong government proposes to establish a 1000 hectare marine sanctuary at Sha Chau and Lung Kwu Chau (Figure 2).

The foraging range of the Chinese white dolphin extends from Fan Lau to the south, Lung Kwu Chau to the north, and Peng Chau/Discovery Bay to the east (Figure 2; Porter, 1994a). The dolphin also feed close to the warm water outfall at Castle Peak Power station (Morton, pers. comm. 1995b). The dolphins prefer feeding in shallow water between 4 to 10 m in depth (Porter, pers. comm. 1994b). Chinese white dolphins feed on a variety of estuarine fish and cephalopod species, but the exact diet is unknown (Parsons, pers. comm. as cited in Hoffmann, 1995; Heinsohn, 1980). Stomach contents of a single stranded dolphin revealed fish otoliths, a single intact fish (*Collichthys lucidus*), and possibly partially digested cephalopod tissue. Since Chinese white dolphins are most likely opportunistic feeders, they probably feed on a variety of common fish found in their feeding grounds (Morton, pers. comm. 1995b). Their tooth and jaw structure suggests a robust diet (e.g., crab, squid, bottom fish species) with a minimum size of perhaps 5 cm (Jefferson, pers. comm. 1995).

Humans — Hong Kong residents were identified as a receptor of concern because consumption of locally caught seafood could be an important exposure route for COCs, in particular COCs such as methylmercury, which has a tendency to biomagnify in food chains. Concentrations of methylmercury in fish are often several thousand times higher than chemical concentrations in the water from which the fish were caught. Although, fish caught at the ESC site probably represent a small fraction of fish consumed by the general public of Hong Kong, certain individuals such as fishermen and their families may consume a disproportionate amount of seafood from ESC. These subpopulations have the potential to be at increased risk from the consumption of seafood from ESC.

A traditional fishing ground exists to the north of Lantau Island. There are two important fishing ports located at Castle Peak Bay and Tai O, and a number of minor anchorages for small craft. Over 700 vessels may operate in the region. Both fin fish and shellfish are commonly taken from these waters by gill netters and trawlers. In general, very little of the catch is discarded; seafood not sold fresh may be dried (Wilson, pers. comm. 1995a).

2.5 CONCEPTUAL SITE MODEL

The conceptual risk assessment model describes the physical relationship between the stressor and the receptors. For this screening-level risk assessment, the stressor is considered as the toxicological effects of the COCs associated with disposal activities at ESC on the ROCs (i.e., fisheries species, Chinese white dolphin, humans) exposed through the consumption of contaminated prey or through contact with contaminants (fisheries species only). Only contaminants directly measured in biota were considered (see Section 2.3.2).

2.5.1 Exposure Pathway Analysis

A conceptual diagram of exposure routes from contaminated sediments at ESC to the ROCs is presented in Figure 3. While the disposal pits are ultimately capped with three metres of inert (i.e., non-contaminated) sand and mud, the disposal process does not prevent all exposure to contaminated muds. Pits are only capped after they are filled to -9 mPD, so ROCs may come into direct contact with contaminated muds before capping. In addition, the sequential use of pits potentially results in continuous exposure (i.e., at least one pit is always operating at any given time). Inadvertent spillage of contaminated mud during the dumping process may result in contamination of the seabed adjacent to the disposal pits. This conservative approach is appropriate in a screening-level risk assessment. The exposure routes considered in this risk assessment are formalized in an exposure pathway analysis schematic in Figure 4.

2.5.2 Endpoint Selection

Assessment endpoints in risk assessments are defined as formal expressions of the values to be protected (Suter, 1993). Possible assessment endpoints include protection of individuals of a single species from adverse effects or protection of a population, community, or ecosystem. For humans, these considerations include ecological relevance, policy goals and societal values, susceptibility to the COCs, and the ability to define the endpoint in operational terms.

The assessment endpoints for this screening-level risk assessment are:

- Health of human seafood consumers in Hong Kong.
- Viability of Chinese white dolphin populations feeding at ESC area.
- Health of individual Chinese white dolphins feeding at ESC area.
- Abundance of commercially-exploited fisheries species.

Measurement endpoints are defined as measurable responses to the COCs that are related to the valued characteristics chosen as the assessment endpoints (Suter, 1993). They should be used to address testable hypotheses relating to the assessment endpoint. The hypotheses provide the logical linkage between measurement and assessment endpoints. The selection of measurement endpoints, therefore, must consider how well they correspond to, or are predictive of, the assessment endpoint. The measurement endpoints and testable hypotheses for corresponding assessment endpoints are provided in Table 4.

3.0
EFFECTS ASSESSMENT

The effects assessment establishes the toxicological relationship between the stressor (i.e., COCs) and the measurement endpoint for each ROC. The end result is of this exercise is the identification of toxicological benchmarks that will be used to evaluate the significance of exposure concentrations to receptor species. The toxicological benchmarks usually represent the highest COC concentrations that are not expected to result in adverse effects.

3.1 FISHES

The measurement endpoint for *Cynoglossus* spp. identified in Section 2.5.2 was the concentration of COCs in muscle tissue. Any assessment of effects, therefore, needs to be linked to muscle tissue concentrations. Two approaches were used to identify COC tissue concentrations not expected to induce adverse effects: (1) maximum allowable toxicant concentrations (MATC) were determined from literature-reported studies linking exposure (i.e., tissue concentrations) to adverse effects, and (2) comparison of tissue concentrations in flatfish from areas generally considered contaminated and uncontaminated. The MATC approach was the preferred option, however, data availability dictated which option was used. Both approaches rely on the assumption that the risk of adverse effects can be linked to muscle tissue concentrations.

Regardless of the approach used, appropriate data was collected through a literature search using the DIALOG online service for scientific and technical literature. Databases accessed on the DIALOG system included Oceanic Abstracts, Enviroline, Pollution Abstracts, Aquatic Science and Fisheries Abstracts, BIOSIS, NTIS, Toxline and others. The search focussed on obtaining studies pertaining to metal accumulation and toxicity in flatfish (i.e., sole, flounder, dab etc.). Supporting information for other fish species was also obtained when species-specific data was lacking.

Maximum Acceptable Toxicant Concentration — Despite an extensive literature search, few studies reported data to support the derivation of a MATC for any of the seven COCs. The lack of a clear relationship between body burdens and toxic effects for many trace metals may be due to the ability of certain organisms to regulate internal concentrations of both essential and non-essential metals. For essential metals (e.g., copper and zinc) which are required for growth and metabolism, optimal concentrations are narrow and under strict homeostatic control (Goldman, 1972; Leland and Kuwabara, 1985). If an organisms is exposed to an environment containing excess quantities of essential or non-essential metals (e.g., cadmium and lead), several strategies are employed to counter potential toxicity. Organisms can limit trace metal accumulation (reduce intake or increase excretion) or sequester metals in tissues rendering them non-toxic (Depledge and Rainbow, 1990; Baker, 1981; Depledge, 1990). In fish, metals are sequestered in the liver by metallothionein, a metal-binding protein (Duquesne and Richard, 1994). The levels of metallothionein were positively correlated with zinc tissue levels in place (Overnell et al., 1987; 1988). The ability to regulate internal concentrations of metals is species-specific. Some organisms such as ascidians and barnacles are non-regulators, while finfish and decapod crustaceans are strong regulators (White and Rainbow, 1987; Phillips and Rainbow, 1989).

The determination of MATC for metals other than mercury was not possible because either data are limited or the results of laboratory tests which have measured concentration of metals in muscle tissue of fish before and after exposure are inconclusive. For instance, cadmium concentration in the muscle of plaice (*Pleuronectes platessa*), exposed to waterborne cadmium sufficient to reduce growth (0.028 ug/g dry weight) was only slightly higher than the concentration in control fish (0.017 ug/g dry weight) (von Westernhagen et al., 1978). In a later experiment, von Westerhagen et al. (1980) exposed plaice to cadmium concentrations sufficient to cause fin erosion, but once again muscle concentrations were only slightly higher in exposed fish than in control fish. Van Hoof and Van San (1981) exposed rudd (*Scardinius erythrophtalmus*) to concentrations of cadmium, chromium, copper and zinc sufficient to cause mortality. Although metal concentrations in the gills, liver and kidney were generally elevated in exposed fish, concentrations in the muscle were either unchanged or only slightly elevated. Pereira et al. (1993) found that cadmium levels above about 0.1 ug/g dry weight reduced hepatosomatic and gonadosomatic indices in winter flounder (*Pleuronectes americanus*), but unfortunately muscle tissue concentrations were not reported in this study.

Mercury was the only COC for which a MATC could be determined. The results of laboratory and field investigations suggest that mercury concentrations above 10-20 ug/g wet weight in muscle are lethal to fish and mercury concentrations above 1-5 ug/g wet weight could cause chronic effects (Niimi and Krisson, 1994). For instance, fish exhibiting lethargy that were collected from Minamata Bay, Japan had mercury concentrations of 20 ug/g wet weight in muscle tissue (Matida and Kumada, 1969), and in a 108-week study with brook trout, tissue concentrations below 2.7 ug/g wet weight did not cause abnormalities, but tissue concentrations of 5-7 ug/g wet weight were associated with associated with toxic effects (McKim et al., 1976). In an experiment with winter flounder (*Pleuronectes americanus*) dosed with methylmercury, fish with muscle tissue concentrations between 1 and 2 ppm did not exhibit adverse physiological effects such as altered osmoregulation (Schmidt-Nielson et al., 1977). Based on this data, a conservative MATC of 1 ug/g wet weight in muscle tissue was derived for mercury.

Environmental Concentrations in Contaminated and Uncontaminated Areas Worldwide — In order to overcome the limitations of the MATC approach for metals other than mercury, a second approach was used comparing body burdens (i.e., tissue concentrations) of COCs in flatfish muscle tissue from areas generally considered contaminated and areas considered uncontaminated around the world. Area designation (i.e., uncontaminated or contaminated) was qualitatively determined based on information provided in each study. It is important to note that the COC concentrations in flatfish reported for contaminated areas were not necessarily associated with adverse effects. In addition, the areas indicated as contaminated may only contain elevated concentrations of a single COC, therefore, values reported for other metals may not represent contamination. Caution must be used when interpreting these results.

Tables 5 and 6 present flatfish muscle tissue COC concentrations for uncontaminated and contaminated areas, respectively. Although, many studies reported metal concentrations in whole body or liver, only concentrations reported in muscle tissue were summarized here to remain consistent with the data collected in the ESC environmental monitoring program. Metals concentrations can vary significantly among tissues, therefore there is little utility in pooling data for different tissues. For instance, metal concentrations in liver, kidney and gills may be significantly higher than concentrations in muscle (Thompson, 1990). COC concentrations originally reported on a dry weight basis were converted to wet weight by assuming a muscle tissue moisture content of 80% (U.S. EPA, 1993).

The data reported in Tables 5 and 6 were reviewed to establish range information for each COC in flatfish muscle tissue from uncontaminated and contaminated areas (see Table 7). In most cases, there is overlap between the ranges found at uncontaminated and contaminated areas, however, this is not unexpected given the nature of the data set and the COCs themselves. Note that in the areas designated as "contaminated," some of the metals may not be elevated with respect to background concentrations. This impacts the contaminated area ranges by artificially lowering the bottom end of the range. It would be most prudent to focus on the ranges for uncontaminated areas, however, limited data availability precludes relying solely on this data. Another factor potentially responsible for overlapping ranges between contaminated and uncontaminated areas is that a variety of factors affect metals uptake and accumulation in fish. Site-specific factors (e.g., sediment grain size, total organic carbon [TOC]) may affect bioavailability of metals and at both contaminated and uncontaminated areas. Furthermore, inter-specific variation in the ability to regulate certain metals may also be a confounding factor. In conclusion, these ranges should be used solely as indicators to qualitatively assess the probability of adverse effects to *Cynoglossus* spp. at ESC and the comparative areas (i.e., VH and TMW).

3.2 CHINESE WHITE DOLPHIN

The effects assessment for the Chinese white dolphin focussed on the derivation of toxicity reference values (TRV). TRV are estimates of the maximum contaminant exposures at which no adverse acute or chronic effects are expected to occur (i.e., a no observed adverse effect level [NOAEL]). They are unique for each COC and are used as ecotoxicity screening values with which to compare actual exposure estimates (calculated in Section 4). The measurement endpoint identified in Section 2.5.2 for the Chinese white dolphin was the daily dose of each COC from the consumption of contaminated prey.

TRV, therefore, must be compatible (i.e., expressed in terms of dosage of COC to dolphins) in order to make relevant comparisons. The approach used for deriving the receptor-specific TRV used in this risk assessment is outlined below.

Opresko et al. (1995) evaluated literature-reported exposure studies in order to select the most appropriate critical concentration (i.e., test organism dosage used as the basis for TRV derivation). The evaluation process used the following hierarchical criteria for selecting critical concentrations for each COC:

- The chemical was administered orally to the test organism.
- Exposure was chronic (i.e., greater than one year or during critical life stage).
- A reproductive endpoint was considered where possible.
- The highest value never causing adverse effects (i.e., NOAEL) was used if available.
- The lowest value causing any adverse effects (i.e., LOAEL) was used if no NOAEL was reported.

Table 8 summarizes the selected exposure studies and the relevant information used to derive each TRV. The derivation process is described below.

The critical concentrations from each exposure study are expressed as the concentration of COC (i.e., mg/kg) in the food administered. Standardized NOAEL or LOAEL dosages (i.e., weight-normalized dosages in units of mg COC/kg test organism/day) were obtained using the following conversion equation:

Equation 3-1

$$Dosage = \frac{food\ concentration\ (mg/kg)\ x\ ingestion\ rate\ (kg/day)}{body\ weight\ of\ test\ organism\ (kg)}$$

where:

food concentration	=	critical concentration reported in study
ingestion rate	=	rate reported in study or calculated allometrically
body weight	=	reported in study or estimated (wet weight)

The resulting weight-normalized critical dosages are referred to as $NOAEL_t$ and $LOAEL_t$, where the subscripted "t" refers to test organism. As the TRV should represent maximum concentrations of COC not associated with adverse effects, any reported $LOAEL_t$ critical dose was extrapolated to a $NOAEL_t$ using widely used extrapolation factor. The following conversion equation was used (Opresko et al., 1995):

Equation 3-2

$$NOAEL_t = \frac{LOAEL_t}{10}$$

where:

$NOAEL_t$	=	test organism NOAEL (mg/kg body weight per day, wet weight)
$LOAEL_t$	=	test organism LOAEL (mg/kg body weight per day, wet weight)
10	=	extrapolation factor

A similar equation was used to convert a subchronic $NOAEL_t$ (i.e., a $NOAEL_t$ from an exposure duration less than one year or considering a non-sensitive life stage) to a chronic $NOAEL_t$ (Opresko et al., 1995):

Equation 3-3

$$chronic\ NOAEL_t = \frac{subchronic\ NOAEL_t}{10}$$

where:

chronic $NOAEL_t$	=	$NOAEL_t$ for chronic (i.e., >10 weeks) exposure to COC
subchronic $NOAEL_t$	=	$NOAEL_t$ for COC exposure <10 weeks
10	=	extrapolation factor

After calculating chronic $NOAEL_t$ dosages for each COC, the values were extrapolated to NOAELs for the Chinese white dolphin using an allometric body scaling factor. This scaling method assumes that responses to toxic chemicals are a function of body size. Smaller animals have higher metabolic rates and are usually more resistant to toxic chemicals because of more rapid rates of detoxification (Opresko et al., 1995). Opresko et al. (1995) provide the following equation to convert $NOAEL_t$ to $NOAEL_w$ (subscripted "w" refers to wildlife species, which is the Chinese white dolphin in this case) (1/4 power in equation based on latest information on allometric scaling between mammals [Sample, pers. comm. 1996]):

Equation 3-4

$$NOAEL_w = NOAEL_t\ x \left[\frac{bw_t}{bw_w}\right]^{\frac{1}{4}}$$

where:

$NOAEL_w$	=	allometrically scaled ROC-specific TRV (mg/kg body weight per day, wet weight)
$NOAEL_t$	=	test organism NOAEL (mg/kg body weight per day, wet weight)
bw_t	=	body weight of test organism (kg wet weight)
bw_w	=	body weight of ROC (kg wet weight)

$NOAEL_w$ values were derived for each COC. To account for the uncertainty associated with extrapolating $NOAEL_t$ values across mammalian orders, a safety factor of 2 was applied to $NOAEL_w$ values. The resulting $NOAEL_{w2}$ values for each COC were used as benchmark toxicity reference values (TRV) for the Chinese white dolphin (see Table 8).

3.3 HUMANS

The effects assessment for humans focussed on gathering the latest toxicological information on each of the COCs, relying primarily on databases provided by U.S. EPA for human health risk assessment. The measurement endpoint listed in Section 2.5.2 for humans is oral intake of COCs. The primary source of information for the effects assessment was the U.S. EPA's Integrated Risk Information System (IRIS) database, which contains the most up-to-date health risk data for humans. If appropriate data were not available through IRIS, then the U.S. EPA's Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1994a) were consulted. Finally, in cases where neither IRIS or HEAST provided data for a particular COC, drinking water quality criteria were used to estimate safe oral intake levels. There are two possible types of resulting benchmark doses depending on the type of toxicological response caused by exposure to a COC causes: reference doses (RfDs) for non-carcinogens and slope factors (SF) for carcinogens.

3.3.1 Systemic Toxicity

Systemic (i.e., non-carcinogenic) toxicity is considered to follow a typical dose-response relationship: there is a dose threshold (i.e., RfD) below which adverse effects are not expected. This concept is based on the existence of protective mechanisms in the body that must be overcome by a toxicant before an adverse effect can be manifested (U.S. EPA, 1989). Given response variability to toxicants in the human population, the RfD derivation approach attempts to be protective of even the most sensitive individuals. Furthermore, the RfDs used herein are specifically developed to be protective of long-term exposure (i.e., over a lifetime) to a compound.

Exposure to any of the COCs at sufficient concentrations may result in adverse systemic effects. It should be noted that exposure to metals is not necessarily negative (see Appendix C). Copper and zinc are essential for life; copper functions in oxygen transport and both copper and zinc are enzyme co-factors or metalloenzymes. Chromium is an example of a desirable element, while humans can survive deficiencies, they are not completely healthy without it (George, 1990). Over-exposure to even these metals, however, can lead to adverse effects. Table 9 presents RfDs for each COC. IRIS (1996) listed accepted RfDs for five of seven COCs; RfDs for copper and lead were not developed due to inconclusive toxicological data.

HEAST (U.S. EPA, 1994a) provides the following equation for calculating an oral RfD from a corresponding drinking water criteria:

Equation 3-5

$$RfD = \frac{WQC \ x \ WI}{BW}$$

where:

RfD	=	Oral reference dose (mg COC/kg body weight wet weight per day)
WQC	=	Water quality criteria (mg/L)
WI	=	Water intake rate (L/day)
BW	=	Body weight (kg, wet weight)

HEAST lists a drinking water criteria of 1.3 mg/L as a guideline for oral ingestion of copper. Using Equation 3-5 and an estimated human body weight of 60 kg (realistic estimate; Shaw, 1995) and a daily water intake rate of 2 L/day, the calculated RfD for copper is 0.043 mg/kg-day. Neither IRIS nor HEAST listed any numerical guidance for lead. The primary reason for this is that lead has been linked to toxic effects (e.g., changes in blood enzymes and neurobehaviour development) at very low levels, which makes the application of the threshold concept difficult to justify. While recognizing this difficultly, it is still important to derive a RfD to provide some indication of risks due to lead ingestion. Two approaches were used to derive an RfD value for lead. First, the proposed U.S. EPA drinking water criterion of 0.005 mg/L (U.S. EPA, 1993) was used in Equation 3-5 to derive a RfD of 0.00017 mg/kg-day for lead. The conservative approach used in drinking water quality criteria deviation means that this RfD is likely to have a high degree of conservatism. Due to the high uncertainty it will be used and interpreted cautiously. Second, the U.S. Food and Drug Administration's Provisional Tolerable Total Intake Level (PTTIL; U.S. FDA, 1993) for lead was used to derive an RfD. The PTTIL was based on blood lead concentrations associated with adverse effects, but reported as ug Pb ingested per day. A safety factor of 10 was incorporated into the development of the PTTIL. Conversion to RfDs involved dividing the PTTIL by adult body weight (i.e., 60 kg) to obtain an RfD of 0.00125 mg Pb/kg body weight per day.

3.3.2 Carcinogenicity

U.S. EPA (1989) states that carcinogenesis is thought not to conform to the threshold concept. Exposure to only a few molecules of a carcinogenic substance can theoretically trigger an adverse effect (e.g., uncontrolled cellular proliferation). There is essentially no level of exposure that does not pose some finite probability, however small, of generating a carcinogenic response (i.e., no threshold exposure level exists below which adverse effects are not expected; U.S. EPA, 1989). IRIS and HEAST were consulted to evaluated the carcinogenic potential of each COC.

Table 10 presents the U.S. EPA's weight-of-evidence classification system for human carcinogenicity. The U.S. EPA uses available data from human studies and animal studies to derive the classification for each compound. The data are combined, and based on the extent to which carcinogenicity was observed in animals or humans, or both, the agent is given a provisional weight-of-evidence classification. Table 11 summarizes the status of each COC in terms of potential for carcinogenic effects. The current toxicological database does not provide sufficient supporting data to evaluate any of the COCs for carcinogenic effects.

4.0
EXPOSURE ASSESSMENT

The exposure assessment develops an exposure profile describing interactions between the stressor (i.e., COCs) and the ROCs. Specifically, the exposure profile quantifies the magnitude and spatial and temporal distributions of exposure for each combination of COC and ROC. In reality, exposure of ROCs to COCs is dependent on a variety of factors (e.g., site use, dietary preference, prey tissue concentrations etc.). For comparative purposes in this risk assessment, however, exposure predictions at TMW and VH will rely on site-specific COC tissue concentration data for target fishery species, but all other exposure information will remain constant among areas.

