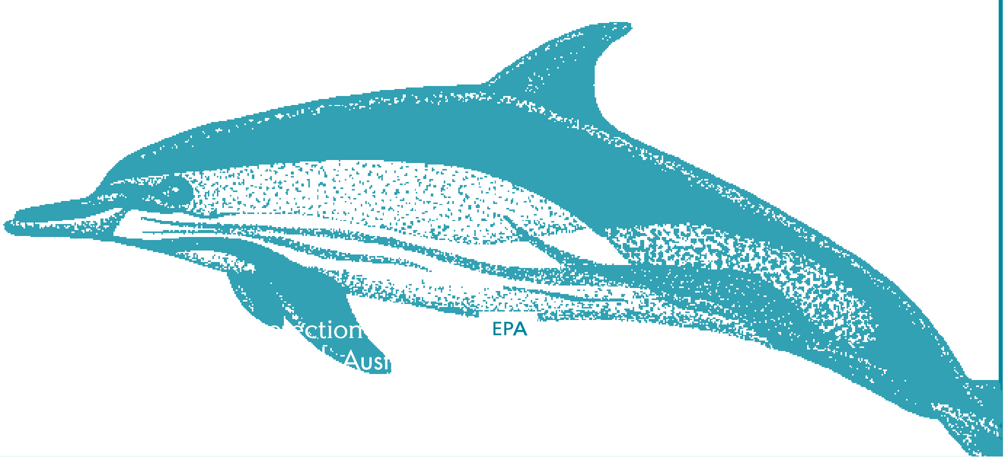
Monitoring Report

SPECIAL SURVEY OF THE PORT RIVER

Heavy Metals and PCBs in Dolphins, Sediment and Fish



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MARCH 2000

ISBN 1 876562 15 3

Printed on recycled paper

EXECUTIVE SUMMARY

In response to media reports of high concentrations of polychlorinated biphenyls (PCBs) and mercury in dolphins from the Port River the Environment Protection Agency (the EPA) undertook a study to assess the findings in more detail. This report presents the results of the study, which had three main objectives:

- Assess PCB, mercury and cadmium in blubber, liver and kidney tissue samples respectively from dolphins found dead in various locations around South Australia to determine if the levels of these pollutants found in the Port River dolphins were unusually high compared with dolphins found elsewhere around South Australia.
- Determine possible sources of contaminants in and around the Port River estuary by undertaking a survey of sediments for PCBs and heavy metals in stormwater drains, sumps and other sites.
- Determine if fish caught in the Port River met food standards for heavy metals and were safe to eat.

Tissue samples were analysed from 15 bottlenose dolphins, *Tursiops truncatus*, stored by the South Australian Museum. Liver tissue was tested for mercury, kidney tissue was tested for cadmium, and blubber tissue was tested for PCBs (Arochlors 1260 and 1254). These tissues were specifically chosen because they tend to accumulate the toxins of interest.

Sediment samples were taken from 26 sites in and around the estuary. Samples were analysed for heavy metals (mercury, cadmium, copper, chromium, nickel, lead and zinc) and PCBs (Arochlors 1260 and 1254).

Fish were caught from the Port River and tested for mercury, cadmium and lead to determine if they complied with the Food Standards Code. Compliance with the code means that the fish are safe to eat.

The study found that:

- PCB (Arochlor 1260) levels in blubber samples from dolphins found in the vicinity of the Port River were substantially higher than from dolphins at other sites around the State. The levels in the Port River dolphins were, however, well below most levels reported in the scientific literature over the last 10 years on dolphins found elsewhere around the world and about 80 times less than the maximum value reported.
- PCBs (Arochlor 1260) were detected in sediment samples from four sites in the area with at least two of these likely to be the result of recent contamination.
- Mercury levels found in liver samples from Port River dolphins were not unusual compared to those found in dolphins elsewhere around the State. There was no significant correlation between the locality in which dolphins were found and mercury levels in liver.
- Cadmium levels in kidney samples from the Port River dolphins were generally lower than dolphins found elsewhere around South Australia. This may be related to the cadmium levels in their diet.