4.1 EXPOSURE DATA

Routine monitoring of muscle tissue chemistry in eight target fishery organisms (*Charibdis cruciata* [crab], *Cynoglossus* sp. [fish]), *Leiognathus brevirostris* [fish], *Trypauchen vagina* [fish], *Metapenaeus affinis* [shrimp], *Metapenaeus ensis* [shrimp], *Oratosquilla oratoria* [stomatopod], and *Turitella* sp. [mollusc]) has been conducted as part of the ESC cumulative impact monitoring program. A separate sampling program was carried out in September, October and November 1995 to collect consistent data for the two comparative areas (i.e., TMW and VH). To ensure appropriate comparability between datasets, relative risk estimates were calculated for ESC, TMW and VH using data collected during the fall of 1995 (September-November). Absolute risk estimates were calculated for ESC using data collected during the period of 1993-1995 (see EVS, 1996 for details of data quality evaluation).

4.2 FISHES

Muscle tissue concentration measurements have been routinely conducted at ESC as part of CED's environmental monitoring program and have been conducted at TMW and VH as part of a separate sampling program. These measurements are conducted to monitor the degree of transfer of sediment-bound contaminants to marine organisms. Most metals can be metabolically regulated by organisms to a certain degree, however, accumulation in tissues can occur if fish are exposed to sufficient concentrations. Exposure is comprised of two elements: exposure concentration and exposure duration. Measurement of tissue concentrations in marine organisms integrates these two elements to provide a direct indication of exposure to contaminants. The results of muscle tissue monitoring for the target seafood species at ESC for each COC are presented in Figures 5 through 11; muscle tissue monitoring results for VH and TMW are shown for comparative purposes. While the fish *Cynoglossus* spp. was selected as a surrogate for all target fishery organisms, exposure data is provided for all target seafood species to document tissue concentrations in all species used in estimating exposure for the Chinese white dolphin and humans.

Note that arithmetic mean concentrations are shown in Figures 5 through 11; sample variability and sample size can vary dramatically among areas, which is a source of uncertainty when making direct comparisons. Descriptive statistics for each variable are provided in Appendix A by area, COC and species.

4.3 CHINESE WHITE DOLPHIN

4.3.1 Dose Model

The equation used to estimate contaminant uptake for ecological receptors is different from that typically used in human health exposure assessments in that it directly incorporates dietary information and does not include parameters defining exposure frequency, duration, or averaging time. Exposure for ecological receptors is assumed to be continuous unless site-specific behaviourial data show otherwise. The contaminant intake equation used to estimate dolphin exposure to each COC (i.e., intake) through the consumption of contaminated prey is as follows:

Equation 4-1

$$Intake\ (mg/kg\text{-}day) = R \times \Sigma\ (FR_i \times CF_i) \times U$$

where:

R	=	food ingestion rate (kg food/kg of body weight per day, wet weight)
Cf_i	=	concentration of COC contained in i^{th} food source (mg/kg, wet weight)
Fr_i	=	fraction of diet of an i^{th} food source (unitless)
U	=	fraction of time spent at site (unitless)

4.3.2 Exposure Profile

A summary of the biological data used in the dolphin exposure model is shown in Table 12. Ingestion rates of Chinese white dolphins typically range from 0.04-0.06 kg food/kg body weight per day, but could be as high as 0.065 kg food/kg body weight per day (Parsons, 1994b). To be conservative, an ingestion rate of 0.065 kg food/kg body was assumed for the dolphin exposure assessment model. The dolphin was assumed to eat a diet consisting of 50% fish (comprised of equal portions of *Cynoglossus* spp., *Leiognathus brevirostris* and *Trypauchen vagina*) and 50% shrimp (*Metapenaeus affinis* and *M. ensis*). These values are based on the diet of striped dolphins from the Ligurian Sea which consists of about 50% fin fish and 50% invertebrates (Wurtz and Marrale, 1993). Although the Chinese white dolphin is likely to eat mainly pelagic fish and invertebrates, a conservative approach was taken by including benthic organisms, which generally have higher exposure to contaminated sediments. Note that tissue chemistry measurements conducted under the ESC environmental monitoring program and the separate sampling program conducted at TMW and VH have focussed on compositing those tissues considered edible by humans (i.e., muscle tissue). While this adequately addresses risks to public health, muscle tissue concentrations likely underestimate whole-body concentrations. The latter are likely more realistic for estimating dolphin exposure to COCs as they consume the entire organism. The use of muscle tissue concentrations in this risk assessment does not affect relative risk estimates, but may underestimate absolute risks (see uncertainty assessment in Table 22).

Although, dolphins do not feed exclusively at ESC, it may be an important feeding ground. For the exposure model, dolphins were assumed to feed solely at ESC (i.e., U = 1); this assumption was based on two factors: (1) there is no site-specific information to indicate otherwise, and (2) the home range of target fishery species may not be limited to the mud disposal area (i.e., prey tissue concentrations already account for fraction of time prey spend at the site). The latter factor is important if prey species exposed to ESC are fed on in areas away from ESC. As protection of individual Chinese white dolphins was identified as an assessment endpoint (see Section 2.5.2), the 95% upper confidence limit (UCL) of the arithmetic mean value was used to represent prey tissue concentrations for the model.

The predicted intake of COCs to the Chinese white dolphin from ingestion of shrimp and flatfish for ESC, TMW and VH are presented in Table 13.

4.4 HUMANS

4.4.1 Dose Model

The dose equation for human intake of seafood is as follows (modified from U.S. EPA, 1989):

Equation 4-2

$$Intake\ (mg/kg\text{-}day) = \frac{CF \times IR \times FI \times EF \times ED}{BW \times AT}$$

where:

CF	=	Mean contaminant concentration in food (mg/kg, wet weight) (see Equation 4-3)
IR	=	Ingestion rate (kg/day, wet weight)
FI	=	Fraction of seafood ingested from contaminated area (unitless)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)

BW = Body weight (kg)
AT = Averaging time (period over which exposure is averaged [in days]) for non-carcinogens, AT = ED x 365 days/year

Equation 4-2 considers dietary intake of a single seafood species, however, the intake estimates can be refined to account for different diets. A more representative CF term in Equation 4-2 was calculated using the following equation:

Equation 4-3

$$CF = \sum(CF_i \ x \ P_i)$$

where:

CF = Mean contaminant concentration in diet (mg/kg wet weight)
Cf_i = Contaminant concentration in i^{th} seafood species (mg/kg wet weight)
P_i = Proportion of i^{th} seafood species in diet (unitless)

4.4.2 Exposure Profile

To account for natural variability in exposure among different groups of the Hong Kong population, three exposure scenarios were modelled for the exposure assessment:

- *Central Tendency (CT)* - the central tendency exposure scenario will consider risks to the 50th percentile seafood consumer (i.e., average consumer or general population) in Hong Kong.

- *Reasonable Maximum Exposure (RME)* - this exposure scenario can be defined as the highest exposure that is reasonably expected to occur at a site. The RME should not be confused with the upper-bound exposure estimate (i.e., the estimate obtained by using limits to variables that result in the mathematically highest possible dose), which is expected to exceed exposure of all individuals. The intent of the RME is to estimate a conservative case (i.e., well above the average case) that is still within the range of possible exposures.

- *Subsistence Fishing Subpopulation (SFS)* - this exposure scenario will address a specific subpopulation considered to be greatest risk from consumption of contaminated seafood from ESC. Fishermen and their families are likely to consume significantly more seafood than other people in Hong Kong. In addition, the area fished by many fishermen might be restricted due to vessel soundness and power limitations (i.e., may not have access to fishing grounds other than ESC). Thus, not only would this group eat more fish, a higher proportion would come from ESC.

The parameterization (i.e., selection of input values for each parameter) of Equation 4-2 for this screening-level risk assessment relied heavily on the exposure factors reported in Shaw (1995; modified from U.S. EPA, 1992b). Shaw noted that standard default exposure values used in North America were likely to be inappropriate for the Hong Kong population. While Shaw (1995) put much thought into selecting Hong Kong-specific values for each of the exposure variables, the final selection generally relied on making conservative assumptions based on best professional judgement. This is the accepted practice in risk assessment when site-specific information is not available, and was the approach taken for the purposes of the present screening-level investigation. The exposure factors used to parameterize the dose model for each exposure scenario are presented in Table 14.

Seafood represents an important component of the diet of Hong Kong residents. On average, Hong Kong residents consume about 100 grams of seafood each day (Shaw, 1995). In comparison, U.S. residents eat only about 14 grams per day (U.S. EPA, 1994b). Consumption rates are likely to be considerably higher for the RME and SFS exposure scenarios, but no data are available to directly quantify these rates (Shaw, 1995). The consumption rates for these exposure scenarios were assumed to be 200 g/day and 300 g/day for the RME and SFS exposure scenarios, respectively (Shaw, 1995).

Seafood purchased at local markets may come from a variety of geographic locations. Hong Kong Agriculture and Fisheries Department (AFD; as cited in Shaw, 1995) estimates that about 10% of the Hong Kong commercial seafood catch comes from territorial waters. Of this local catch, AFD estimated about 2-4% comes from the ESC area (Shaw, 1995). Based on this data, only 0.2-0.4% of all seafood would come from the ESC region. However, it is likely that local fishermen and their families consume a much larger proportion of seafood from this area. It was assumed for this risk assessment that up to 75% of the seafood in the diet of local fishermen could have been harvested in the vicinity of ESC (Wilson, pers. comm. 1995b). While some local fishermen may have reduced access to areas other than ESC, and thus harvest 75% of their seafood from ESC, it should be noted that this situation is not likely to apply to the entire subsistence fishing community. Therefore, the use of 75% as the fraction of seafood ingested from ESC is conservative. At this point, the proportion of subsistence fishermen that this would accurately apply to is not known.

The average seafood diet of Hong Kong residents consists of 76% fish, 12% crustaceans, 8% molluscs, and 4% cephalopods (Shaw, 1995). These values take into consideration local food preparation methods and eating habits. If cephalopods are classified as fish (they occupy a similar ecological niche as many fish species), then Hong Kong residents eat about 80% fish, 12% shrimp, and 8% benthic molluscs. No data are available to determine the dietary composition of local fishers and their families. Trading amongst local fishers would likely result in long-term exposure to a similar dietary composition as the general public in Hong Kong.

Two types of point estimates of tissue concentrations were used to calculate COC intake rates (i.e., doses) depending on the exposure scenario: arithmetic mean or 95% upper confidence limits (UCL). Arithmetic mean values were used for the General Population exposure scenario. Arithmetic mean values range from realistically estimating the central tendency of a parameter with a normal distribution to conservatively estimating the central tendency of a log-normally distributed parameter. The 95% UCL value represents a conservative estimate of the arithmetic mean. The 95% UCL implies that if one were to randomly re-sample tissue concentrations at an area, there would be a 95% chance that the newly calculated arithmetic mean would fall below the 95% UCL of the first arithmetic mean. The 95% UCL was used for both the Reasonable Maximum Exposure and Subsistence Fishing Subpopulation exposure scenarios.

Confident use of the 95% UCL for the RME and SFS exposure scenarios requires fairly large, or at least consistent, sample sizes at each of the study areas (i.e., ESC, VH, TMW). While tissue concentrations of the target fishery species are routinely monitored at ESC, the database for VH and TMW is based on three monthly sampling investigations. Comparing 95% UCL values among all areas to evaluate relative risks, therefore, is inappropriate. To overcome this problem, comparisons of relative risk for the RME and SFS exposure scenarios among areas were based on arithmetic mean tissue concentrations (n.b., comparisons among areas were made using only data collected during the fall of 1995). Note that absolute COC risk estimates for ESC were still calculated with the 95% UCL (i.e., absolute risk estimates at ESC for RME and SFS were calculated using 95% UCL of all available data, but relative risk estimates were based on the arithmetic mean of data collected in the fall of 1995 [to ensure appropriate comparisons among areas]).

The predicted intakes of COCs by humans through the consumption of seafood for each exposure scenario is presented in Table 15.

5.0 RISK CHARACTERIZATION

The Risk Characterization phase evaluates the likelihood and magnitude of adverse effects occurring as a result of exposure to a stressor. Risks are estimated by integrating the exposure and effects profiles and summarizing the associated uncertainties. The resulting risk estimates are then interpreted in terms of public health and ecological significance. The comparison of risks predicted for East Sha Chau with those predicted for Victoria Harbour and Tai Mun Wan will help the risk interpretation process.

5.1 RISK ESTIMATION

Estimating the risks posed by the disposal of contaminated mud at ESC and the two comparative areas (i.e., TMW and VH) to all ROCs followed the same general approach. Measured or predicted exposure concentrations (i.e., tissue concentrations [fish] or oral doses [dolphins and humans]) were compared to concentrations not expected to result in adverse effects (i.e., MATC or range of COC tissue concentrations at uncontaminated sites [fish], benchmark doses [dolphins and humans]). Where single values were derived for both exposure and effects concentrations, the hazard quotient method was used to evaluate risks. Hazard quotients (HQ) were calculated using the following equation (modified from U.S. EPA, 1989):

Equation 5-1

$$HQ = \frac{Exposure}{Critical\ Value}$$

where:

HQ	=	hazard quotient (unitless)
Exposure	=	exposure concentration (fishes [mg COC/kg wet muscle tissue], dolphins and humans [mg COC/kg body weight per day])
Critical value	=	acceptable risk benchmark (same units as exposure); MATC for fishes, TRV for dolphins, RfD for humans

The interpretation of HQ values is largely dependent on the degrees of conservatism and uncertainty of a particular risk assessment. Based on our experience with screening-level (i.e., conservative) risk assessments, HQs will be interpreted using the following guidelines:

- < 1 = risk of adverse effects is low

- 1 to 10 = some risk of adverse effects, however, typically within the bounds of uncertainty in screening-level risk assessments

- > 10 = moderate to high risk of adverse effects (depending on magnitude of HQ)

The HQ method is simplistic, intuitive and appropriate for screening-level risk assessments. Its primary advantage is its ease of use for screening numerous ROC/COC combinations to determine which might be at greatest risk. The main disadvantage of this approach is that it uses deterministic estimates to predict risk (i.e., single point estimates of exposure and toxicity parameters are used to predict risk).

In an effort to avoid under-estimating risks, the risk assessor conservatively selects the single point estimates; this approach likely leads to risk over-estimation. Probabilistic risk analysis (e.g., Monte Carlo analysis), which is used in quantitative risk assessments, uses the entire distribution of key exposure or toxicity parameters, (i.e., not single point estimates of the parameter) to obtain a more complete picture of risk for a given situation. The disadvantage of probabilistic risk analysis is that it is more labour intensive (i.e., requires more time to complete) and requires more information for each parameter (i.e., entire probability distribution, not just single point estimates), which usually makes it inappropriate for screening-level risk assessments. Ideally, the HQ method is used for screening-level risk assessments and probabilistic risk analysis is subsequently used only for those ROC/COC combinations where HQ estimates are close to or exceed 1.

Exposure to multiple chemicals is not addressed using the HQ method. One technique, called the hazard index (HI) method, that can be applied for exposure scenarios with multiple chemicals involves summing HQ values calculated for each COC. The major disadvantage of the HI method, particularly for metals, is the uncertainty associated with assuming additive interaction among metals. Therefore, the HI method will not formally be used in this risk assessment. Rather, the overall interpretation of each exposure scenario will qualitatively address the possible implications of additive or synergistic effects among metals.

5.1.1 Fishes

For fishes, the HQ method could only be applied to one COC, mercury, because MATC values could not be derived for the other COCs. Risks to fish posed by the other COCs were assessed by qualitatively comparing exposure tissue concentrations to the ranges found in flatfish from uncontaminated and contaminated areas. The HQ result for mercury and the comparisons with flatfish tissue concentration ranges from uncontaminated and contaminated areas worldwide for all COCs are presented in Table 16; their ecological significance is discussed in Section 5.3.1.

5.1.2 Chinese White Dolphin

The risk of adverse ecological effects to Chinese white dolphin was assessed using the HQ method. Comparisons were made between predicted dietary exposure for each COC (Exposure Assessment) and the dolphin-specific ecotoxicological benchmark TRV (Effects Assessment). The HQ results for each exposure scenario are presented in Table 17. Note that absolute risk predictions for ESC are represented by the 95% UCL-based exposure data, while relative risks are represented by the arithmetic mean-based exposure data. The 95% UCL-based HQs for ESC were all less than 1, except for cadmium, which was 1.1. The relative risk HQs showed similar results for all COCs; cadmium HQs for all three areas were close to 1. The ecological significance of these risk estimates is discussed in Section 5.3.2.

5.1.3 Humans

Human health risks due to the consumption of fish exposed to metals-contaminated sediments at ESC were assessed using the HQ method. For each exposure scenario (i.e., CT, RME, SFS), comparisons were made between predicted dietary exposure for each COC and acceptable daily intake levels (i.e., RfDs) established to protect humans. The HQ results are presented in Tables 18 through 20. HQ results for the exposure scenario representing the general population of Hong Kong (i.e., CT exposure scenario) were all substantially less than 1 at ESC, VH and TMW. HQ results for the Reasonable Maximum Exposure exposure scenario were also considerably less than 1 for all areas. HQs for the Subsistence Fishing Subpopulation exposure scenario for ESC were mostly below 1, however, HQs for mercury and lead exceeded 1 (i.e., 1.2 and 2.9, respectively). The relative risk HQs generally showed similar results at all three areas: lead HQs ranged from 0.84 at VH to 2.1 at ESC and TMW, and mercury HQs ranged from 0.90 at VH to 0.98 and 1.1 at TMW and ESC, respectively. The significance of these results is discussed in Section 5.3.3.

As discussed in Section 3.3.1, the approach used to derive the RfD for lead was considered very conservative (i.e., based on drinking water criteria) and interpretations of significance to public health must be made cautiously. A second approach, based on provisional tolerable intake levels used by the U.S. Food and Drug Administration, was used to help place risks from lead into perspective. The HQ results using the U.S. FDA-based RfD for lead are provided in Table 21. None of the resulting HQs exceed 1.

5.2 UNCERTAINTY ASSESSMENT

Uncertainty is defined as imperfect knowledge concerning the present or future state of the system under consideration (Suter, 1993). The degree and magnitude of uncertainty have implications for the interpretation of risk estimates.

Uncertainty in this type of risk assessment is noteworthy because while some values were actually measured (e.g., fish tissue concentrations) and thus have relatively low uncertainty, other values were based on literature-reported information or best professional judgement and have unknown/or higher relative uncertainty. Unmeasured values were assumed to be representative of the prevailing conditions at ESC, however, there is some degree of uncertainty associated with all assumptions. Ideally, the uncertainty of an assumption is low, but high uncertainty does not necessarily mean that the results of a risk assessment are not useful. The use of conservative assumptions, particularly in screening-level risk assessments, can be used to determine upper-bound risk estimates. The resulting risk estimates, while uncertain (i.e., not necessarily precise), are likely to over-estimate potential risks (i.e., predict that a situation is posing unacceptable risks when in fact it is not, which is also known as a false positive). Where appropriate, this approach (i.e., use of conservative assumptions in the face of uncertainty) has been used in this risk assessment to reduce the chances of false negatives.

Table 22 presents the key issues of uncertainty for this risk assessment and estimates their magnitude and potential implications on the risk estimates described in Sections 5.1.1, 5.1.2 and 5.1.3. The compounding of conservative assumptions means that predictions of low risk (i.e., HQ < 1) can be made with a relatively high degree of confidence. In contrast, however, whenever the use of multiple conservative assumptions are applied, the likelihood of over-estimating risk increases. Consequently, any predicted risks, particularly those with HQ between 1 and 10, must be verified before they are used as a basis for action.

5.3 PUBLIC HEALTH AND ECOLOGICAL SIGNIFICANCE

The data reviewed herein and the resultant risk estimates must be interpreted in a realistic context. Communicating the implications and assumptions of this integrated risk assessment is essential to meeting the study objectives and this section therefore discusses the public health and ecological context of the study findings.

5.3.1 Fishes

The HQ for mercury is substantially less than 1 for all of the areas evaluated (ESC, VH and TMW); risks of adverse ecological affects to *Cynoglossus* spp. are low. The comparisons between ESC, VH and TMW, and uncontaminated and contaminated areas worldwide indicate that, as a whole, COC concentrations in fish tissue do not appear significantly elevated at Hong Kong sites. None of the COCs exceeded the range of concentrations found in uncontaminated areas worldwide; those COCs that fell within both ranges were usually only just high enough to enter the range of concentrations found in contaminated areas. As discussed in Section 3.1, the low end of the range found in contaminated areas may actually represent background concentrations for that particular metal in cases where no anthropogenic source of that COC exists (i.e., the designation of that area as "contaminated" was not due to that COC). Therefore, slight exceedences at the low end of the range of concentrations found at contaminated areas does not likely indicate a problem. This is supported by the fact that in each case where a COC concentration falls within both ranges (i.e., within both uncontaminated and contaminated concentration ranges), the COC concentration is still well within the uncontaminated area concentration range.

In conclusion, there is no indication that COC concentrations in fish tissue are sufficiently elevated to result in adverse effects to fish population at ESC. This statement is supported by the EVS (1996) review of fish survey data conducted as part of the ESC environmental monitoring program. Abundance and diversity of fisheries species in trawl catches near or over the ESC disposal area were greater than or similar to those from other more remote stations. This pattern held when only commercially important fish and invertebrates species were considered. No consistent or obvious impacts of disposal activities on trawl catches were detected.

5.3.2 Chinese White Dolphin

The risk estimates presented in Section 5.1.2 indicate very low risks (<1) to the Chinese white dolphin from all COCs except cadmium, where the HQ was 1.1. As a whole (i.e., considering all assumptions), the risk estimates are moderately conservative (see Table 22), therefore, an HQ of this magnitude falls within the bounds of uncertainty of a screening-level risk assessment.

How do the risks posed from cadmium at ESC compare to those predicted for VH or TMW? The relative risk estimates for all three areas are approximately the same; this indicates that: (1) broad-ranging low-level cadmium contamination exists within Hong Kong territorial waters which may be adversely affecting dolphin (i.e., relative risks posed at ESC are not significantly higher than other areas within Hong Kong's territorial waters), or (2) that the degree of conservatism associated with the relative risk estimates has resulted in an overestimation of risks to the Chinese white dolphin. Based on the moderately conservative approach used to derive the risk estimates, and the fact that the supposedly uncontaminated area is predicted to pose similar relative risks for cadmium to the dolphins, it is most likely that the conservative approach has resulted in over-estimating risks to the Chinese white dolphins. However, based on the current uncertainty regarding the general health of the dolphin population in Hong Kong, this issue needs to be further addressed. Recommendations for further actions geared towards resolving this issue are provided in Section 6.

5.3.3 Humans

None of the HQ risk estimates for the CT or the RME exposure scenarios approached 1. This suggests that disposal activities at ESC do not pose unacceptable public health risks for both the general population, represented by the CT exposure scenario, and a subsection of that population deemed at highest risk, represented by the RME exposure scenario. This conclusion is supported by the fact that mean COC concentrations in target fishery species were all well below the limits specified in Hong Kong's Food Adulteration Regulations for metals in seafood.

Risk estimates for subsistence fishermen and their families, represented by the SFS exposure scenario, however, were not as conclusive as for the CT or RME exposure scenarios. HQ results for both lead and mercury exceeded 1 at ESC. The overall approach for the SFS exposure scenario, while highly uncertain in some aspects, was moderately conservative.

The RfD for lead, for example, was derived using a proposed U.S. EPA water quality criteria. The derivation process for water quality criteria involves the application of relatively large safety factors. As discussed in Section 3.3.1, this value should be interpreted cautiously (i.e., it is likely very conservative). To place the risk estimate for ESC in context, the HQ for lead was also just above 1 at TMW, which is intended to represent a relatively uncontaminated area. Furthermore, HQs derived using the U.S. FDA-based RfD for lead were all below 1. These two points suggest that: (1) lead risks are not ESC-specific, and (2) that lead risks may be over-estimated due to the conservatism of the U.S. EPA drinking water-derived RfD. Notwithstanding the possible conservatism of the U.S. EPA drinking water criteria approach, the overall uncertainty regarding lead toxicity to humans precludes ignoring the risk estimates of this approach. Furthermore, the potential for additive or synergistic interactive effects with mercury means that even HQs less than 1 may result in some risks.

The situation for mercury for the SFS exposure scenario is similar to that for the Chinese white dolphin. The absolute risk estimate for ESC is 1.2; relative risk estimates for all areas were approximately 1 (Section 5.3.2).

It is clear the ESC does not pose elevated risks from lead and mercury for fishermen consuming seafood, relative to other areas within Hong Kong's territorial waters. However, there is still a question as to whether fishermen are at risk from consuming seafood caught within Hong Kong waters. Given the moderately conservative approach used in this risk assessment, it is unlikely that consumption of fish from ESC is posing significant health risks to fishermen and their families. Reducing the uncertainty associated with this exposure scenario would provide more conclusive results. Recommendations in this regard are discussed in Section 6.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The screening-level comparative integrated risk assessment focussed on estimating risks posed by mud disposal activities at ESC on local fisheries, the Chinese white dolphin, and humans. The risk assessment was limited to the seven target metals routinely monitored in fishery species at ESC. The major conclusions of the risk assessment are provided below, along with recommendations for further actions where such actions are required.

6.1 FISHERY SPECIES

Conclusions:

- Commercially important fishery species, based on an analysis of the benthic flatfish *Cynoglossus* spp., are not at risk from metals in contaminated sediments disposed of at ESC.

Recommendations:

- None at the present time.

6.2 CHINESE WHITE DOLPHIN

Conclusions:

- Cadmium is the only COC predicted to pose potentially unacceptable risks to the Chinese white dolphin; risks associated with other COCs ranged from slightly below acceptable for mercury to negligible for the remaining five metals.

- Predicted risks due to consumption of cadmium in prey were slightly elevated, but may not be related to mud disposal activities at ESC as similar risks were predicted for VH and TMW.

- In this screening-level risk assessment, predicted risk for cadmium was a consequence of the moderately conservative approach used which may result in an overestimation of risk. However, due to current uncertainty regarding the general health of the local Chinese white dolphin population, further effort would be necessary to confirm this conclusion.

Recommendations:

- Over-estimation of risks results from compounding use of conservative assumptions. Probabilistic risk analysis (e.g., Monte Carlo analysis) is recommended to obtain a more complete estimate of potential risks. Rather than relying on single point estimates of certain parameters as in the current deterministic risk assessment. Probabilistic risk analysis considers the entire distribution of each parameter and uses that information in the risk calculations, reducing the conservative estimates of each variable. Probabilistic risk analysis should be conducted to address risks posed to the Chinese white dolphin from cadmium and mercury, particularly since predicted HQs were slightly above 1 (cadmium) and slightly below 1 (mercury).

- If unacceptable risk levels remain after application of probabilistic risk analysis for mercury, a probabilistic sensitivity analysis should be conducted to determine which parameters should be refined.

- Tissue samples from stranded dolphins should be analyzed for a suite of metal and organic contaminants in a variety of organs and tissues. Results of these analyses could then be evaluated by a toxicologist specializing in marine mammals.

- Risks associated with organic contaminants need to be addressed, particularly since many organic contaminants have a demonstrated potential to bioaccumulate.

- Whole body contaminant measurements in fish should be incorporated into the [ESC environmental monitoring] risk assessment to address maximum intake of COCs by dolphins.

6.3 HUMANS

Conclusions:

- The general population of Hong Kong is not at risk through the consumption of metals in seafood from the ESC.

- The subsection of the general population exposed to reasonable maximum levels of metals in seafood from ESC is also not at risk.

- The subsistence fishing subpopulation may be at risk from the consumption of mercury and lead in seafood. However, those risks may not be related to disposal activities at ESC; similar risks were predicted for VH and TMW.

- Predicted risks for lead and mercury are likely a result of the moderately conservative approach used in this screening-level risk assessment. However, further effort is needed to confirm this conclusion.

Recommendations:

- Over-estimation of risks results from compounding use of conservative assumptions. Probabilistic risk analysis (e.g., Monte Carlo analysis) is recommended to obtain a more complete estimate of potential risks. Rather than relying on single point estimates of certain parameters as in the current deterministic risk assessment. Probabilistic risk analysis considers the entire distribution of each parameter and uses that information in the risk calculations, reducing the conservative estimates of each variable. Probabilistic risk analysis should be conducted to address risks posed to the Chinese white dolphin from cadmium and mercury, particularly since predicted HQs were slightly above 1 (cadmium) and slightly below 1 (mercury).

- If unacceptable risk levels remain after application of probabilistic risk analysis for mercury, a probabilistic sensitivity analysis should be conducted to determine which parameters should be refined (i.e., could evaluate the need for a consumption survey targeting subsistence fishing community).

- More detailed assessment of lead and mercury should also consider how potential interactions between the two metals may affect the subsistence fishing subpopulation.

- Risks associated with organic contaminants need to be addressed, particularly since many organic contaminants have a demonstrated potential to bioaccumulate.

- This risk assessment assumes that exposure to contaminants from sources other than ESC is negligible. There is some indication that consumption of seafood purchased from markets in Hong Kong is another source of exposure to contaminants (Shaw, 1995). Quantifying this exposure route would serve as an additional mechanism to evaluate the relative risks posed by disposal activities at ESC.

- Contaminated concentration data from seafood sold in Hong Kong markets should be evaluated to determine risks compared to ESC.

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FIGURES

Figure 1. General ecological risk assessment framework.

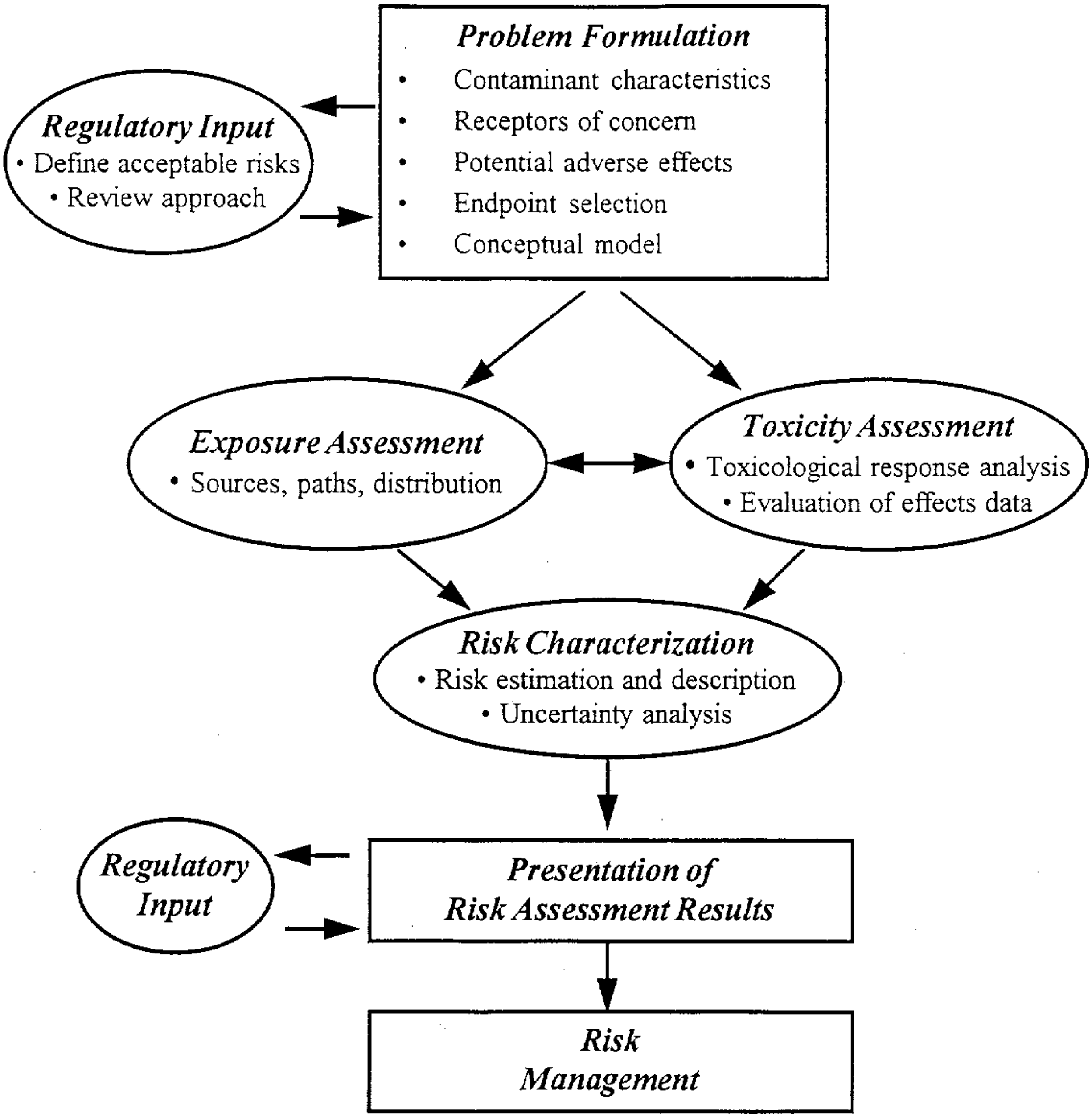


Figure 2. Hong Kong's territorial waters showing East Sha Chau, Victoria Harbour, Tai Mun Wan and foraging area information for the Chinese white dolphin.

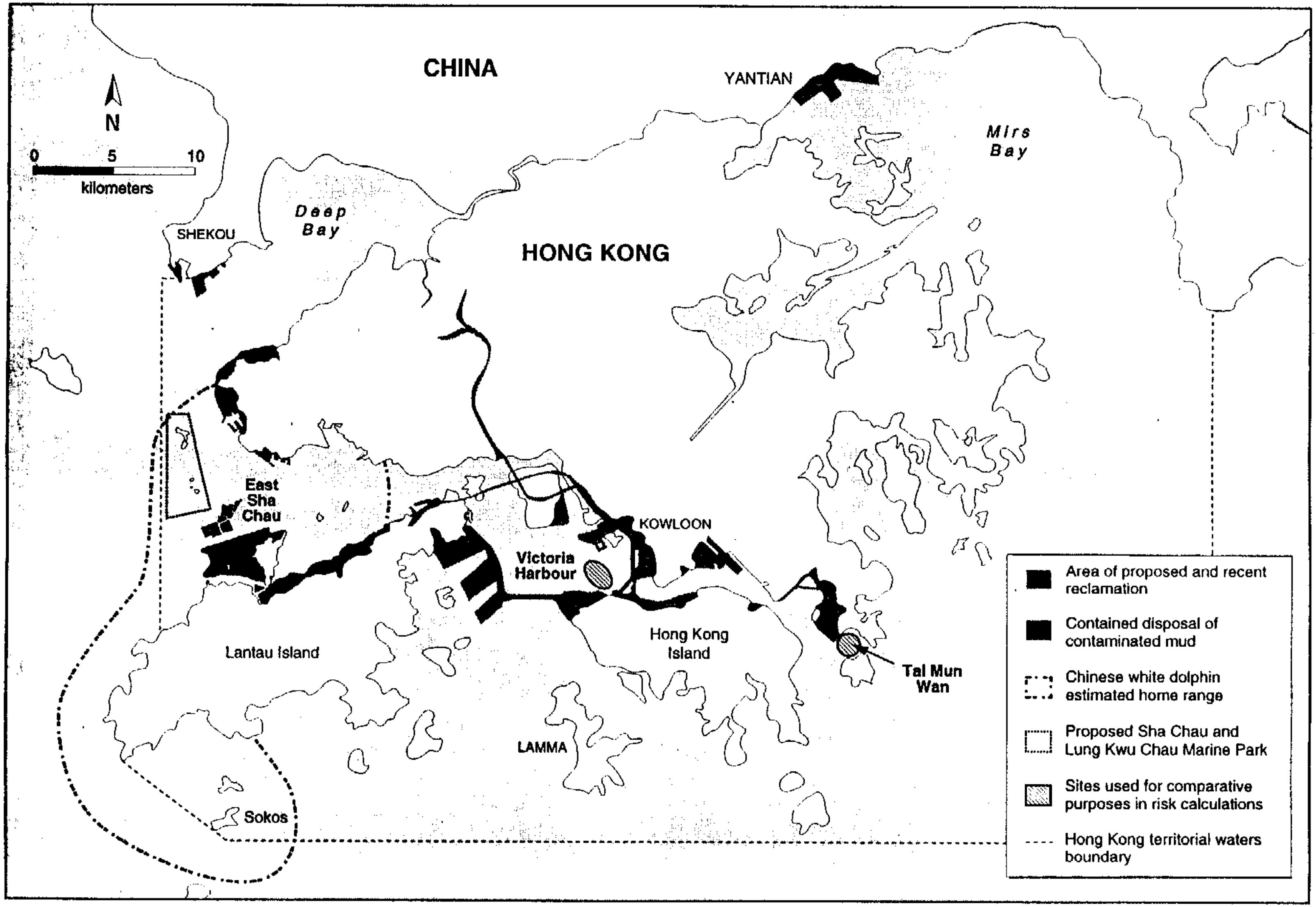


Figure 3. Conceptual diagram of exposure routes.

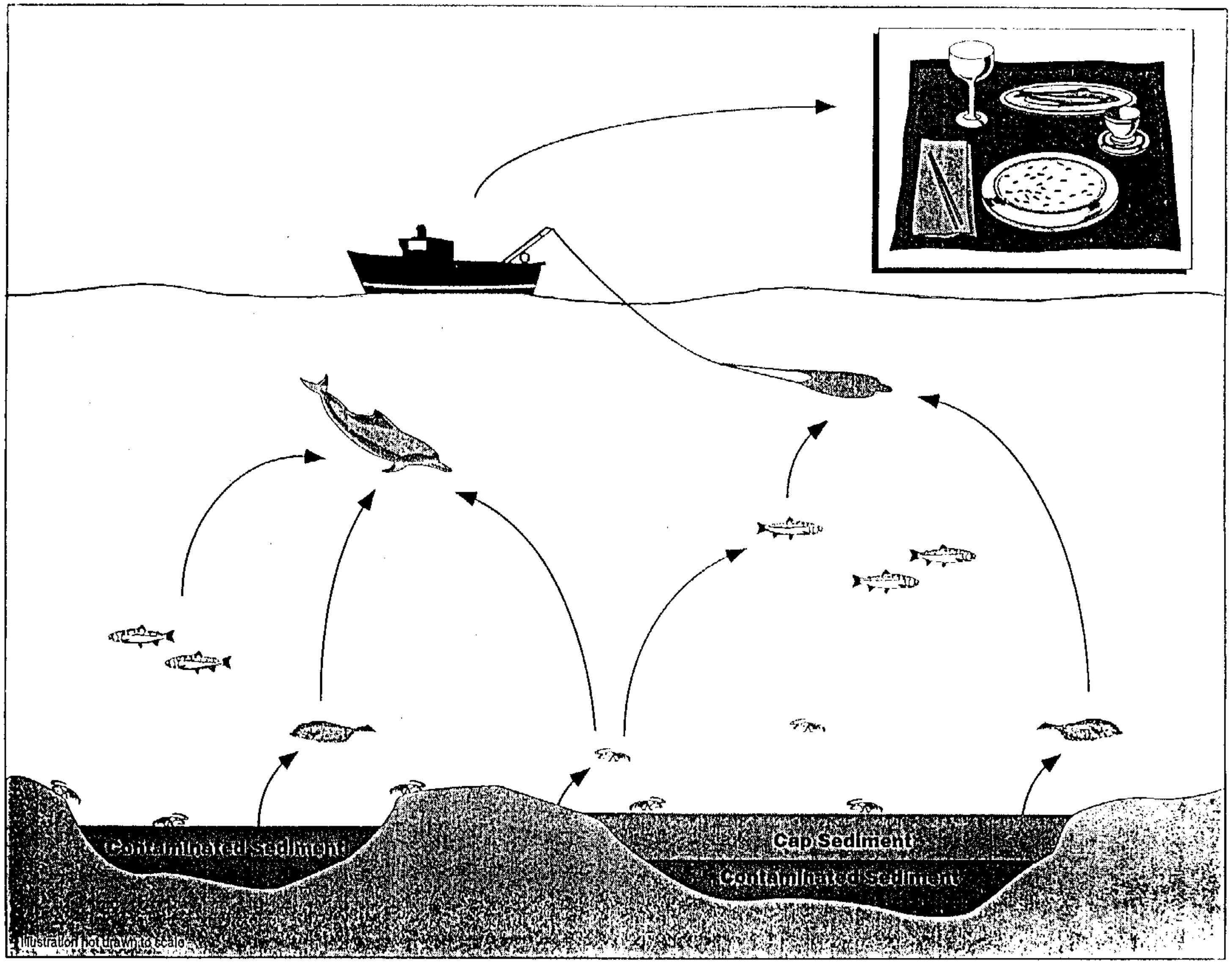


Figure 4. Exposure pathway schematic for East Sha Chau.

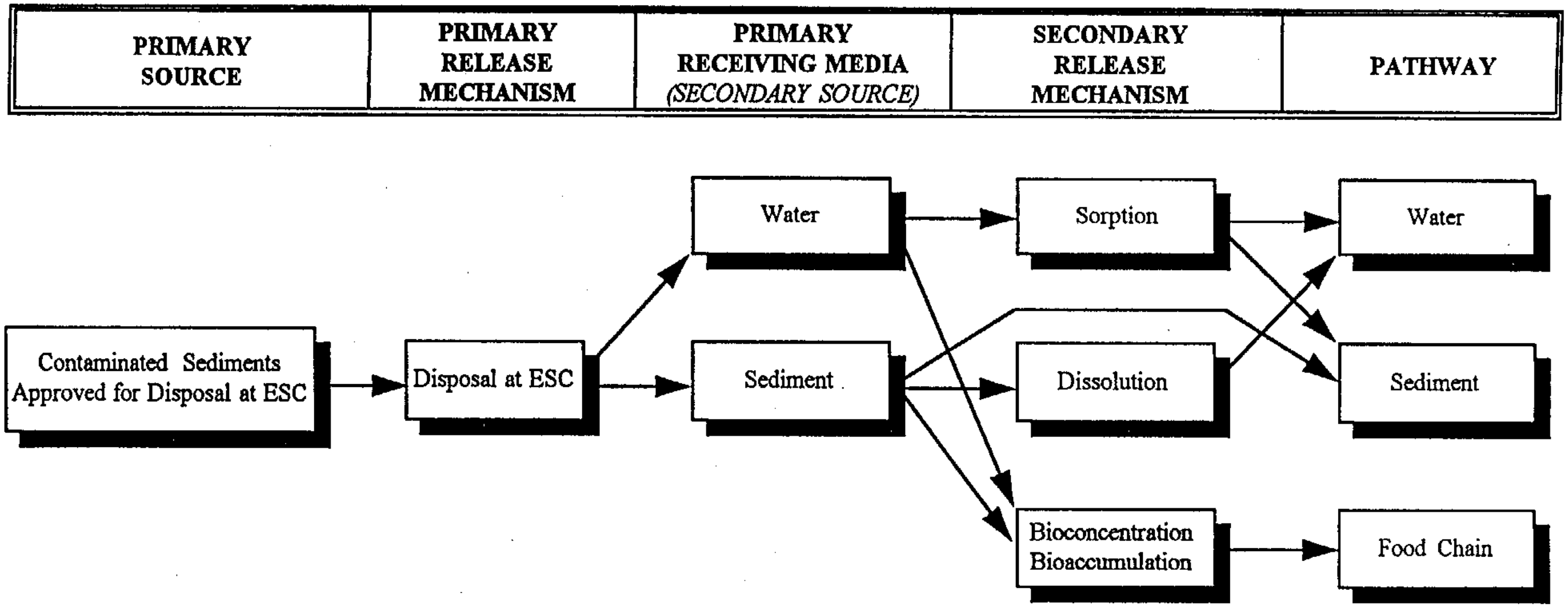


Figure 5. Muscle tissue cadmium concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.