- Elevated levels of mercury were found in sediment samples taken from 5 sites. The contamination at some of these sites could have been due to past practices, but the possibility of recent contamination cannot be excluded.
- Monitoring of sediment showed that 17 of the 26 sites samples had high lead and zinc concentrations. The source of the lead and zinc is likely to be road runoff and indicates that more needs to be done to stop these pollutants from entering the river.
- Other contaminants found at high levels in the survey include copper at five sites and nickel at one site. Most of the high copper results, and the high nickel result, were near ship or boat building activities, or areas where boats are repaired or maintained. These activities need to be investigated.
- Testing of fish caught in the Port River for mercury, cadmium and lead found that they met food standards and are safe to eat. Levels were comparable with those found in similar fish caught elsewhere in South Australia.

In response to these findings the EPA is undertaking an audit of industries in the area to locate the source of the PCB and mercury pollution and is investigating practices at some shipyards and marinas to reduce pollution from these activities.

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INTRODUCTION

Background to survey

In 1998 the Australian Dolphin Research Foundation undertook a study to determine if polychlorinated biphenyls (PCBs) were present in mussels and fish taken from the Port River estuary of South Australia. PCBs are known environmental toxicants and have been banned in many countries, including Australia, for many years. This work followed an earlier report in the same year that high levels of PCBs (approximately 18 parts per million or mg/kg) had been found in blubber samples from a dolphin, known as Jock, which had died in the area in 1993 possibly as a result of injury.

The report of the findings (Bossley and Burzacott 1999) failed to detect PCBs in any of the mussel samples analysed but did find low levels of PCBs (approximately 0.7 mg/kg) in one fish sample out of five sampled.

At the time the study was being undertaken two bottlenose dolphins were found dead from gunshot wounds and another, the calf of one of the shot dolphins, subsequently died from malnutrition. Blubber samples from these dolphins were analysed for PCBs. The younger two dolphins were found to have PCB levels of 5–6 mg/kg, and the older dolphin (a female known as Hilo or Eleanor Rigby, which was the mother of one of the younger dolphins) had low levels of PCB (less than 1 mg/kg).

Samples of liver tissue from the dolphin Hilo were also tested for mercury as mercury is potentially toxic and is known to accumulate in the liver. The mercury level was found to be 465 mg/kg (wet weight), and on the basis of this result a media release was issued (Bossley 1999) stating that:

> *An Adelaide dolphin has been found to have the highest level of mercury contamination ever recorded in a bottlenose dolphin anywhere in the world.*

As a result of these reports the Environment Protection Agency (the EPA) and the Department of Human Services undertook a three-part study to determine the full extent of the problem. The objectives were to:

- Assess PCB, mercury and cadmium in blubber, liver and kidney tissue samples respectively from dolphins found dead in various locations around South Australia to determine if the levels of these pollutants found in the Port River dolphins were unusually high compared with dolphins found elsewhere around South Australia.
- Determine possible sources of contaminants in and around the Port River estuary by undertaking a survey of sediments for PCBs and heavy metals in stormwater drains, sumps and other sites.
- Determine if fish caught in the Port River met food standards for heavy metals and were safe to eat.

Dolphins in South Australia

Two main species of dolphin inhabit South Australian coastal waters: the bottlenose dolphin, *Tursiops truncatus*; and the common dolphin, *Delphinus delphis* (Long 1996). Bottlenose dolphins were used in this survey.

The bottlenose dolphin is distributed widely in coastal and inshore regions of tropical and temperate waters of the world, and in Australia is found in all states and the Northern Territory.

Currently there is taxonomic confusion within *Tursiops truncatus*, and two forms (possibly species) are found in South Australia. One is a smaller inshore form and the other is a larger oceanic form. The inshore form is thought to occur within about 10 km of the coast and is the form most likely to be found in the Port River.

Male bottlenose dolphins reach physical and sexual maturity at about 15 years of age and have a lifespan of about 43 years (Long 1996). Females calve every 3–6 years and have a gestation period of 12.3 months. A mature adult will consume about 10 kg of fish and squid per day.