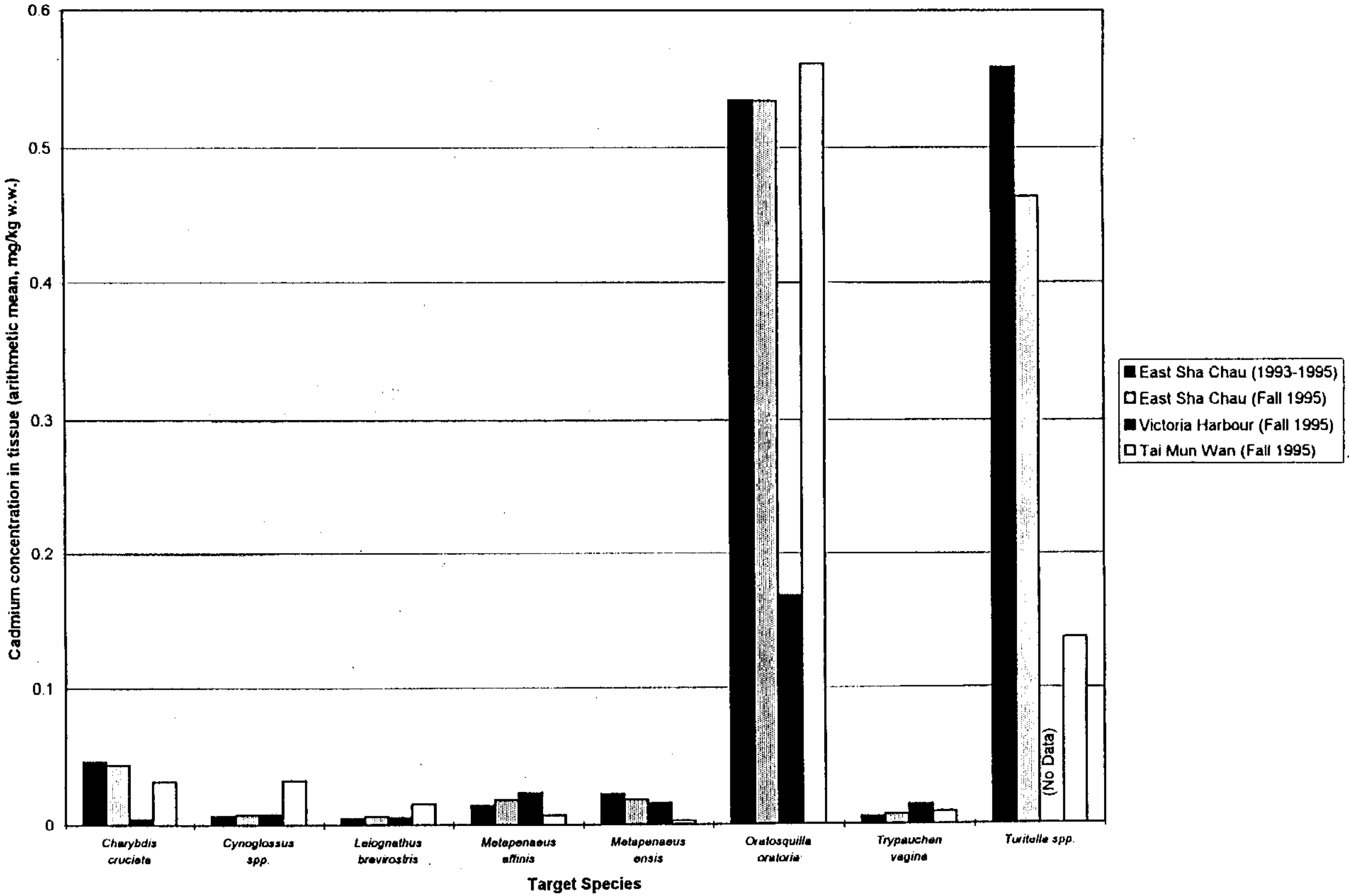


Figure 6. Muscle tissue chromium concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.

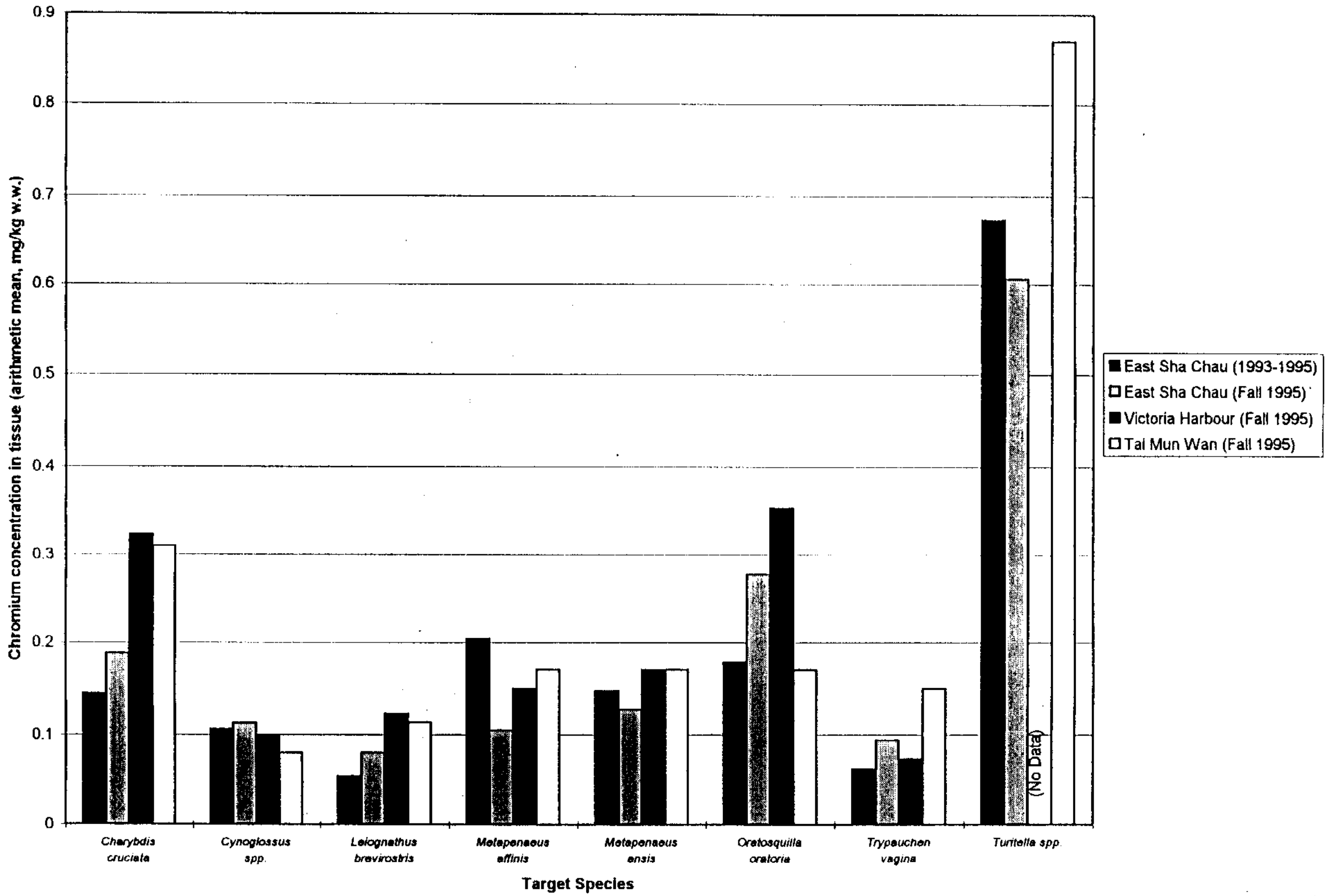


Figure 7. Muscle tissue copper concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.

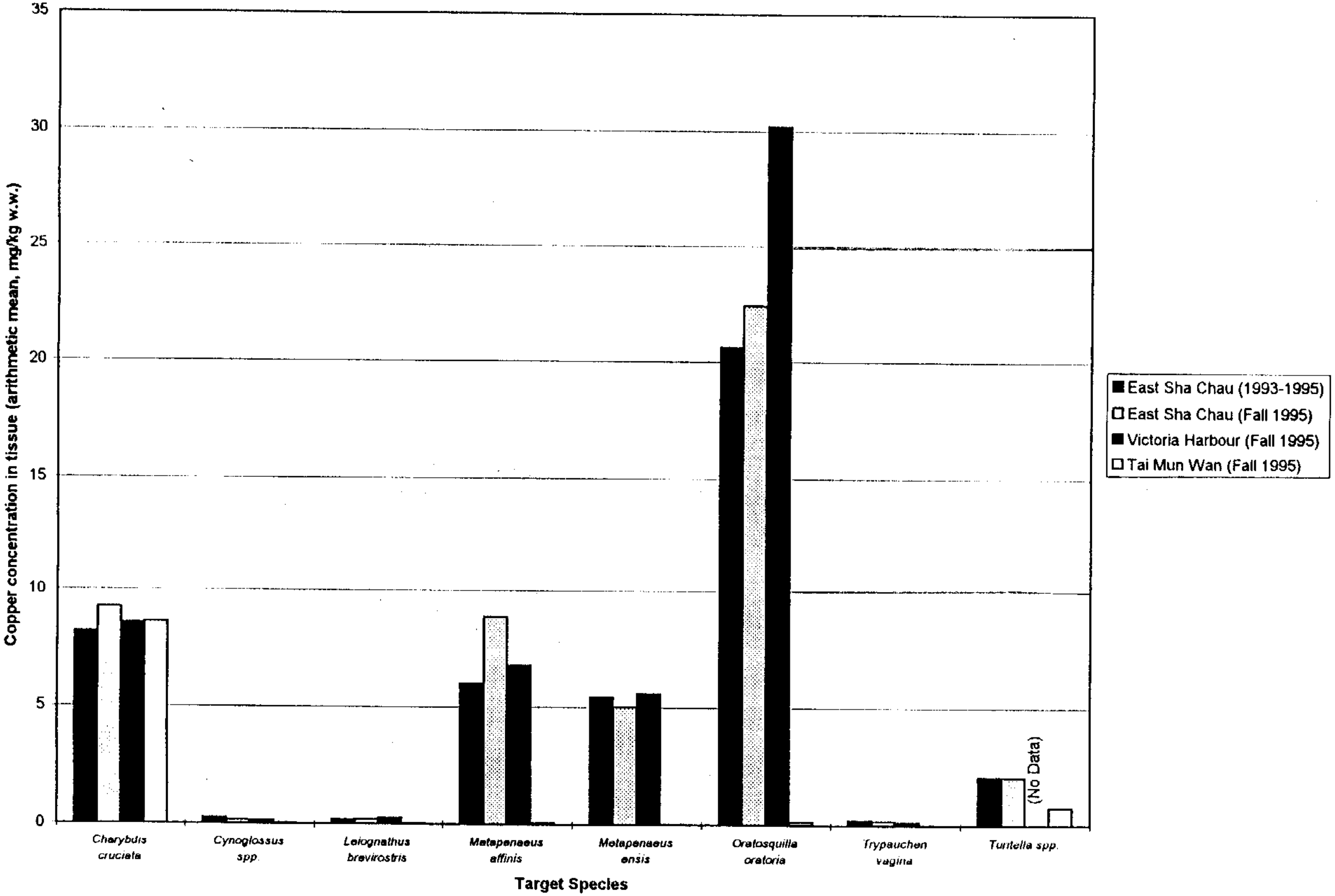


Figure 8. Muscle tissue lead concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.

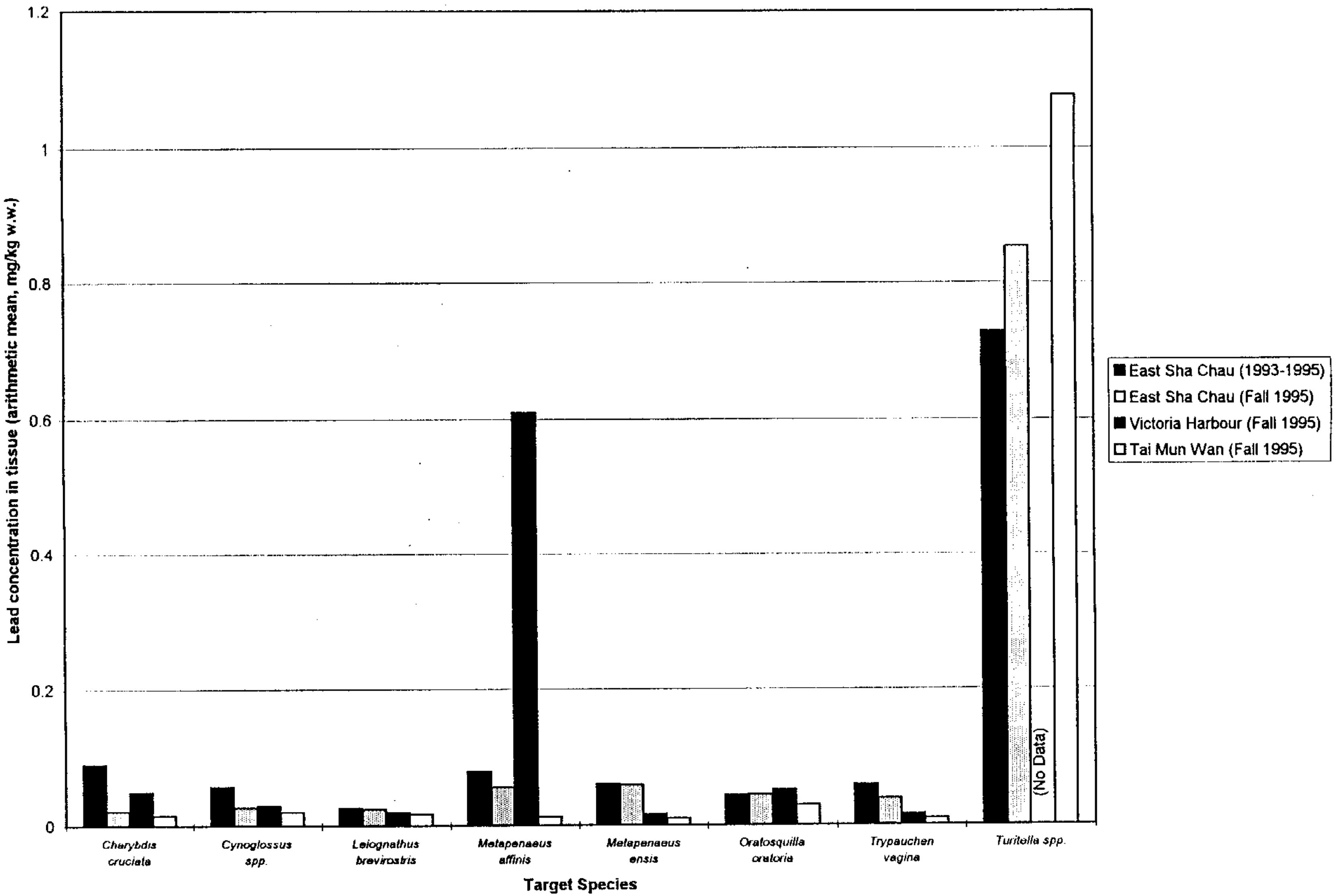


Figure 9. Muscle tissue mercury concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.

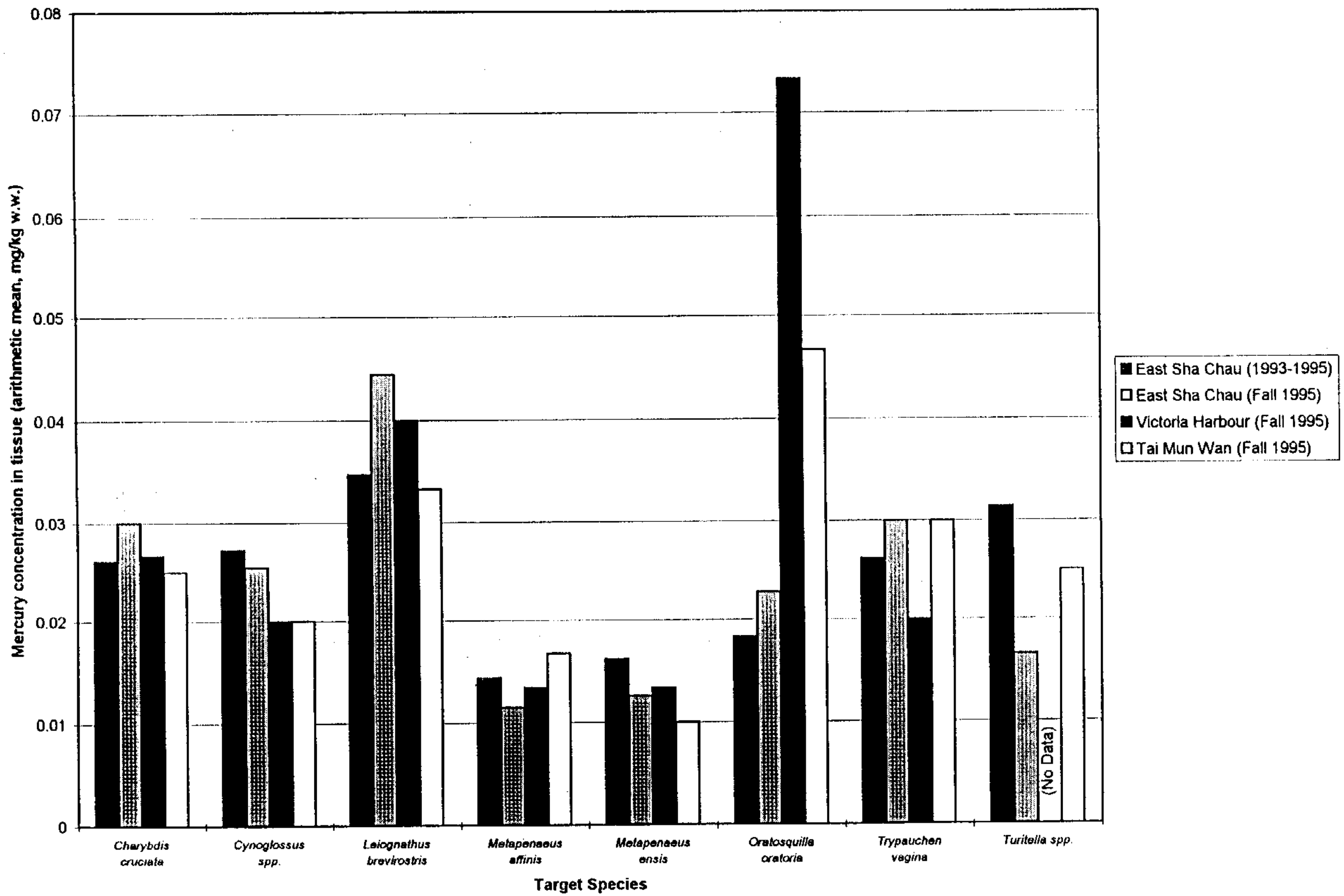


Figure 10. Muscle tissue nickel concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.