Bioaccumulation and biomagnification of toxins

Certain heavy metals, such as mercury and cadmium, and most chlorinated organic compounds, such as PCBs, are known to be cumulative toxins.

These types of materials usually enter the environment bound to clay and other particles and are deposited in sediments. They can become biologically available through microbial and/or chemical action and taken up by benthic (bottom dwelling) organisms such as worms, crabs and shellfish. Once taken up into the body of these animals they tend to accumulate in certain body tissues and are not readily excreted. This process is called bioaccumulation.

When these animals are in turn eaten by fish, and these fish by bigger fish, and the bigger fish by dolphins, the toxins are transferred up the food chain and concentrations are increased along the way. This process is called biomagnification.

In fish and dolphins the highest concentrations of mercury and cadmium are found in the liver and kidney respectively. PCBs, being fat soluble, tend to concentrate in fatty tissue such as blubber. Longer lived species, such as dolphins, which consume considerable amounts of fish every day can accumulate very high levels of these toxicants over their life time. Biomagnification of background levels can be considerable, with factors of 1000–100,000, or higher, being reported.

Analysis of tissue samples from dolphins can therefore be a useful means of determining whether these toxicants are present in significant amounts in the environment. In the case of the Port River dolphins, which have mostly spent a considerable proportion of their life in the estuary, analysis of tissue samples can indicate the presence of localised pollution problems.

PCBs

Description

PCBs are chlorinated biphenyl isomers with a structure as shown in Figure 1.

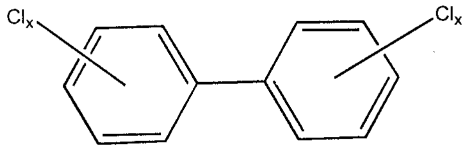


Figure 1 Chemical structure of PCB

When PCBs were available commercially as mixtures of isomers, Arochlor was the most commonly used mixture and was designated Arochlor 12XX, where the XX denoted the percentage of chlorine in the mixture. For example Arochlor 1254 had approximately 54% chlorine and was a mixture of 11% tetra-, 49% penta-, 34% hexa- and 6% heptachlorobiphenyl isomers. The Arcochlors were commonly referred to as congeners.

PCBs were manufactured and used extensively from the 1930s. They were widely used in industrial applications because of their excellent thermal stability, strong resistance to both acid and base hydrolysis, general inertness, solubility in organic solvents, excellent dielectric properties, resistance to oxidation and reduction, and non-flammability. They were also good lubricants and had high film strength.

Commercial PCBs were widely used in industry as heat transfer fluids, hydraulic fluids, solvent extenders, plasticisers, and dielectric fluids in capacitors and transformers. Other uses included flame retardants, additives, waterproofing agents, paints, surface coatings, adhesives, printing inks and pesticide extenders. Common articles containing PCBs were plastics, wrapping papers, carbon paper, printing inks, paints and vehicle tyres.

As a result of concerns about the environmental impact of PCBs, they were extensively banned in many countries, including Australia, in the 1970s. Material containing PCBs can no longer be made in, or imported into, Australia. In South Australia there was a concerted effort to collect and destroy waste PCB-containing material in the early 1980s. It is thought that very little PCB-containing equipment is still in use in South Australia, although very low levels may still exist in some waste material.

PCBs are suspected environmental endocrine disrupters (Keith 1997). This type of chemical affects the balance of normal hormonal functions in animals. Information from the Environment Protection Agency in the United States indicates that PCBs have been implicated in numerous conditions ranging from breast cancer to lowered IQs and memory disorders (Keith 1997).

Poor reproduction of bald eagles has been linked to levels of PCBs found in their body fat. Deformities in birds including clubfeet, crossed bills and missing eyes are also suspected links with exposure to PCBs (Keith 1997).

Published findings of PCBs in dolphins

A number of papers have been published in the last 10 years on PCB levels in dolphin tissue. The findings are summarised below (Table 1). PCBs accumulate in fatty tissue, with blubber having the highest reported concentrations.

Results are reported on either a wet weight or a lipid weight (fat content) basis and both are given in the table. Conversion between lipid and wet weight depends on the fat content of the tissue and, for blubber, this can vary considerably between samples (20–100% fat content).

It can be seen from this table that the level of 18 mg/kg (wet weight) reported in blubber tissue from the dolphin Jock, which was found dead in the Port River in 1993, is less than most average or median levels reported in the literature. The maximum level reported is 1400 mg/kg, which is approximately 80 times higher than that found in Jock.

Table 1 Summary of literature review findings of PCBs in dolphins.

Reference	Description of study	PCB levels in blubber	
		Wet weight (mg/kg)	Lipid weight
Crockcroft et al 1989	105 bottlenose dolphins from the east coast of South Africa	Median = 7.7 Average = 11.3 Max = 67.18	
Kannan et al 1993	10 striped dolphins found dead in the western Mediterranean	Median = 515 Average = 393 Max = 670	
Kemper et al 1994	2 bottlenose dolphins from around Australia	Median = n.a. Average = n.a. Max = 2.4	
	1 common dolphin	Max = 0.18	
Salata et al 1995	33 bottlenose dolphins found stranded in the Gulf of Mexico		Median = 39.6 Average = 36.1 Max = 149
Corsolini et al 1995	8 bottlenose dolphins collected from Italian coastal waters.	Median = 380 Average = 584 Max =1400	
Marsili et al 1997	25 striped dolphins found stranded on the coasts of Italy		Median = n.a. Average = 92 * Max = 371 *
Reich et al 1999	6 striped dolphins found dead in the Mediterranean Sea	Median = n.a. Average = 35.6 Max = 89.9	

* Calculated using dry weight and organic content data supplied by authors
n.a. not available

The high levels reported in a number of the studies involved dolphins found in the Mediterranean which is generally regarded as a highly polluted with industrial discharges from a variety of countries.

The issue here is whether the levels of PCBs found in dolphins from the Port River area are high compared with levels from dolphins found elsewhere in South Australia.

Heavy metals

Description

Heavy metals (mercury, cadmium, lead, copper, nickel, chromium and zinc) occur naturally in mineral deposits and enter the broader environment from the weathering of rocks and ores. They are also used for a variety of purposes and waste discharges can contain elevated concentrations. Heavy metals can be toxic to many species of aquatic (and terrestrial) plants and animals, and can bioaccumulate through the food chain.

Most heavy metals (with the exception of zinc and possibly copper) are non-essential elements and can cause health effects in animals, such as kidney disease, bone disease, reduced immunity, behavioural disorders and other problems. Once absorbed into the body they are slow to be released.

Mercury

Mercury is used in the chlor-alkali industry, which produces chlorine, caustic soda (sodium hydroxide) and hydrogen, and in the paint industry in paint pigments and preservatives. Other uses of mercury include pulp and paper manufacture, thermometers, electrical equipment such as mercury switches, batteries, fluorescent and mercury vapour lamps, dental amalgams and some therapeutic medicinal compounds. Mercury based pesticides were once used in agriculture but the use of such pesticides has been restricted.

Mercury can exist in three forms: mercury metal, mercury salts and organic mercury. Mercury metal can be converted to mercury salts by chemical reaction. Both metal mercury and mercury salts can be converted into organic mercury (particularly methylmercury) through the action of micro-organisms, particularly those present in anoxic muds. Methylmercury is more toxic than other forms of mercury.

Mercury accumulates mostly in the livers of fish and mammals.

Cadmium

Cadmium is used in electroplating other metals or alloys for protection against corrosion, in the manufacture of pigments, nickel-cadmium storage batteries, solders, electronic equipment, lubricants, photography supplies, glass ceramics and some biocides and stabilisers for plastics. Cadmium is also present in superphosphate used for fertilisers. The main anthropogenic sources of cadmium in the environment are emissions to air and water from mining and metal smelters; industries involved in manufacturing alloys, paints, batteries and plastics; burning of fossil fuels; and agricultural use of fertilisers containing cadmium.