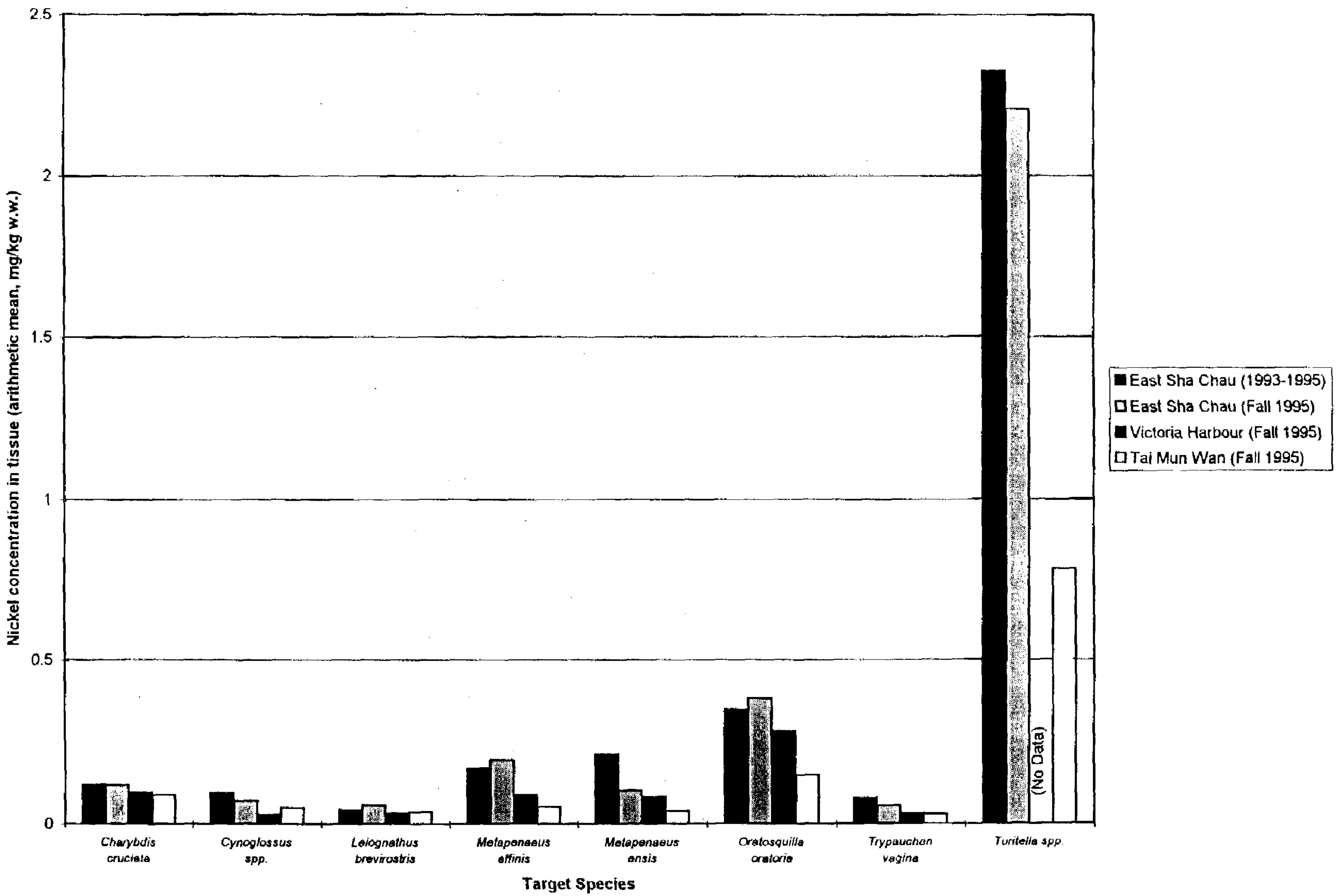
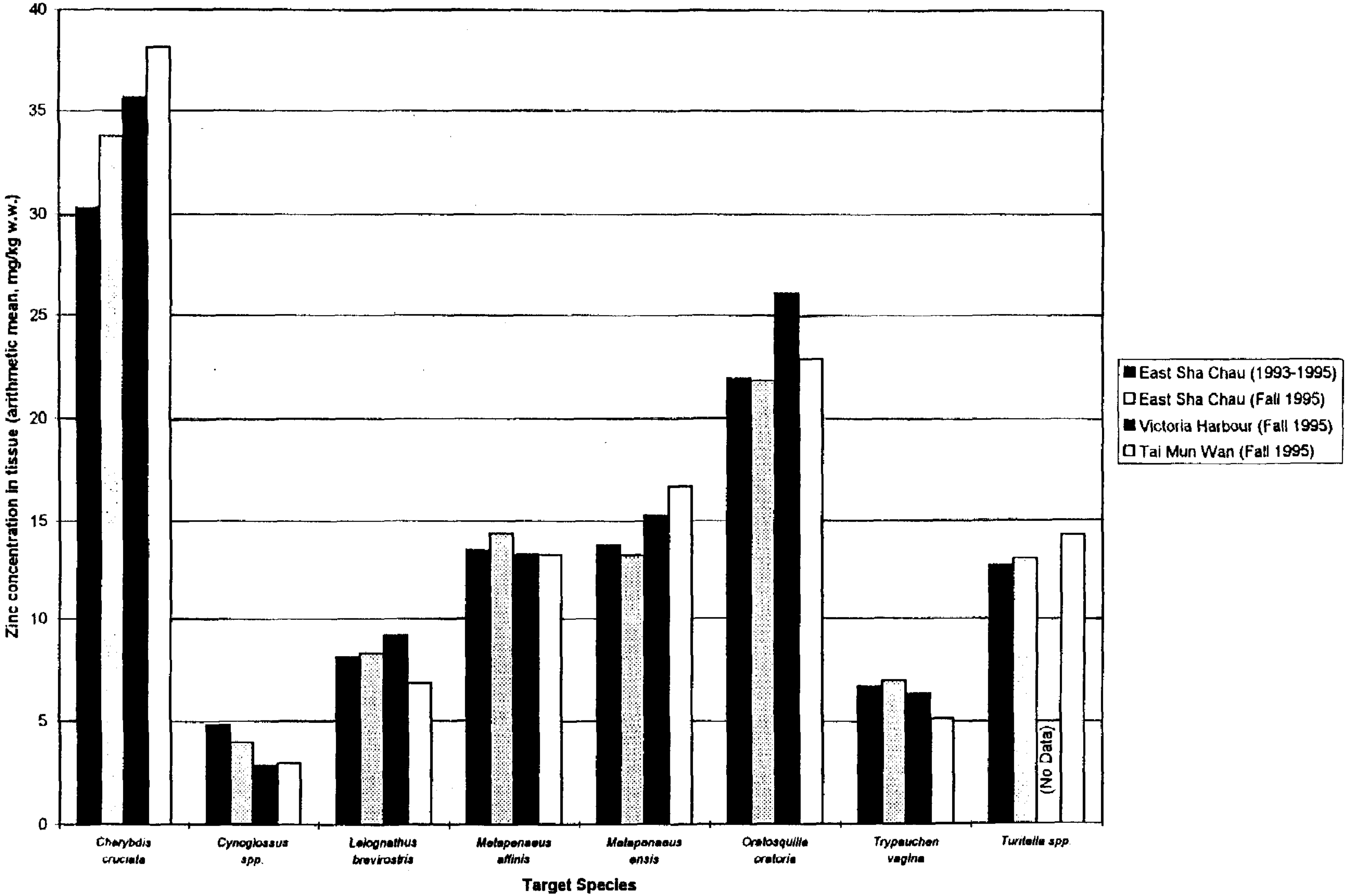


Figure 11. Muscle tissue zinc concentrations for target fishery species for East Sha Chau, Victoria Harbour and Tai Mun Wan.



TABLES

Table 1. Transport and fate properties of COCs. For details see Appendix B.

Contaminants of Concern	General Environmental Transport and Fate Characteristics
Trace Metals	
Cadmium (Eisler, 1985; Clement Associates, 1985)	• naturally occurring but rare • anthropogenic sources include smelters, incineration of fossil fuels and Cd containing materials, fertilizers • insoluble in water unless complexed to ligands such as humic acids, hydroxyl, carbonate, chloride and sulphate ions • mobile in the aquatic environment • removed from aqueous media by complexing with organic materials and adsorbing onto sediment • pH and redox potential may increase chemical mobility and bioavailability of sediment-bound cadmium
Chromium (Clement Associates, 1985; Eisler, 1986a)	• exists in nature and is an essential nutrient • exists as trivalent or hexavalent state; trivalent state strongly adsorbs to sediments hexavelant state is soluble and mobile in surface water • state depends on pH, Eh, hardness, and other compounds present • marine biota, especially benthic organisms accumulate chromium in high levels • uptake through the food chain is more important than direct uptake from seawater • bioaccumulation a minor fate process

Table 1 (continued).

Contaminants of Concern	General Environmental Transport and Fate Characteristics
Copper (Clement Associates, 1985; U.S. EPA, 1985)	• cuprous copper is unstable in normal aquatic pH (6-8), and oxidizes into cupric state • also present as soluble salts with chloride, nitrate, sulphate • speciation depends on complexation, adsorption , precipitation constituents, and pH • copper precipitates at pH>6 and has a strong affinity for hydrous iron and manganese oxides, clay, carbonate minerals, and organic matter • main sources are mining industries and smelters • essential nutrient readily taken up by aquatic organisms • toxicity depends on hardness, alkalinity, total organic carbon concentration, and complexing ability • does not bioaccumulate extensively in aquatic organisms
Lead (Clement Associates, 1985)	• mostly insoluble, except industry produces soluble forms • free lead is adsorbed by metal hydroxides or combines with carbonate or sulphide to produce insoluble compounds • in polluted waters, organic complexation removes lead • fate in aquatic environment mostly due to adsorption to inorganic solids, organic matter, and hydrous metal oxides • sorption depends on pH, Eh, availability of ligands, dissolved and particulate ion concentrations, salinity, and chemical composition • increasing mobility with increasing salinity, decreasing pH, and increasing dissolved organic carbons • strong sorption to sediments • food chain biomagnification is negligible

Table 1 (continued).

Contaminants of Concern	General Environmental Transport and Fate Characteristics
Mercury (Clement Associates, 1985)	• several forms exist: insoluble elemental mercury, inorganic species, and organic species • mercurous (+1) salts are much less soluble than the more commonly found mercuric (+2) salts • forms stable organic complexes that are soluble in organic liquids • nature and solubility of chemical species depend on redox potential and pH of the environment • several compounds can volatilize from aquatic and terrestrial sources into the atmosphere • atmospheric transport is the major environmental distribution pathway and precipitation is the major removal from the atmosphere • photolysis may be important in aquatic systems • adsorption onto suspended and bed sediments is probably the most important fate process in aquatic environments • microbial conversion to methyl and dimethyl forms will remobilize any mercury compound • biomethylation is enhanced by large amounts of available mercury, large numbers of bacteria, the absence of strong complexing agents, near neutral pH, high temperatures, and moderately aerobic environments • strongly bioaccumulated by numerous mechanisms, especially methylmercury in aquatic biota • once it enters a biological system, it is very difficult to eliminate

Table 1 (continued).

Contaminants of Concern	General Environmental Transport and Fate Characteristics
Nickel (Clement Associates, 1985)	• highly soluble in water, therefore very mobile in aquatic systems • becomes insoluble under reducing conditions and with sulphur • forms soluble compounds with hydroxide, carbonate, sulphate, and organic ligands, in aerobic environments below pH 9 • mobility limited by sorption and co-precipitation in unpolluted waters • very little sorption occurs in polluted, organic-rich waters • important fate is incorporation into bed sediments in surface waters • aquatic organisms do not generally accumulate significant amounts from sediment

Table 1 (continued).

Contaminants of Concern	General Environmental Transport and Fate Characteristics
Zinc (Clement Associates, 1985)	• dissolved zinc may occur as free (hydrated) zinc ion or as dissolved complexes and compounds with varying degrees of stability and toxicity. • suspended (undissolved) zinc will either sorb to suspended matter or dissolve with changes in the water chemistry. • zinc is predominantly in the sediment • predominant fate in aerobic systems is sorption of the divalent cation by hydrous iron and manganese oxides, clay minerals, and organic matter • removing zinc from solution depends on composition and concentration of organic ligands, pH, water salinity, and zinc concentration • in reducing environments, zinc precipitates and is less mobile • sorbs readily at higher pH; desorbs from sediments as salinity increases • readily transported in most unpolluted, relatively organic-free waters • essential nutrient, thus strongly bioaccumulates even at low concentrations in aquatic systems • biomagnifies slightly through food web • biota appear to represent a relatively minor sink compared to sediments

Table 2. Toxicological profile of COCs. For details see Appendix C.

Contaminant	General Ecotoxicity of Contaminants of Concern
Cadmium	*Fish* Reduced survival, growth and reproduction, decreased oxygen consumption, enzyme disruption, kidney disfunction, and altered blood chemistry
	Mammals Reduced hemoglobin levels, decreased growth, immunotoxicity, histopathology, birth defects, and leukemia In humans, kidney damage, possible increased risk of cancer, and skeletal disorders
Chromium	*Fish* Reduced growth and survival, altered plasma cortisol metabolism and locomotor activity
	Mammals Adverse effects on blood chemistry, and morphological changes in liver, teratogenic effects, genotoxicity and possibly carcinogenicity In humans, respiratory disease due to inhalation, and possible carcinogenicity
Copper	*Fish* Mortality and behavioral changes in fish
	Mammals Mortality, growth retardation and teratogenicity
Lead	*Fish* Anemia, enzyme inhibition, paralysis, teratogenicity, growth reduction, and reduced survival
	Mammals Mortality, behavioral effects, paralysis, developmental effects, weight loss, and reduced reproduction In humans, loss of appetite, cramps, headaches, fatigue, paralysis, lead encephalopathy, and death

Table 2 (continued).

Contaminant	General Ecotoxicity of Contaminants of Concern
Mercury	*Fish* Mortality, reproductive impairment, behavioral effects, lesions, enzyme disruption, and neurotoxicity
	Mammals Carcinogenic and teratogenic effects In humans, motor and mental impairment, blindness, deafness, microcephaly, intestinal disturbances, tremors, and tissue pathology
Nickel	*Fish* Mortality, deformities, and reduced growth and reproduction.
	Mammals Mortality, genotoxicity, carcinogenicity, immunological, neurological, developmental, and reproductive effects In humans, high doses result in intoxication and nausea
Zinc	*Fish* Mortality, reduced growth, teratogenicity, and reproductive impairment
	Mammals Mortality, immunological, neurological, developmental, genotoxic, and reproductive effects. In humans, digestive disorders, altered immune system, headache, muscular incoordination, renal failure, and death.

Table 3. List of commercially important fish species from the East Sha Chau area (Parsons, 1994b).

Scientific name	Common name
Apogon spp.	Cardinal fishes
Caranx spp.	Scads
Decapterus spp.	Crevalles
Cynoglossus spp.	Soles
Eleutheronema tetradactylus	Threadfin
Gymnothorax reticularis	Moray eel
Hilsa spp.	Hilsa herrings
Ilisha elongata	White herring
Lateolabrax japonicus	Sea perch
Leiognathus spp.	Pony fishes
Mugil spp.	Mullets
Muraepesox spp.	Conger-pike eels
Mylio spp.	Sea breams
Collichthys lucida	Lion head croaker
Pseudosciaena crocea	Yellow croaker
Sciaenidae	Croakers
Sardinella spp.	Sardines
Sebasticus marmoratus	Rockfish
Serranidae	Groupers
Signaus oramia	Rabbitfish
Sillago sibama	Sand borer
Stolephorus spp.	Anchovies
Stromateoides argenteus	White pomfret

Table 4. Assessment and measurement endpoints.

Assessment Endpoints	Testable Hypotheses	Measurement Endpoints
Fisheries Abundance of commercially-exploited fisheries species.	Exposure to sediment contaminants from ESC will result in unacceptable decreases in populations.	Compare tissue concentrations in *Cynoglossus* spp. to concentrations associated with literature-reported reproductive or developmental effects. Compare tissue concentrations in *Cynoglossus* spp. to concentrations found in flatfish from uncontaminated and contaminated areas worldwide. Compare tissue concentrations in *Cynoglossus* spp. from ESC to concentrations found in uncontaminated and contaminated areas in Hong Kong.
Chinese White Dolphin Viability of dolphin populations and the protection of individual dolphins feeding at ESC area.	The consumption of contaminated seafood by the Chinese white dolphin at ESC will result in unacceptably high risks to individuals and/or the population.	Comparison of estimated contaminant doses due to ingestion of seafood from ESC to toxicological reference values. Compare risk estimates for dolphins feeding at ESC to hypothetical risk estimates for dolphins feeding at uncontaminated and contaminated areas in Hong Kong.
Public Health Health of human seafood consumers in Hong Kong.	The consumption of contaminated seafood caught at ESC will result in unacceptably high risks to human consumers in Hong Kong.	Comparison of estimated contaminant doses due to ingestion of seafood caught from the ESC area to human toxicological reference doses (systemic effects) and slope factors (carcinogenic effects). Compare tissue concentrations in *Cynoglossus* spp. from ESC to concentrations found in uncontaminated and contaminated areas in Hong Kong.

Table 5. Concentrations of COCs in flatfish muscle tissue from areas (worldwide) considered uncontaminated.

Species	Location	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Source
Glyptocephalus zachirus	Remote areas off B.C. coast (Canada)	0.029	0.17	0.15	0.346	0.017	-	3.22	Hamilton, 1989
Hippoglossoides ellasodon	Remote areas off B.C. coast (Canada)	0.034	0.14	0.27	0.4	0.117	-	4.14	Hamilton, 1989
Lyopsetta exilis	Remote areas off B.C. coast (Canada)	0.028	0.2	0.19	0.518	0.1	-	3.57	Hamilton, 1989
Microstomas pacificus	Remote areas off B.C. coast (Canada)	0.031	0.12	0.22	0.46	0.037	-	3.5	Hamilton, 1989
Parophyrs vetulus	Remote areas off B.C. coast (Canada)	0.038	0.26	0.42	0.372	0.056	-	4.34	Hamilton, 1989
Atherestes stomias	Remote areas off B.C. coast (Canada)	0.032	0.166	0.34	0.286	0.086	-	4.16	Hamilton, 1989
Merluccius productus	Remote areas off B.C. coast (Canada)	0.04	0.26	0.46	0.528	0.0394	-	3.82	Hamilton, 1989
Inopsetta ischyra	Remote areas off B.C. coast (Canada)	0.036	0.13	0.37	0.252	0.01	-	4.36	Hamilton, 1989
Limanda limanda	Norway (Hvaler Archielago)	0.0012			0.01				Goksoyr et al., 1991
Platichthys flesus	Norway (Hvaler Archielago)	0.0011			0.007				Goksoyr et al., 1991
Pleuronectes platessa	Norway (Hvaler Archielago)	0.00073			0.02				Goksoyr et al., 1991

"-" = no value

All values reported in mg/kg wet weight

Table 6. Concentrations of COCs in flatfish muscle tissue from areas (worldwide) considered contaminated.

Species	Location	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc	Source
Merluccius productus	Puget Sound, U.S.A.	0.012						6.0	Cutshall et al., 1977
Limanda limanda	Great Britain	0.18					7.1	8.1	Wright, 1976
Merluccius merluccius	Israel						0.08		Roth and Hornung, 1977
Pleuronectes platessa	Great Britain	1.44		0.5			2.8	30.3	Wright, 1976
Pleuronectes americanus	Texas, U.S.A.						0.66		Horowitz and Presley, 1977
Pleuronectes americanus	New York Bight, U.S.A.	<0.1	<0.3	0.5-1.1	<0.2-<0.8	0.06-0.09	<0.3-0.5	5.2-6.0	Greig and Wenzloff, 1977
Limanda ferruginea	New York Bight, U.S.A.	<0.1-0.1	<0.1-0.2	0.3-1.2	<0.2-0.8	0.06-0.13	<0.2-0.4	4.2	Greig and Wenzloff, 1977
Microstomus pacificus	California, U.S.A.		0.4	0.6	0.5	0.3	0.2	4	Fowler et al., 1975
Microstomus pacificus	California, U.S.A.						<0.4		McDermott et al. 1976
Solea vulgaris	Israel						0.22		Roth and Hornung, 1977
Platichthys flesus	Norway (Glomma)					0.16			Staveland et al., 1993
Platichthys flesus	Norway (Sorfjorden)					0.28-0.6			Julshamn et al., 1985
Pleuronectes platessa	Firth of Clyde, Great Britain	0.16	0.22	0.46	3.0		0.6	3.4	Halcrow et al., 1973
Platichthys flesus	Firth of Clyde, Great Britain	0.2	0.34	0.6	1.4		0.7	4.4	Halcrow et al., 1973
Whiting	Firth of Clyde, Great Britain	0.18	0.24	0.48	1.4		0.56	3.8	Halcrow et al., 1973
Paralichthys dentatus	Delaware Bay, USA					0.096			Gerhart, 1977
Pleuronectes americanus	Delaware Bay, USA					0.057			Gerhart, 1977
Scophthalmus aquosus	Delaware Bay, USA					0.149			Gerhart, 1977
Pleuronectes platessa	England and Wales	0.07	<0.5	0.85	<0.5	0.08		5.36	Portmann, 1972
Pleuronectes platessa	Iceland, Barents Sea, Norway Coast	0.05	<0.5	1.5	<0.5	0.05		6.6	Portmann, 1972
Pleuronectes platessa	North Sea	0.12	<0.5	0.85	<0.5	0.08		5.7	Portmann, 1972
Platichthys flesus	Danish Coastal waters	0.09		8.62	0.06	0.14		26.34	Jensen and Cheng, 1987
Pleuronectes platessa	Great Britain (Liverpool Bay)					0.13-0.21			Leah et al, 1993
Pleuronectes platessa	Great Britain (Walsey Island)					0.1-0.15			Leah et al, 1993
Platichthys flesus	Netherlands	0.07				0.107			Stronkhorst, 1992
Pleuronectes vetulus	Puget Sound, U.S.A.					0.053-0.163			Bloom, 1992
Microstomus pacificus	Puget Sound, U.S.A.					0.111			Bloom, 1992
Platichthys flesus	Irish Sea					0.23			Leah et al., 1992
Pleuronectes platessa	Scotland (Aberdeen and Stonehaven)			0.38					Syed and Coombs, 1982
Platichthys flesus	Denmark					0.791			Kiorboe et al., 1983
Pseudorhombus jenynsii	Australia (Cockburn Sound)	0.33	0.09	0.17	0.46		0.21	4.9	Plaskett and Potter, 1979
Pleuronectes platessa	Great Britain					0.103			Pentreath, 1976
Limanda limanda1	Norway (Hvaler Archielago)					0.06			Goksoyr et al., 1991
Platichthys flesus1	Norway (Hvaler Archielago)					0.12			Goksoyr et al., 1991
Pleuronectes platessa1	Norway (Hvaler Archielago)					0.12			Goksoyr et al., 1991

All values reported in mg/kg wet weight

Table 7. Ranges of COC concentrations in flatfish muscle tissue from uncontaminated and contaminated areas. Summarized from data presented in Tables 5 and 6.

COC	Uncontaminated Areas (mg/kg wet wt.)	Contaminated Areas (mg/kg wet wt.)
Cadmium	0.00073* - 0.04	0.05 - 1.44
Chromium	0.12 - 0.26	0.09 - <0.5
Copper	0.15 -0.46	0.17 - 8.62
Lead	0.007* - 0.53	0.06 - 3.0
Mercury	0.01 - 0.12	0.05 - 0.79
Nickel	NF	0.08 - 2.8
Zinc	3.2 - 4.4	3.4 - 30.3

* Value reported from area considered contaminated for other metals: no sources of cadmium and lead
NF Not found

Table 8. Toxicity reference values for the Chinese white dolphin and supporting data. See explanatory text in Section 3-2.

	COC						
	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Reference	Wills et al., 1981	Mackenzie et al., 1958	Aulerich et al., 1982	Azar et al., 1973	Wobeser et al., 1976	Ambrose et al., 1976	Schlicker and Cox, 1968
Form	Cadmium Chloride	Chromium (VI)	Copper sulphate	Lead Acetate	Methyl Mercury Chloride	Nickel Sulfate Hexahydrate	Zinc Oxide
Test Species	Rat	Rat	Mink	Rat	Mink	Rat	Rat
Duration	4 generations	1 yr	12 months	3 generations	20 months	3 generations	1-16 days of gestation
Chronic/Subchronic?[1]	Chronic	Chronic	Chronic	Chronic	Subchronic	Chronic	Chronic
Endpoint	reproduction	weight/feeding rate	reproduction	reproduction	reproduction	reproduction	reproduction
Critical concentration type	NOAEL	NOAEL	NOAEL	NOAEL	NOAEL	NOAEL	NOAEL
Critical concentration (mg/kg diet)	0.1	25	85.5	100	1.1	500	2000
Ingestion rate$_t$ (kg/d)	0.028	0.046(water)	0.137	0.028	0.137	0.028	0.028
Body weight$_t$ (kg)	0.35	0.35	1	0.35	1	0.35	0.35
Critical Exposure Dose (mg/kg/d)[2]	0.008	3.28	11.7135	8	0.1507	40	160
Convert to NOAEL$_t$?[3]	N	N	N	N	N	N	N
Convert to Chronic?[4]	N	N	N	N	Y	N	N
NOAEL$_t$ (mg/kg/d)	0.008	3.28	11.7135	8	0.01507	40	160
NOAEL$_w$ (mg/kg/d)[5]	0.001704099	0.698680503	3.24395224	1.704098789	0.004173506	8.520493943	34.08197577
Safety Factor[6]	2	2	2	2	2	2	2
TRV (mg/kg/d)	0.00085	0.35	1.6	0.85	0.0021	4.3	17

NOAEL$_t$ refers to test organism
NOAEL$_w$ refers to wildlife organism

[1] Test rated chronic if exposure over a significant portion of test animal's lifetime or during a sensitive life stage).

[2] Critical concentration reported in study converted to daily dose normalized per kilogram body weight (see text for description).

[3] If critical exposure dose is for a LOAEL, apply an extrapolation factor of 10 (see text for description).

[4] If exposure period was subchronic an extrapolation factor of 10 was applied (see text for description).

[5] Extrapolate to Chinese white dolphin (170 kg) using allometric scaling technique (see text for description).

[6] Safety factor applied to all TRVs to account for potential differences between marine and terrestrial mammals.

Table 9. Reference doses for humans for non-carcinogenic effects.

COC	Reference Dose (mg/kg/day)	Source
Cadmium	0.001	IRIS, 1996
Chromium	0.005	IRIS, 1996
Copper[1]	0.043	U.S. EPA, 1994a
Lead[2]	0.00017	U.S. EPA, 1993
Mercury	0.0001	IRIS, 1996
Nickel	0.02	IRIS, 1996
Zinc	0.3	IRIS, 1996

[1] IRIS did not contain a RfD for copper. Value derived from HEAST-reported water quality criteria using Equation 3-5 (U.S. EPA, 1994a).

[2] Neither IRIS nor HEAST contained a RfD for lead. The U.S.EPA (1993) proposed water quality criteria for lead was used to derive a RfD using Equation 3-5 (U.S. EPA, 1994a).

Table 10. U.S. EPA weight-of-evidence classification system for carcinogenicity (U.S. EPA, 1989).

Group	Description
A	Human carcinogen
B1 or B2	Probable human carcinogen: B1 indicates that limited human data are available B2 indicates sufficient evidence in animals and inadequate or no evidence for humans
C	Possible human carcinogen
D	Not classifiable as to human carcinogenicity
E	Evidence of non-carcinogenicity for humans

Table 11. Current carcinogenicity status of COCs.

COC	Carcinogenicity Classification	Summary of status of carcinogenicity
Cadmium	B1	Inadequate evidence for carcinogenicity via oral exposure route
Chromium	A	Slope factor provided for inhalation exposure route; Inadequate evidence for carcinogenicity via oral exposure route
Copper	D	No data in IRIS or HEAST
Lead	B2	Inadequate evidence for carcinogenicity via oral exposure route
Mercury	C	Inadequate evidence for carcinogenicity via oral exposure route
Nickel	*	No data in IRIS or HEAST
Zinc	*	No data in IRIS or HEAST

* Data not provided in IRIS or HEAST

Table 12. Exposure parameters for dietary intake model for Chinese white dolphin.

Parameter	Units	Value	Refererence
Body weight	kg	170	Parsons, 1994b
Ingestion rate	kg food/kg body wt per day	0.065	Parsons, 1994b
Fraction of diet:			
Shrimp[1]	%	50	Wurtz and Marrale, 1993
Fish[2]	%	50	
Concentration of COC in prey tissue	mg/kg wet weight	95% UCL[3] AM[4]	Binnie and CES, 1994, 1995, 1996 (see Appendix A)
Site use	%	100	Assumed values

[1] Comprised equally of muscle tissue from *Metapenaeus affinis* and *M. ensis*.

[2] Comprised equally of muscle tissue from *Cynoglossus* spp., *Leiognathus brevirostris* and *Trypauchen vagina.*

[3] UCL = upper confidence limit on the arithmetic mean; 95% UCL only calculated for East Sha Chau 1993-1995 data (see text for details)

[4] AM = arithmetic mean; AM calculated for Fall 1995 data from East Sha Chau, Victoria Harbour and Tai Mun Wan (see text for details)

Table 13. Predicted intake of COCs for Chinese white dolphin consuming prey from East Sha Chau, Victoria Harbour, and Tai Mun Wan.

COC	Total Intake[1] (mg/kg/day)			
	East Sha Chau		Victoria Harbour	Tai Mun Wan
	1993-1995 (95% UCL)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)
Cadmium	0.00097	0.00084	0.0010	0.00079
Chromium	0.011	0.0069	0.0084	0.0092
Copper	0.22	0.23	0.21	0.0028
Lead	0.0057	0.0029	0.011	0.00088
Mercury	0.0017	0.0015	0.0013	0.0013
Nickel	0.012	0.0069	0.0039	0.0028
Zinc	0.69	0.66	0.66	0.65

AM = arithmetic mean

UCL = upper confidence limit on the arithmetic mean

[1] Total intake estimates are based on muscle tissue concentrations (see Section 5.2 Uncertainty Assessment for discussion of implications)

Table 14. Exposure parameters for dietary intake model for humans.

Parameter	Units	Value			Source
		General Population (Central Tendency)	Reasonable Maximum Exposure (RME)	Fishermen & Families (Subpopulation [SFS])	
Consumption Rate	kg/day wet weight	0.1	0.2	0.3	Shaw, 1995
Fraction of fish/shellfish ingested from each area	unitless	0.003	0.004	0.75	Shaw, 1995; Wilson, 1995
Fraction of diet:					
Fish[1]	%	80	80	80	Shaw, 1995
Crab and Shrimp[2]	%	12	12	12	Shaw, 1995
Mollusc[3]	%	8	8	8	Shaw, 1995
Concentration of COC	mg/kg wet weight	AM[4]	AM[5] 95% UCL[6]	AM[5] 95% UCL[6]	Binnie and CES, 1994, 1995, 1996 (see Appendix A)
Exposure frequency	days/year	350	350	350	Shaw, 1995
Exposure duration	years	23	43	43	Shaw, 1995
Body weight	kg	60	60	60	Shaw, 1995
Averaging Time	days	8395	15695	15695	Shaw, 1995
Lifetime	years	70	70	70	Shaw, 1995

1 Comprised equally of muscle tissue from *Cynoglossus* spp., *Leiognathus brevirostris* and *Trypauchen vagina*.

2 Comprised equally of muscle tissue from *Charybdis cruciata*, *Metapenaeus affini*, *M. ensis* and the benthic stomatod *Oratosquilla oratoria*.

3 Comprised of muscle tissue from *Turitella* sp. as a surrogate for other benthic molluscs (e.g., clams, mussels) consumed by humans

4 AM = arithmetic mean; AM calculated for both East Sha Chau 1993-1995 and East Sha Chau Fall 1995 data (see text for details)

5 AM calculated for Fall 1995 data from East Sha Chau, Victoria Harbour and Tai Mun Wan (see text for details)

6 UCL = upper confidence limit on the arithmetic mean; 95% UCL only calculated for East Sha Chau 1993-1995 data (see text for details)

Table 15. Predicted intake of COCs for humans consuming seafood for East Sha Chau, Victoria Harbour, and Tai Mun Wan.

COC	Total Intake (mg/kg/day)											
	East Sha Chau						Victoria Harbour			Tai Mun Wan		
	General Population (Central Tendency[CT])	General Population (Central Tendency[CT])	Reasonable Maximum Exposure (RME)		Subsistence Fishing Subpopulation [SFS])		General Population (Central Tendency[CT])	Reasonable Maximum Exposure (RME)	Subsistence Fishing Subpopulation [SFS])	General Population (Central Tendency[CT])	Reasonable Maximum Exposure (RME)	Subsistence Fishing Subpopulation [SFS])
	1993-1995 (AM)	Fall 1995 (AM)	1993-1995 95% UCL	Fall 1995 (AM)	1993-1995 95% UCL	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)
Cadmium	3.3E-07	2.9E-07	9.7E-07	7.8E-07	2.7E-04	2.2E-04	6.7E-08	1.8E-07	5.0E-05	2.1E-07	5.7E-07	1.6E-04
Chromium	6.4E-07	7.0E-07	2.1E-06	1.9E-06	6.0E-04	5.2E-04	5.2E-07	1.4E-06	3.9E-04	8.9E-07	2.4E-06	6.7E-04
Copper	7.5E-06	8.1E-06	2.3E-05	2.1E-05	6.5E-03	6.0E-03	8.1E-06	2.2E-05	6.1E-03	1.7E-06	4.6E-06	1.3E-03
Lead	5.0E-07	4.7E-07	1.8E-06	1.3E-06	5.0E-04	3.5E-04	1.9E-07	5.1E-07	1.4E-04	4.8E-07	1.3E-06	3.6E-04
Mercury	1.4E-07	1.5E-07	4.3E-07	3.9E-07	1.2E-04	1.1E-04	1.2E-07	3.2E-07	9.0E-05	1.3E-07	3.5E-07	9.8E-05
Nickel	1.3E-06	1.2E-06	4.2E-06	3.2E-06	1.2E-03	9.0E-04	2.0E-07	5.4E-07	1.5E-04	5.0E-07	1.3E-06	3.7E-04
Zinc	4.1E-05	4.2E-05	1.2E-04	1.1E-04	3.4E-02	3.1E-02	3.6E-05	9.7E-05	2.7E-02	3.8E-05	1.0E-04	2.8E-02

AM = arithmetic mean
UCL = upper confidence limit on the arithmetic mean

Table 16. Risks to the flatfish *Cynoglossus spp.*: (A) hazard quotient risk estimate for mercury; (B) comparison of exposure concentrations of COCs in muscle tissue to literature-reported environmental concentrations for flatfish from uncontaminated and contaminated areas worldwide.

(A)

Study Area	Mercury (AM) (mg/kg wet wt.)	MATC (mg/kg wet wt.)	HQ (unitless)
East Sha Chau (1993-1995)	0.027	1.0	0.027
East Sha Chau (Fall 1995)	0.026	1.0	0.026
Victoria Harbour (Fall 1995)	0.020	1.0	0.020
Tai Mun Wan (Fall 1995)	0.020	1.0	0.020

(B)

COC	Uncontaminated Areas - Worldwide	Contaminated Areas - Worldwide	East Sha Chau		Victoria Harbour	Tai Mun Wan
	Range (mg/kg wet wt.)	Range (mg/kg wet wt.)	1993-1995 (AM) (mg/kg wet wt.)	Fall 1995 (AM) (mg/kg wet wt.)	Fall 1995 (AM) (mg/kg wet wt.)	Fall 1995 (AM) (mg/kg wet wt.)
Cadmium	0.00073* - 0.040	0.05 - 1.44	*0.0070*	*0.0076*	*0.0080*	*0.033*
Chromium	0.12 - 0.26	0.09 - <0.5	<u>*0.11*</u>	<u>*0.11*</u>	<u>*0.10*</u>	*0.080*
Copper	0.15 - 0.46	0.17 - 8.62	<u>*0.28*</u>	<u>*0.17*</u>	<u>*0.17*</u>	*0.050*
Lead	0.0070* - 0.53	0.06 - 3.0	*0.058*	*0.027*	*0.030*	*0.020*
Mercury	0.010 - 0.12	0.05 - 0.79	*0.027*	*0.026*	*0.020*	*0.020*
Nickel	NF	0.08 - 2.8	<u>*0.096*</u>	*0.071*	*0.030*	*0.050*
Zinc	3.2 - 4.4	3.40 - 30.3	<u>4.8</u>	<u>*4.0*</u>	*2.9*	*3.0*

* From a contaminated area, but no major source of this particular metal.
AM = arithmetic mean
NF = Not found.
Italic font means value falls within uncontaminated range only.
<u>Underlined standard font</u> means value falls within contaminated range only.
<u>*Underlined italic font*</u> means value falls within both ranges.

Table 17. Summary of hazard quotient risk estimates for Chinese white dolphin consuming prey from East Sha Chau, Victoria Harbour and Tai Mun Wan.

COC	TRV (mg/kg/day)	East Sha Chau				Victoria Harbour		Tai Mun Wan	
		Total intake[1] (mg/kg/day)	HQ (unitless)	Total intake[1] (mg/kg/day)	HQ (unitless)	Total intake[1] (mg/kg/day)	HQ (unitless)	Total intake[1] (mg/kg/day)	HQ (unitless)
		1993-1995 (95% UCL)	1993-1995 (95% UCL)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)
Cadmium	0.00085	0.00097	**1.1**	0.00084	**1.0**	0.0010	**1.1**	0.00079	0.92
Chromium	0.35	0.011	0.030	0.0069	0.020	0.0084	0.024	0.0092	0.026
Copper	1.6	0.22	0.13	0.23	0.14	0.21	0.13	0.0028	0.0017
Lead	0.85	0.0057	0.0067	0.0029	0.0034	0.011	0.013	0.00088	0.0010
Mercury	0.0021	0.0017	0.82	0.0015	0.70	0.0013	0.62	0.0013	0.64
Nickel	4.3	0.012	0.0028	0.0069	0.0016	0.0039	0.00091	0.0028	0.00065
Zinc	17	0.69	0.040	0.66	0.039	0.66	0.039	0.65	0.038

AM = arithmetic mean

UCL = upper confidence limit on the arithmetic mean

Bold-underline indicates HQ > 1

[1] Total intake estimates are based on muscle tissue concentrations (see Section 5.2 Uncertainty Assessment for discussion of implications)

Table 18. Summary of hazard quotient risk estimates for General Population (Central Tendancy) exposure scenario for consumption of seafood from East Sha Chau, Victoria Harbour and Tai Mun Wan.

COC	Reference Dose (mg/kg/day)	General Population (Central Tendency[CT])							
		East Sha Chau				Victoria Harbour		Tai Mun Wan	
		Total Intake (mg/kg/day)	HQ (unitless)	Total Intake (mg/kg/day)	HQ (unitless)	Total Intake (mg/kg/day)	HQ (unitless)	Total Intake (mg/kg/day)	HQ (unitless)
		1993-1995 (AM)	1993-1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)
Cadmium	0.001	3.3E-07	0.00033	2.9E-07	0.00029	6.7E-08	0.000067	2.1E-07	0.00021
Chromium	0.005	6.4E-07	0.00013	7.0E-07	0.00014	5.2E-07	0.00010	8.9E-07	0.00018
Copper	0.043	7.5E-06	0.00017	8.1E-06	0.00019	8.1E-06	0.00019	1.7E-06	0.000040
Lead	0.00017	5.0E-07	0.0030	4.7E-07	0.0028	1.9E-07	0.0011	4.8E-07	0.0028
Mercury	0.0001	1.4E-07	0.0014	1.5E-07	0.0015	1.2E-07	0.0012	1.3E-07	0.0013
Nickel	0.02	1.3E-06	0.000065	1.2E-06	0.000060	2.0E-07	0.000010	5.0E-07	0.000025
Zinc	0.3	4.1E-05	0.00014	4.2E-05	0.00014	3.6E-05	0.00012	3.8E-05	0.00013

AM = arithmetic mean
Bold-underline indicates HQ > 1

Table 19. Summary of hazard quotient risk estimates for Reasonable Maximum Exposure (RME) exposure scenario for consumption of seafood from East Sha Chau, Victoria Harbour and Tai Mun Wan.

COC	Reference Dose (mg/kg/day)	Reasonable Maximum Exposure (RME)							
		East Sha Chau				Victoria Harbour		Tai Mun Wan	
		Total Intake (mg/kg/day)	HQ (unitless)	Total Intake (mg/kg/day)	HQ (unitless)	Total Intake (mg/kg/day)	HQ (unitless)	Total Intake (mg/kg/day)	HQ (unitless)
		1993-1995 (95% UCL)	1993-1995 (95% UCL)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)	Fall 1995 (AM)
Cadmium	0.001	9.7E-07	0.0010	7.8E-07	0.00078	1.8E-07	0.00018	5.7E-07	0.00057
Chromium	0.005	2.1E-06	0.00043	1.9E-06	0.00037	1.4E-06	0.00028	2.4E-06	0.00047
Copper	0.043	2.3E-05	0.00054	2.1E-05	0.00050	2.2E-05	0.00050	4.6E-06	0.00011
Lead	0.00017	1.8E-06	0.010	1.3E-06	0.0074	5.1E-07	0.0030	1.3E-06	0.0076
Mercury	0.0001	4.3E-07	0.0043	3.9E-07	0.0039	3.2E-07	0.0032	3.5E-07	0.0035
Nickel	0.02	4.2E-06	0.00021	3.2E-06	0.00016	5.4E-07	0.000027	1.3E-06	0.000066
Zinc	0.3	1.2E-04	0.00040	1.1E-04	0.00037	9.7E-05	0.00032	1.0E-04	0.00033

AM = arithmetic mean
UCL = upper confidence limit on the arithmetic mean
Bold-underline indicates HQ > 1

Table 20. Summary of hazard quotient risk estimates for Subsistence Fishing Subpopulation (SFS) exposure scenario for consumption of seafood from East Sha Chau, Victoria Harbour, and Tai Mun Wan.

COC	Reference Dose (mg/kg/day)	Subsistence Fishing Subpopulation (SFS)							
		East Sha Chau				Victoria Harbour		Tai Mun Wan	
		Total Intake (mg/kg/day) 1993-1995 (95% UCL)	HQ (unitless) 1993-1995 (95% UCL)	Total Intake (mg/kg/day) Fall 1995 (AM)	HQ (unitless) Fall 1995 (AM)	Total Intake (mg/kg/day) Fall 1995 (AM)	HQ (unitless) Fall 1995 (AM)	Total Intake (mg/kg/day) Fall 1995 (AM)	HQ (unitless) Fall 1995 (AM)
Cadmium	0.001	2.7E-04	0.27	2.2E-04	0.22	5.0E-05	0.050	1.6E-04	0.16
Chromium	0.005	6.0E-04	0.12	5.2E-04	0.10	3.9E-04	0.078	6.7E-04	0.13
Copper	0.043	6.5E-03	0.15	6.0E-03	0.14	6.1E-03	0.14	1.3E-03	0.030
Lead	0.00017	5.0E-04	**2.9**	3.5E-04	**2.1**	1.4E-04	0.84	3.6E-04	**2.1**
Mercury	0.0001	1.2E-04	**1.2**	1.1E-04	**1.1**	9.0E-05	0.90	9.8E-05	0.98
Nickel	0.02	1.2E-03	0.059	9.0E-04	0.045	1.5E-04	0.0076	3.7E-04	0.019
Zinc	0.3	3.4E-02	0.11	3.1E-02	0.10	2.7E-02	0.091	2.8E-02	0.094

AM = arithmetic mean

UCL = upper confidence limit on the arithmetic mean

Bold-underline indicates HQ > 1

Table 21. Summary of non-carcinogenic lead risks for public health risk estimates for all exposure scenarios using U.S. Food and Drug Administration based RfD.

Exposure Group	Provisional Tolerable Total Intake Level[1] (mg/kg/day)	East Sha Chau				Victoria Harbour		Tai Mun Wan	
		Total Intake (mg/kg/day) 1993-1995 (AM/95% UCL)[2]	HQ (unitless) 1993-1995 (AM/95% UCL)[2]	Total Intake (mg/kg/day) Fall 1995 (AM)	HQ (unitless) Fall 1995 (AM)	Total Intake (mg/kg/day) Fall 1995 (AM)	HQ (unitless) Fall 1995 (AM)	Total Intake (mg/kg/day) Fall 1995 (AM)	HQ (unitless) Fall 1995 (AM)
General Population	0.00125	5.0E-07	0.00040	4.7E-07	0.00038	1.9E-07	0.00015	4.8E-07	0.00039
Reasonable Maximum Exposure	0.00125	1.8E-06	0.0014	1.3E-06	0.0010	5.1E-07	0.00041	1.3E-06	0.0010
Subsistence Fishing Subpopulation	0.00125	5.0E-04	0.40	3.5E-04	0.28	1.4E-04	0.11	3.6E-04	0.29

AM = arithmetic mean
UCL = upper confidence limit on the arithmetic mean
Bold-underline indicates HQ > 1

[1] U.S. Food and Drug Administration, 1993; values for adult tolerable intake converted to mg Pb/kg body weight per day.

[2] Arithmetic mean tissue concentrations used for General Population; 95% UCL used for Reasonable Maximum Exposure and Subsistence Fishing Subpopulation.

Table 22. Evaluation of magnitude of uncertainty, degree of conservatism, and implications of key risk assessment assumptions.

Assumption	Magnitude of Uncertainty	Degree of Conservatism[1]	Implications to Risk Estimates
FISHES			
Selected MATC values are appropriate toxicological benchmark concentrations for risk estimation	Moderate	Moderate MATC for mercury selected after extensive literature search; a NOAEL	Will only affect risk estimate for mercury; any change in toxicological benchmark will directly impact risk estimates.
Tissue concentrations ranges at uncontaminated and contaminated areas worldwide provide adequate information regarding potential risks of adverse effects.	High	Moderate Three main issues: (1) fish have the ability to metabolically regulate some metals to a certain extent; (2) areas indicated as "contaminated" did not likely contain elevated concentrations of all metals; and (3) contamination does not imply adverse biological effects.	This is a complex issue; for some metals a body burden approach may not adequately reflect potential for adverse effects; in these cases, data must be supplemented with population-type studies.
Designation of comparative risk areas as "contaminated" and "uncontaminated."	Moderate	Moderate Little sediment data were available to support designation of areas.	May make some results difficult to interpret (e.g., relatively low lead concentrations in fishery species from Victoria Harbour).

Table 22 (continued).

Assumption	Magnitude of Uncertainty	Degree of Conservatism[1]	Implications to Risk Estimates
CHINESE WHITE DOLPHIN			
Biological characteristics (e.g., size, ingestion rate).	Low	High Where possible, conservative estimates of dolphin characteristics were used to ensure that risk estimates applied to whole population, not just the average member.	While risks to the general population may be over-estimated, the risk estimates are not likely to under-estimate risks to those members of the population at higher risk.
Muscle tissue concentrations in prey are representative of whole body tissue concentrations.	Moderate to High	Moderate to Low Dolphins consume entire prey organism, not just muscle tissue; as metals are often sequestered in internal organs (e.g., liver) as part of metabolic regulation, organs can contain higher concentrations of metals than muscle tissue.	Dietary COC intake estimates may be under-estimated; doses based on whole-body tissue concentrations would not be expected to vary more than 100%. Resulting HQ values potentially two-fold too low, although other conservative assumptions would likely negate any impact on risk estimate.
95% UCL of arithmetic mean muscle tissue concentrations accurately reflects exposure concentrations at ESC.	Moderate	Moderate 95% UCL was used to ensure that exposure concentrations were valid for all members of dolphin population.	Using 95% UCL may increase COC intake estimates by 10% or more for ESC

Table 22 (continued).

Assumption	Magnitude of Uncertainty	Degree of Conservatism[1]	Implications to Risk Estimates
Selected TRV are appropriate toxicological benchmark concentrations for risk estimation.	High	Moderate TRV were extrapolated from studies on other mammals using allometric scaling equation (low conservatism); exposure studies were all equivalent to chronic NOAEL (moderate conservatism); additional safety factor of 2 was incorporated (moderate conservatism).	Any change in toxicological benchmark will directly impact risk estimates. Physiological differences between marine mammals and terrestrial mammals were considered in the application of the additional safety factor.
Diet comprised of benthic and pelagic prey organisms.	High	High Dolphins most likely to consume pelagic species; species used were caught in bottom trawls (i.e., were in close association with sediments).	Actual COC concentrations ingested are by dolphins are likely to be lower than those used in exposure assessment.
Home range limited to size of ESC disposal area (i.e., they only feed at ESC).	High	Moderate Dolphin site use known to extend much farther than ESC (high conservatism); range of prey organisms caught at ESC largely unknown, but likely smaller than dolphins (moderate conservatism).	Proportion of prey in dolphin diet from ESC area assumed to be 100%; in reality this may be much lower which would reduce risk estimates.

Table 22 (continued).

Assumption	Magnitude of Uncertainty	Degree of Conservatism[1]	Implications to Risk Estimates
Designation of comparative risk areas as "contaminated" and "uncontaminated."	Moderate	Moderate Little sediment data were available to support designation of areas.	May make some results difficult to interpret (e.g., relatively low lead concentrations in fishery species from Victoria Harbour).
		HUMANS	
Use of muscle tissue data to estimate exposure to COCs.	Moderate	Moderate The majority of seafood consumption is limited to muscle tissues, however, some use of internal organs does occur.	Actual concentrations ingested in some situations may be slightly higher. Risk estimates, therefore, may be slightly under-estimating risks.
Seafood consumption rates for various exposure scenarios.	Low to Moderate	Low to Moderate Estimates from Shaw (1995) based on retained local landings and retained imports. Consumption rates of fishermen and families based on best professional judgement.	Risk estimates are directly affected by consumption rates. Most likely area of impact would be on RME (likely conservative) and SFS (impact unknown) exposure scenarios.
Dietary make-up assumed to be 80% fish:12% crustaceans:8% molluscs) for each exposure scenario.	Low to High	Low Estimates from Shaw (1995) based on AFD statistics. Likely realistic for CT and RME; unknown for SFS exposure scenario.	Risk estimates directly impacted by COC concentrations in diet; changes in dietary make-up could raise or lower risk estimates.

Table 22 (continued).

Assumption	Magnitude of Uncertainty	Degree of Conservatism[1]	Implications to Risk Estimates
Fraction of seafood from ESC area for various exposure scenarios.	Moderate to High	Low to High Based on AFD estimates reported in Shaw (1995). Estimate likely realistic for CT and RME; SFS fraction of 0.75 likely to be conservative.	Risk estimates are directly affected by what fraction of seafood comes from ESC; changes could lower or raise risk estimates.
Selected TRV are appropriate toxicological benchmark concentrations for risk estimation.	High	Moderate TRV were extrapolated from studies on other mammals using allometric scaling equation (low conservatism); exposure studies were all equivalent to chronic NOAEL (moderate conservatism); additional safety factor of 2 was incorporated (moderate conservatism).	Any change in toxicological benchmark will directly impact risk estimates. Physiological differences between marine mammals and terrestrial mammals were considered in the application of the additional safety factor.
Designation of comparative risk areas as "contaminated" and "uncontaminated."	Moderate	Moderate Little sediment data were available to support designation of areas.	May make some results difficult to interpret (e.g., relatively low lead concentrations in fishery species from Victoria Harbour).

Note: [1] Degrees of conservatism range from high (i.e., high probability of being unrealistically conservative) to low (i.e., realistic) to not conservative (i.e., possibility of under-estimating risks).

APPENDIX A

Fish Tissue Chemistry Data

Chromium concentrations in fishery biota tissue at East Sha Chau

March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.070	0.310	0.130	0.145	0.070	0.180	18	0
Cynoglossus spp.	0.010	1.938	0.060	0.106	0.184	0.135	164	13
Leiognathus brevirostris	0.010	0.170	0.050	0.054	0.035	0.064	46	2
Metapenaeus affinis	0.010	3.562	0.110	0.204	0.410	0.294	82	2
Metapenaeus ensis	0.010	0.500	0.115	0.148	0.111	0.174	72	5
Oratosquilla oratoria	0.060	1.790	0.130	0.178	0.281	0.273	36	0
Trypauchen vagina	0.020	0.190	0.050	0.062	0.041	0.076	34	0
Turitella spp.	0.120	2.660	0.440	0.673	0.593	0.822	64	0

Nickel concentrations in fishery biota tissue at East Sha Chau

March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.060	0.320	0.100	0.122	0.069	0.156	18	0
Cynoglossus spp.	0.001	2.070	0.050	0.096	0.211	0.129	159	55
Leiognathus brevirostris	0.030	0.260	0.030	0.044	0.035	0.055	46	22
Metapenaeus affinis	0.009	1.140	0.100	0.171	0.203	0.217	77	9
Metapenaeus ensis	0.030	3.920	0.120	0.212	0.464	0.322	71	6
Oratosquilla oratoria	0.140	1.190	0.330	0.349	0.173	0.408	36	0
Trypauchen vagina	0.030	0.290	0.070	0.081	0.050	0.098	34	2
Turitella spp.	0.220	7.010	1.730	2.327	1.707	2.756	63	0

Copper concentrations in fishery biota tissue at East Sha Chau

March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.860	18.100	6.280	8.137	5.044	10.645	18	0
Cynoglossus spp.	0.010	1.598	0.235	0.277	0.185	0.306	164	1
Leiognathus brevirostris	0.110	0.470	0.200	0.222	0.082	0.246	46	0
Metapenaeus affinis	2.772	39.400	5.359	5.983	4.156	6.896	82	0
Metapenaeus ensis	2.360	12.480	5.116	5.431	1.892	5.875	72	0
Oratosquilla oratoria	5.710	47.700	19.100	20.641	8.459	23.503	36	0
Trypauchen vagina	0.130	0.560	0.210	0.223	0.082	0.252	34	0
Turitella spp.	0.780	5.760	1.715	2.109	1.201	2.409	64	0

Zinc concentrations in fishery biota tissue at East Sha Chau

March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	5.630	55.400	29.370	30.331	11.132	35.867	18	0
Cynoglossus spp.	1.710	16.200	3.895	4.794	2.369	5.160	164	0
Leiognathus brevirostris	4.410	14.300	8.155	8.110	2.018	8.709	46	0
Metapenaeus affinis	7.669	28.200	13.345	13.544	2.676	14.132	82	0
Metapenaeus ensis	9.520	18.200	13.850	13.780	1.588	14.153	72	0
Oratosquilla oratoria	14.800	32.600	20.510	21.925	4.681	23.509	36	0
Trypauchen vagina	2.230	14.000	6.725	6.683	1.876	7.338	34	0
Turitella spp.	8.340	23.700	12.565	12.779	2.476	13.397	64	0

Cadmium concentrations in fishery biota tissue at East Sha Chau
March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.007	0.152	0.030	0.047	0.042	0.068	18	0
Cynoglossus spp.	0.001	0.042	0.004	0.007	0.007	0.008	163	65
Leiognathus brevirostris	0.003	0.021	0.003	0.005	0.004	0.006	46	23
Metapenaeus affinis	0.003	0.063	0.012	0.015	0.012	0.017	81	5
Metapenaeus ensis	0.000	0.116	0.017	0.023	0.022	0.028	72	5
Oratosquilla oratoria	0.007	1.063	0.517	0.534	0.216	0.607	36	0
Trypauchen vagina	0.003	0.018	0.004	0.006	0.004	0.007	34	10
Turitella spp.	0.110	1.158	0.560	0.558	0.205	0.610	64	0

Lead concentrations in fishery biota tissue at East Sha Chau
March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.010	0.930	0.040	0.091	0.211	0.196	18	0
Cynoglossus spp.	0.004	1.260	0.020	0.058	0.121	0.077	163	34
Leiognathus brevirostris	0.010	0.110	0.020	0.027	0.019	0.032	46	8
Metapenaeus affinis	0.005	2.370	0.030	0.080	0.263	0.137	82	17
Metapenaeus ensis	0.000	1.010	0.030	0.062	0.123	0.091	72	15
Oratosquilla oratoria	0.010	0.150	0.030	0.045	0.030	0.055	36	4
Trypauchen vagina	0.010	0.270	0.050	0.061	0.052	0.079	34	1
Turitella spp.	0.090	5.250	0.455	0.727	0.783	0.923	64	0

Mercury concentrations in fishery biota tissue at East Sha Chau

March 1993 - November 1995 (excluding October 1993 - November 1994)

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.010	0.070	0.025	0.026	0.016	0.034	18	4
Cynoglossus spp.	0.007	0.090	0.020	0.027	0.018	0.030	164	36
Leiognathus brevirostris	0.010	0.130	0.030	0.035	0.022	0.041	46	0
Metapenaeus affinis	0.004	0.060	0.010	0.014	0.011	0.017	82	29
Metapenaeus ensis	0.006	0.050	0.010	0.016	0.010	0.018	72	22
Oratosquilla oratoria	0.010	0.050	0.010	0.018	0.012	0.022	35	13
Trypauchen vagina	0.010	0.100	0.020	0.026	0.021	0.033	34	11
Turitella spp.	0.010	0.300	0.020	0.031	0.039	0.041	64	15

Chromium concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.100	0.310	0.185	0.188	0.066	0.235	10	0
Cynoglossus spp.	0.010	0.800	0.090	0.113	0.138	0.165	29	1
Leiognathus brevirostris	0.020	0.170	0.075	0.080	0.039	0.101	16	0
Metapenaeus affinis	0.010	0.200	0.110	0.105	0.046	0.131	14	1
Metapenaeus ensis	0.010	0.320	0.135	0.128	0.098	0.210	8	2
Oratosquilla oratoria	0.070	1.790	0.170	0.278	0.438	0.531	14	0
Trypauchen vagina	0.020	0.190	0.090	0.094	0.049	0.124	13	0
Turitella spp.	0.120	2.660	0.470	0.606	0.585	0.907	17	0

Nickel concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.060	0.320	0.100	0.119	0.076	0.173	10	0
Cynoglossus spp.	0.030	0.600	0.030	0.071	0.106	0.112	29	13
Leiognathus brevirostris	0.030	0.260	0.040	0.058	0.056	0.088	16	6
Metapenaeus affinis	0.030	1.140	0.115	0.196	0.286	0.361	14	1
Metapenaeus ensis	0.050	0.200	0.080	0.104	0.053	0.148	8	0
Oratosquilla oratoria	0.140	1.190	0.305	0.383	0.253	0.529	14	0
Trypauchen vagina	0.030	0.080	0.060	0.055	0.020	0.068	13	2
Turitella spp.	0.370	7.010	1.510	2.205	2.062	3.265	17	0

Copper concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.860	18.100	8.330	9.201	6.142	13.595	10	0
Cynoglossus spp.	0.010	0.350	0.150	0.165	0.084	0.197	29	1
Leiognathus brevirostris	0.110	0.390	0.200	0.215	0.080	0.258	16	0
Metapenaeus affinis	4.460	39.400	5.360	8.814	9.024	14.024	14	0
Metapenaeus ensis	2.360	6.840	5.215	5.036	1.516	6.304	8	0
Oratosquilla oratoria	5.710	47.700	19.400	22.403	10.050	28.206	14	0
Trypauchen vagina	0.130	0.310	0.180	0.190	0.050	0.220	13	0
Turitella spp.	0.780	5.330	1.760	2.071	1.441	2.811	17	0

Zinc concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	5.630	55.400	33.050	33.763	13.827	43.654	10	0
Cynoglossus spp.	2.370	12.400	3.320	3.995	2.061	4.779	29	0
Leiognathus brevirostris	4.410	14.300	8.290	8.288	2.800	9.780	16	0
Metapenaeus affinis	10.600	28.200	13.450	14.379	4.292	16.857	14	0
Metapenaeus ensis	11.500	15.500	12.850	13.275	1.426	14.467	8	0
Oratosquilla oratoria	14.800	32.600	18.800	21.786	6.227	25.381	14	0
Trypauchen vagina	2.230	14.000	6.880	6.958	2.657	8.563	13	0
Turitella spp.	8.380	19.300	13.000	13.109	2.727	14.511	17	0

Cadmium concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.007	0.130	0.025	0.045	0.039	0.072	10	0
Cynoglossus spp.	0.003	0.036	0.003	0.008	0.008	0.010	29	15
Leiognathus brevirostris	0.003	0.021	0.003	0.007	0.006	0.010	16	8
Metapenaeus affinis	0.003	1.780	0.017	0.144	0.471	0.416	14	2
Metapenaeus ensis	0.003	0.054	0.009	0.019	0.020	0.035	8	2
Oratosquilla oratoria	0.007	0.813	0.535	0.533	0.225	0.663	14	0
Trypauchen vagina	0.003	0.018	0.006	0.007	0.005	0.011	13	6
Turitella spp.	0.110	0.940	0.518	0.464	0.251	0.593	17	0

Lead concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.010	0.060	0.020	0.022	0.016	0.034	10	0
Cynoglossus spp.	0.004	0.080	0.010	0.027	0.025	0.037	29	7
Leiognathus brevirostris	0.010	0.060	0.020	0.024	0.017	0.033	16	1
Metapenaeus affinis	0.010	0.460	0.020	0.057	0.118	0.125	14	2
Metapenaeus ensis	0.010	0.260	0.015	0.060	0.089	0.135	8	1
Oratosquilla oratoria	0.010	0.140	0.030	0.046	0.034	0.066	14	1
Trypauchen vagina	0.010	0.070	0.040	0.040	0.019	0.052	13	1
Turitella spp.	0.090	5.250	0.510	0.854	1.252	1.498	17	0

Mercury concentrations in fishery biota tissue at East Sha Chau

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.010	0.070	0.030	0.030	0.019	0.043	10	0
Cynoglossus spp.	0.010	0.060	0.020	0.026	0.014	0.031	29	8
Leiognathus brevirostris	0.020	0.130	0.030	0.044	0.028	0.059	16	0
Metapenaeus affinis	0.010	0.020	0.010	0.011	0.004	0.014	14	9
Metapenaeus ensis	0.010	0.020	0.010	0.013	0.005	0.016	8	4
Oratosquilla oratoria	0.010	0.050	0.020	0.023	0.012	0.030	14	3
Trypauchen vagina	0.010	0.100	0.020	0.030	0.025	0.045	13	4
Turitella spp.	0.010	0.050	0.010	0.016	0.010	0.022	17	4

Chromium concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.300	0.360	0.310	0.323	0.032	0.403	3	0
Cynoglossus spp.	0.100	0.100	0.100	0.100	NA	NA	1	0
Leiognathus brevirostris	0.070	0.170	0.130	0.123	0.050	0.248	3	0
Metapenaeus affinis	0.140	0.170	0.140	0.150	0.017	0.193	3	0
Metapenaeus ensis	0.160	0.190	0.160	0.170	0.017	0.213	3	0
Oratosquilla oratoria	0.230	0.500	0.330	0.353	0.137	0.692	3	0
Trypauchen vagina	0.050	0.110	0.060	0.073	0.032	0.153	3	0
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Nickel concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.080	0.130	0.080	0.097	0.029	0.168	3	0
Cynoglossus spp.	0.030	0.030	0.030	0.030	NA	NA	1	0
Leiognathus brevirostris	0.030	0.040	0.030	0.033	0.006	0.048	3	1
Metapenaeus affinis	0.050	0.150	0.070	0.090	0.053	0.221	3	0
Metapenaeus ensis	0.060	0.110	0.080	0.083	0.025	0.146	3	0
Oratosquilla oratoria	0.180	0.390	0.280	0.283	0.105	0.544	3	0
Trypauchen vagina	0.030	0.040	0.030	0.033	0.006	0.048	3	2
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Copper concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	3.490	15.100	6.980	8.523	5.957	23.321	3	0
Cynoglossus spp.	0.170	0.170	0.170	0.170	NA	NA	1	0
Leiognathus brevirostris	0.150	0.440	0.260	0.283	0.146	0.647	3	0
Metapenaeus affinis	5.920	8.230	6.080	6.743	1.290	9.948	3	0
Metapenaeus ensis	2.530	7.870	6.330	5.577	2.749	12.404	3	0
Oratosquilla oratoria	21.300	37.400	31.900	30.200	8.184	50.529	3	0
Trypauchen vagina	0.120	0.220	0.130	0.157	0.055	0.293	3	0
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Zinc concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	25.400	40.900	40.700	35.667	8.892	57.755	3	0
Cynoglossus spp.	2.870	2.870	2.870	2.870	NA	NA	1	0
Leiognathus brevirostris	5.600	15.100	6.830	9.177	5.166	22.011	3	0
Metapenaeus affinis	12.500	14.400	13.100	13.333	0.971	15.746	3	0
Metapenaeus ensis	13.300	16.700	15.800	15.267	1.762	19.643	3	0
Oratosquilla oratoria	18.600	33.300	26.300	26.067	7.353	44.332	3	0
Trypauchen vagina	5.560	7.400	6.030	6.330	0.956	8.705	3	0
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Cadmium concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.003	0.007	0.004	0.005	0.002	0.010	3	1
Cynoglossus spp.	0.008	0.008	0.008	0.008	NA	NA	1	0
Leiognathus brevirostris	0.003	0.010	0.004	0.006	0.004	0.015	3	1
Metapenaeus affinis	0.003	0.045	0.024	0.024	0.021	0.076	3	1
Metapenaeus ensis	0.012	0.023	0.014	0.016	0.006	0.031	3	0
Oratosquilla oratoria	0.109	0.266	0.128	0.168	0.086	0.381	3	0
Trypauchen vagina	0.005	0.033	0.007	0.015	0.016	0.054	3	1
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Lead concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.030	0.090	0.030	0.050	0.035	0.136	3	0
Cynoglossus spp.	0.030	0.030	0.030	0.030	NA	NA	1	0
Leiognathus brevirostris	0.010	0.040	0.010	0.020	0.017	0.063	3	1
Metapenaeus affinis	0.010	1.800	0.020	0.610	1.031	3.170	3	0
Metapenaeus ensis	0.010	0.030	0.010	0.017	0.012	0.045	3	0
Oratosquilla oratoria	0.040	0.080	0.040	0.053	0.023	0.111	3	0
Trypauchen vagina	0.010	0.030	0.010	0.017	0.012	0.045	3	1
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Mercury concentrations in fishery biota tissue at Victoria Harbour

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.020	0.040	0.020	0.027	0.012	0.055	3	0
Cynoglossus spp.	0.020	0.020	0.020	0.020	NA	NA	1	0
Leiognathus brevirostris	0.040	0.040	0.040	0.040	0.000	0.040	3	0
Metapenaeus affinis	0.010	0.020	0.010	0.013	0.006	0.028	3	1
Metapenaeus ensis	0.010	0.020	0.010	0.013	0.006	0.028	3	2
Oratosquilla oratoria	0.050	0.090	0.080	0.073	0.021	0.125	3	0
Trypauchen vagina	0.010	0.030	0.020	0.020	0.010	0.045	3	1
Turitella spp.	NA	NA	NA	NA	NA	NA	NA	NA

Chromium concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.280	0.340	0.310	0.310	0.042	0.691	2	0
Cynoglossus spp.	0.080	0.080	0.080	0.080	NA	NA	1	0
Leiognathus brevirostris	0.080	0.150	0.110	0.113	0.035	0.201	3	0
Metapenaeus affinis	0.140	0.190	0.180	0.170	0.026	0.236	3	0
Metapenaeus ensis	0.170	0.170	0.170	0.170	NA	NA	1	0
Oratosquilla oratoria	0.120	0.250	0.140	0.170	0.070	0.344	3	0
Trypauchen vagina	0.150	0.150	0.150	0.150	NA	NA	1	0
Turitella spp.	0.290	1.450	0.870	0.870	0.820	8.240	2	0

Nickel concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.080	0.100	0.090	0.090	0.014	0.217	2	0
Cynoglossus spp.	0.050	0.050	0.050	0.050	NA	NA	1	0
Leiognathus brevirostris	0.030	0.050	0.030	0.037	0.012	0.065	3	2
Metapenaeus affinis	0.030	0.080	0.050	0.053	0.025	0.116	3	1
Metapenaeus ensis	0.040	0.040	0.040	0.040	NA	NA	1	0
Oratosquilla oratoria	0.080	0.190	0.180	0.150	0.061	0.301	3	0
Trypauchen vagina	0.030	0.030	0.030	0.030	NA	NA	1	1
Turitella spp.	0.510	1.060	0.785	0.785	0.389	4.279	2	0

Copper concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	6.340	10.800	8.570	8.570	3.154	36.905	2	0
Cynoglossus spp.	0.050	0.050	0.050	0.050	NA	NA	1	0
Leiognathus brevirostris	0.030	0.050	0.030	0.037	0.012	0.065	3	0
Metapenaeus affinis	0.030	0.080	0.050	0.053	0.025	0.116	3	0
Metapenaeus ensis	0.040	0.040	0.040	0.040	NA	NA	1	0
Oratosquilla oratoria	0.080	0.190	0.180	0.150	0.061	0.301	3	0
Trypauchen vagina	0.030	0.030	0.030	0.030	NA	NA	1	0
Turitella spp.	0.510	1.060	0.785	0.785	0.389	4.279	2	0

Zinc concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	20.900	55.300	38.100	38.100	24.324	256.646	2	0
Cynoglossus spp.	2.970	2.970	2.970	2.970	NA	NA	1	0
Leiognathus brevirostris	5.080	9.310	6.100	6.830	2.207	12.314	3	0
Metapenaeus affinis	12.400	14.500	13.000	13.300	1.082	15.987	3	0
Metapenaeus ensis	16.700	16.700	16.700	16.700	NA	NA	1	0
Oratosquilla oratoria	19.700	26.200	22.700	22.867	3.253	30.948	3	0
Trypauchen vagina	5.100	5.100	5.100	5.100	NA	NA	1	0
Turitella spp.	13.300	15.300	14.300	14.300	1.414	27.006	2	0

Cadmium concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.015	0.050	0.033	0.033	0.025	0.255	2	0
Cynoglossus spp.	0.033	0.033	0.033	0.033	NA	NA	1	0
Leiognathus brevirostris	0.003	0.039	0.005	0.016	0.020	0.066	3	1
Metapenaeus affinis	0.003	0.011	0.007	0.007	0.004	0.017	3	1
Metapenaeus ensis	0.003	0.003	0.003	0.003	NA	NA	1	1
Oratosquilla oratoria	0.225	0.807	0.649	0.560	0.301	1.308	3	0
Trypauchen vagina	0.009	0.009	0.009	0.009	NA	NA	1	0
Turitella spp.	0.113	0.158	0.136	0.136	0.032	0.421	2	0

Lead concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.010	0.020	0.015	0.015	0.007	0.079	2	0
Cynoglossus spp.	0.020	0.020	0.020	0.020	NA	NA	1	0
Leiognathus brevirostris	0.010	0.030	0.010	0.017	0.012	0.045	3	1
Metapenaeus affinis	0.010	0.020	0.010	0.013	0.006	0.028	3	1
Metapenaeus ensis	0.010	0.010	0.010	0.010	NA	NA	1	1
Oratosquilla oratoria	0.020	0.050	0.020	0.030	0.017	0.073	3	0
Trypauchen vagina	0.010	0.010	0.010	0.010	NA	NA	1	1
Turitella spp.	0.380	1.770	1.075	1.075	0.983	9.906	2	0

Mercury concentrations in fishery biota tissue, Tai Mun Wan

September 1995 - November 1995

Species	Min.	Max.	Median	Arithmetic Mean	Standard Deviation	95% U.C.L.	n	n (< d.l.)
Charybdis cruciata	0.020	0.030	0.025	0.025	0.007	0.089	2	0
Cynoglossus spp.	0.020	0.020	0.020	0.020	NA	NA	1	0
Leiognathus brevirostris	0.030	0.040	0.030	0.033	0.006	0.048	3	0
Metapenaeus affinis	0.010	0.020	0.020	0.017	0.006	0.031	3	0
Metapenaeus ensis	0.010	0.010	0.010	0.010	NA	NA	1	1
Oratosquilla oratoria	0.040	0.050	0.050	0.047	0.006	0.061	3	0
Trypauchen vagina	0.030	0.030	0.030	0.030	NA	NA	1	0
Turitella spp.	0.020	0.030	0.025	0.025	0.007	0.089	2	0

APPENDIX B

Transport and Fate Behaviour of COCs

Cadmium

Cadmium is a naturally occurring rare element that is insoluble in water as a metal unless it is complexed to ligands such as humic acids, hydroxyl, carbonate, chloride and sulphate ions (Eisler, 1985). Cadmium has a valence of +2 and its properties are similar to zinc. It forms both organic and inorganic compounds (Clement Associates, 1985). Background levels of cadmium in uncontaminated areas have been measured at 0.05 ppb in coastal seawater, 0.01-0.1 ppb in open ocean seawater, and 30-1000 ppb in marine sediments. Adsorption and desorption rates are rapid on mud solids and particles of clay, silica, humic material and other naturally occurring solids.

Availability in living organisms depends on adsorption and desorption rates from terrigenous materials, pH, Eh, chemical speciation and other modifiers. pH and redox potential may increase chemical mobility and bioavailability of sediment-bound cadmium (Eisler, 1985). Marine biota generally contain significantly higher cadmium residues than freshwater or terrestrial counterparts, probably due to total cadmium levels in seawater. In addition, marine vertebrates have much higher concentrations in older organisms (Eisler, 1985).

Cadmium is more mobile in the aquatic environment than many other heavy metals (U.S. EPA, 1979, cited in Clement Associates, 1985). This is due to a low affinity for adsorbents at pH <6.5. Cadmium complexes with organic materials and is adsorbed onto the sediment, thereby being removed from the water column.

Chromium

Chromium generally exists in either a trivalent (Cr^{+3}) or hexavalent (Cr^{+6}) oxidation state. Hexavalent chromium is rather soluble, is quite mobile in surface water and is not adsorbed to any significant degree to clays or hydrous metal oxides. However, in reducing environments it is rapidly converted to trivalent chromium which is strongly adsorbed to sediments and is thus much less mobile than hexavalent chromium. Trivalent and hexavalent chromium are readily interconvertible in nature depending on microenvironmental conditions such as pH, Eh, hardness, and the types of other compounds present (Clement Associates, 1985).

Chromium is an essential nutrient and is accumulated in a variety of marine biota, especially benthic organisms, to levels much higher than in ambient water. Concentrations in biota are usually lower than that in sediments. Passage of chromium through the food chain has been demonstrated and the food chain appears to be a more efficient pathway for chromium uptake than direct uptake from seawater (Clement Associates, 1985), although bioaccumulation is believed to be a minor fate process for chromium (Eisler, 1986a).

Copper

Copper, an essential nutrient for many organisms, forms many compounds and complexes that are readily soluble, and therefore highly mobile in soil and surface water. However, various sorption processes tend to limit the concentration of dissolved copper complexes, especially as pH increases. Sorption onto clay materials, hydrous iron, manganese oxides, and organic material is the primary controlling factor (Clement Associates, 1985). In organically rich sediments, the sorbed and precipitated copper may become redissolved through complexation and may persist in the water column for extended periods (U.S. EPA, 1985).

Copper has two oxidation states: Cu^{+1} (cuprous) and Cu^{+2} (cupric). Cuprous copper is unstable in normal aquatic pH (6 - 8), and oxidizes into the cupric state. Copper can also be present as the soluble salts $CuCl_2$, $Cu(NO_3)_2$, and $CuSO_4$. Speciation can vary according to the type of complexation, adsorption, precipitation constituents, and pH. A high percentage of copper is removed from water at pH higher than 6. Copper has a strong affinity for hydrous iron and manganese oxides, clay, carbonate minerals, and organic matter.

Copper does not bioaccumulate extensively in aquatic organisms. Copper toxicity is governed by hardness, alkalinity, and total organic carbon concentration as well as its ability to complex with other ions or compounds (Clement Associates, 1985).

Lead

Lead is a heavy metal that exists in three oxidation states: Pb, Pb^{+2}, and Pb^{+4}. Most natural lead compounds are insoluble in water, however, many lead compounds produced in industrial processes are soluble. Naturally occurring lead compounds are not usually mobile, largely because free lead is readily adsorbed by metal hydroxides or combines with carbonate or sulphide to produce insoluble compounds (Clement Associates, 1985).

In polluted waters, organic complexation of lead is the most important process removing lead. Adsorption to inorganic solids, organic matter, and hydrous metal oxides exert the dominant effect on the fate of lead in the aquatic environment. Lead is strongly partitioned to bed sediments, with sorption being affected by pH, Eh, availability of ligands, dissolved and particulate ion concentrations, salinity, and chemical composition (Clement Associates, 1985). Lead is increasingly mobile with salinity, increasing dissolved organic concentrations, and decreasing pH values. Food chain biomagnification is negligible. Lead sediment bioconcentration factors collected from the literature were all well below 1.0 for invertebrates and fish.

Mercury

Several forms of mercury exist in the environment, including insoluble elemental mercury, inorganic species, and organic species. Generally, the mercurous (Hg^{+1}) salts are much less soluble than the more commonly found mercuric (Hg^{+2}) salts. Stable organic complexes can be formed with mercury that are much more soluble in organic liquids than water. The chemical species' nature and solubility in the environmental system depends on the redox potential and the pH of the environment (Clement Associates, 1985) and is very site-specific.

Many forms of mercury can volatilize to the atmosphere from aquatic and terrestrial sources. These include metallic mercury, several inorganic species and dimethyl mercury. Volatilization is reduced by conversion of metallic mercury to complexed species and by deposition of HgS in reducing sediments. Adsorption onto suspended and bed sediments is probably the most important process determining the fate of mercury in the aquatic environment. Sorption is strongest into organic materials. Most mercury compounds can be remobilized in aquatic systems by microbial conversion to methyl and dimethyl forms. Biomethylation is enhanced by large amounts of available mercury, large numbers of bacteria, the absence of strong complexing agents, near neutral pH, high temperatures, and moderately aerobic environments. Mercury bioaccumulates strongly by numerous mechanisms. Methylmercury is the most readily accumulated and retained form of mercury in aquatic biota, and once it enters a biological system it is very difficult to eliminate (Clement Associates, 1985).

Nickel

The high solubility of nickel compounds in water makes them mobile in aquatic systems. Under reducing conditions, however, and in the presence of sulphur, an insoluble sulphide is formed. Soluble compounds with hydroxide, carbonate, sulphate, and organic ligands are formed in aerobic environments below pH 9 (Clement Associates, 1985).

Nickel mobility can be limited to some degree by sorption and co-precipitation processes in unpolluted waters. In polluted, organic-rich waters, little sorption occurs. Lacking other significant processes affecting its mobility, the incorporation from surface water into bed sediments is an important fate of nickel. The bulk of nickel entering the aquatic environment, however, is transported to the ocean. Nickel is not generally accumulated in significant amounts from the sediments by aquatic organisms.

Zinc

Dissolved zinc may occur as the free (hydrated) zinc ion or as dissolved complexes and compounds with varying degrees of stability and toxicity. Suspended (undissolved) zinc may be dissolved following minor changes in water chemistry or may be sorbed to suspended matter. The predominant fate of zinc in aerobic systems is sorption of the divalent cation by hydrous iron and manganese oxides, clay minerals, and organic matter. The efficiency of these materials in removing zinc from solution varies according to their compositions and concentrations, the pH and salinity of the water, the concentrations of complexing ligands, and the concentration of zinc. Concentrations of zinc in suspended and bed sediments always exceed concentrations in ambient water. In reducing environments, precipitation of zinc sulphide limits the mobility of zinc. However, under aerobic conditions, precipitation of zinc compounds is probably important only where zinc is present at high concentrations. Zinc tends to be more readily sorbed at higher pH than lower pH and tends to be desorbed from sediments as salinity increases. Compounds of zinc with the common ligands of surface waters are soluble in most neutral and acidic solutions, so that zinc is readily transported in most unpolluted, relatively organic-free waters (Clement Associates, 1985).

Because zinc is an essential nutrient, it is strongly bioaccumulated even in the absence of abnormally high ambient concentrations. Zinc appears to biomagnify slightly through the food web. Although zinc is actively bioaccumulated in aquatic systems, biota appear to represent a relatively minor sink compared to the sediments (Clement Associates, 1985).

APPENDIX C

Toxicology Profile of COCs

Cadmium

Cadmium is not a biologically essential element. Cadmium is especially toxic to freshwater biota, and at sufficient concentrations is toxic to all life forms. For fish, the toxicity of cadmium is dependent on water temperature and salinity, and the concentration of cadmium in the surrounding water (Eisler, 1985). A variety of acute and chronic toxic effects have been noted in various organisms, and cadmium is considered a potential carcinogen and teratogen (Eisler, 1985; Government of Canada, 1994).

Cadmium is generally stored in the kidney and can affect enzyme levels, growth, respiration, reproduction, and lifespan. Elevated cadmium concentrations in liver are an early sign of cadmium exposure. Cadmium bioaccumulates in both plants and animals, and may be taken up from both water and food (Eisler, 1985). Based on studies on dolphins from the eastern Pacific Ocean, bioaccumulation of cadmium occurs primarily through uptake from food (Andre et al., 1990). For humans, cigarette smoking is a major source of cadmium. For non-smokers, the major source of cadmium is usually from the diet (ATSDR, 1991).

Chromium

Chromium is an essential trace element for humans and other mammals. It is required for normal metabolism of carbohydrates. Chromium deficiencies include reduced growth, reduced lifespan, elevated serum chloresterol, and increased formation of aortic plaques. Moderate levels of chromium reduced the toxic effects of cadmium in rats and vanadium in chickens (Eisler, 1986a). At sufficient levels, chromium is toxic to living organisms, but its biological effects are dependent on chemical form, solubility, and valence.

In marine fish, the toxicity of chromium is dependent on water temperature and pH, and the toxicity is additive in the presence of cadmium and zinc (Negilski, 1976). Effects of chromium include reduced survival, growth, altered blood chemistry, abnormal enzyme functioning, behaviour modifications, histopathology, and others. In addition, it is considered a mutagen, carcinogen, and teratogen. Trivalent chromium compounds are generally less toxic than hexavalent compounds. Although both Cr^{+3} and Cr^{+6} can exist in water, Cr^{+6} is most common in seawater. Acute and chronic toxic effects to mammals and birds are usually caused by Cr^{+6} compounds rather than Cr^{+2} or Cr^{+3} compounds which have low toxicities (Eisler, 1986a).

Copper

Copper is an essential nutrient and, therefore, is readily taken up by aquatic organisms. In mammals it is a component of several enzymes involved in oxidative reactions. It is also important for bone development, carbohydrate metabolism, pigment formation, and haematopoietic processes (Janus et al., 1987). In marine and aquatic invertebrates it is the essential element for oxygen transport in invertebrate blood.

Biomagnification of copper in terrestrial and aquatic food chains does not tend to occur (Jaagumagi, 1990; Janus et al., 1987). Copper toxicity is governed by hardness, alkalinity, and total organic carbon concentration as well as its ability to complex with other ions or compounds. Copper can be acutely toxic to animals, and is a known teratogen and possible carcinogen (Mance, 1987; ATSDR, 1990). Acute toxic effects are uncommon in humans because homeostatic mechanisms regulate internal concentrations. In general, the main route of uptake in humans is through oral exposure.

Lead

Lead is not required by living organisms, and at elevated levels may cause adverse effects on growth, survival, reproduction, development, and metabolism (Eisler, 1988). Organolead compounds are usually more toxic than inorganic lead compounds, and lead does not tend to biomagnify in food chains.

Lead is not considered a carcinogen in humans, but it is probably a mutagen. Toxic effects in fish include spinal curvature, anaemia, destruction of spinal neurons, enzyme inhibition, reduced swimming ability, destruction of gill tissues, paralysis, growth inhibition, retardation of sexual maturity, altered blood chemistry and other effects (Eisler, 1988). Based on tests on laboratory and domestic animals, tetramethyllead is about seven times more toxic than tetraethyllead. Lead can cross the placenta and be passed to offsprings through maternal milk. In humans, lead poisoning can cause loss of appetite, constipation, cramps, headaches, fatigue, paralysis, lead encephalopathy, and death. Individuals with hepatitis, anaemia, and nervous disorders are generally more susceptible to lead poisoning (Eisler, 1988). In humans, exposure routes include drinking water, food, and inhaled air.

Mercury

Mercury is among the most toxic of the trace elements, has complex behaviour in the environment, and has no known biological function. An organic form of mercury, methylmercury, is the most toxic and readily bioconcentrated and biomagnified in food chains. This makes it a particular risk to humans and animals in the upper trophic levels. Bioaccumulation of methylmercury is facilitated by its ability to penetrate cell membranes and its strong binding capacity to sulfhydryl groups in proteins. Bioaccumulation of mercury by fish is enhanced at elevated water temperatures, reduced water salinity, hardness, and pH, and reduced organic carbon content of the medium. Furthermore, the presence of zinc, cadmium, and selenium in solution tends to facilitate the bioaccumulation of mercury. Selenium is protective against the adverse effects of mercury on plants and animals. In mammals, mercury is a known mutagen, carcinogen, and teratogen, and the fetus is the most sensitive life stage (Eisler, 1987b; ATSDR, 1993a).

Nickel

Nickel is an essential metal which many organisms naturally bioaccumulate in their tissues. Nickel deficiency can affect the efficiency of iron absorption, enzyme activity, and metabolism (Kirchgessner and Schnegg, 1980). However, nickel deficiency is rare in most animals, and only occurs when environmental or dietary concentrations are very low.

Nickel toxicity to aquatic organisms is governed by water hardness, alkalinity, and chemical speciation. In fish, nickel toxicity tends to decrease as hardness and alkalinity of the water increase (Birge and Black, 1980). Nickel has been shown to cause both acute and chronic effects on fish including effects on survival, growth, and survival (Mance, 1987; Birge and Black, 1980).

In birds and mammals, nickel is a established teratogen and carcinogen (ATSDR, 1992). In humans, the primary route of exposure is from food and inhalation. Once in the body, soluble and insoluble nickel compounds behave differently. Soluble compounds are rapidly absorbed, translocated and excreted, while insoluble forms are retained for longer periods. Nickel that is absorbed accumulates in organs such as the kidney, liver, and lungs (ICME, 1995).

Zinc

Zinc is an essential metal, and animals require zinc for normal growth and reproduction. Zinc is required by more than 200 different enzymes, including enzymes that regulate RNA and DNA synthesis (Cleven et al., 1993). Because zinc is an essential element, organisms naturally accumulate zinc from water and food (U.S. EPA, 1987), however, zinc toxicity can occur when levels in food and/or the surrounding medium are elevated. In natural waters, zinc usually consists of the aquo ion ($(Zn(H_2O)_6)^{2+}$) and various inorganic and organic complexes. The aquo ion is considered to be the most toxic species.

The toxicity of zinc is influenced by calcium and magnesium levels, hardness, pH, and ionic strength. These factors may affect the sorption and binding of zinc by animal and plant tissues (U.S. EPA, 1987). Documented effects of high zinc levels include growth inhibition, effects on reproduction, and decreased survival in plants and animals (Eisler, 1993; ATSDR, 1993b). Acute toxicity in fish is usually caused by the disruption of gas exchange across the gills. In mammals, only very high doses of zinc are considered toxic, because homeostatic processes help maintain zinc levels within certain limits. For humans, food ingestion is the primary source of exposure.

Zinc interacts with other metals including calcium, cadmium, copper, lead, magnesium and nickel. These interactions can affect the patterns of accumulation and toxicity of zinc. For instance, the toxicity of zinc and cadmium mixtures may be additive, and zinc is a copper antagonist and increases the effects of copper deficiency in mammals and birds (Eisler, 1993).

APPENDIX D

Sample Contaminant Intake Calculations

Sample Calculation for Contaminant Intake for Chinese White Dolphin

(Zinc at East Sha Chau: 1993-1995)

Model: Intake (mg/kg body weight per day) = R * Sum (FR_i * CF_i) * U

Where: R = food ingestion rate (kg food/kg body weight per day, wet weight) = 0.065
Sum (FR_i * CF_i) = mean contam. conc. in prey items
FR_i = fraction of prey item in diet (unitless)
CF_i = contaminant concentration in prey item (mg Contam./kg food, wet weight)
U = fraction of time spent at site = 1.0

Sum (FR_i * CF_i) =

Prey Item	FR_i	CF_i	FR_i * CF_i
Cynoglossus	0.17	5.16	0.859918
Leiognathus	0.17	8.71	1.45146
Trypauchen	0.17	7.34	1.222926
M. affinis	0.25	14.13	3.533054
M. ensis	0.25	14.15	3.538337

Sum (FR_i * CF_i) = 10.6057

Intake = 0.69 mg Zn/kg body weight per day

Sample Calculation for Contaminant Intake for Humans

(Zinc at East Sha Chau for General Population Exposure Scenario: 1993-1995)

Model: Intake (mg/kg body weight per day) = $\frac{CF * IR * FI * EF * ED}{BW * AT}$

Where: CF = contaminant concentration in prey item (mg Contam./kg food, wet weight)
IR = food ingestion rate (kg food/kg body weight per day, wet weight)
FI = Fraction of seafood ingested from contaminated area (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (= ED * 365 days/year)

Note: CF = Sum (CF_i * P_i) for diets with multiple seafood types

Where: P_i = Proportion of i^{th} seafood item in diet
CF_i = Contam. conc. in i^{th} seafood item (mg Contam./ kg food, wet weight)

Prey Item	P_i	CF_i	CF_i * P_i
Charybdis	0.03	30.33	0.91
Cynoglossus	0.27	4.79	1.28
Leiognathus	0.27	8.11	2.16
M. affinis	0.03	13.54	0.41
M. ensis	0.03	13.78	0.41
Oratosquilla	0.03	21.93	0.66
Trypauchen	0.27	6.68	1.78
Turitella	0.08	12.78	1.02

Sum (CF_i * P_i) = 8.63

Intake = $\frac{8.63 * 0.100 * 0.003 * 350 * 23}{60 * 8395}$ = 4.1E-05 mg Zn/kg body weight per day