The free cadmium ion is thought to be the species responsible for toxic effects in aquatic organisms. Cadmium forms complexes with inorganic and organic agents, which has the effect of reducing toxicity by reducing the availability of the free ion. The acute toxicity of cadmium generally increases as salinity increases.

Cadmium accumulates mostly in the kidneys of fish and mammals.

Lead

Lead is used in the manufacture of lead acid batteries and in leaded petrol. Lead emissions from the exhaust of vehicles using leaded fuel, and subsequent wash off from roads during rain, is a common source of lead contamination of waterways. Lead and its compounds are also used in electroplating, metallurgy, construction materials, coatings and dyes, electronic equipment, and plastics. Other uses include ammunition, paints, glassware, solder, piping, cable sheathing and roofing.

Anthropogenic input of lead to the environment is thought to outweigh all other sources. Lead reaches the aquatic environment through rainfall, fallout of lead dust, street runoff, and industrial and wastewater discharges.

Lead tends to concentrate in blood and bone tissues of fish and mammals.

Copper

Uses of copper include metal wiring, electroplating, production of alloys, photography, antifouling paint and pesticides. Copper is used extensively in domestic water pipes and hot water services.

Anthropogenic activities can release significant quantities of copper to the aquatic environment. These include corrosion of pipes, sewage treatment plant effluent, the use of copper compounds as algaecides, and discharges and fallout from industrial uses of copper.

Nickel

Nickel is used in the manufacture of stainless steel, nickel plating and nickel alloys. High nickel alloys are used in chemical, marine and electronic applications. Nickel is also used as a catalyst in industrial processes and in oil refining. It is also used in gas turbine engines and pollution abatement equipment.

The major contributor of nickel released to the environment by human activity is the burning of fossil fuels. Nickel ore mining, smelting and refining of concentrates, and casting of alloys and electroplating are also significant sources.

Chromium

Hexavalent chromium compounds are used in the metallurgical industry for chrome alloy and chromium metal production, in the chemical industry as oxidising agents in chrome plating, and in the production of other chrome compounds used in paints, dyes, explosives, ceramics and paper.

Zinc

Zinc is used in coatings to protect iron and steel, in alloys for dye casting, in brass, batteries, roofing and exterior fittings on buildings and some printing processes. It is also used in the manufacture of vehicle tyres, and deposits left on roads, and washed off during rain, are a significant source of zinc to the aquatic environment (Peterson and Batley 1992).

Published findings of mercury and cadmium in dolphins

A number of papers have been published in the last 10 years on mercury and cadmium levels in dolphin tissue. The findings are summarised in Table 2. Mercury is known to accumulate in the liver and cadmium in the kidney.

Results are usually reported on either a wet weight or dry weight basis and both are given in the table. Conversion between dry and wet weight depends on the moisture content of the tissue and this can vary between samples (liver tissue is usually between 70–80% moisture and kidney tissue is usually between 75–85% moisture).

Table 2 Summary of literature review findings of mercury and cadmium in dolphins.

Reference	Description of study	Liver mercury levels		Kidney cadmium levels	
		Wet weight (mg/kg)	Dry weight (mg/kg)	Wet weight (mg/kg)	Dry weight (mg/kg)
Andre et al 1991	33 striped dolphins from the French Atlantic and Mediterranean coast	Median = 139 Average = 275 Max = 1544			
Leonzio et al 1992	19 striped dolphins from the NW Mediterranean		Median = 12.6 Average = n.a. Max = 4400		Median = 7.33 Average = n.a. Max = 12.8
	4 bottlenose dolphins from the same region		Median = 270 Average = n.a. Max = 13155		Median = 0.1 Average = n.a. Max = 216
Augier, et al 1993	13 striped dolphins from the Mediterranean		Median = 481 Average = 668 Max = 2271		
Kemper et al 1994	10 bottlenose dolphins from around Australia	Median = n.a. Average = n.a. Max = 10.18		Median= n.a. Max = n.a. Max = 25.5	
	Common dolphins from around Australia	Median = n.a. Average = n.a. Max = 72.1 Number = 2		Median= n.a. Average= n.a. Max = 32.6 Number = 17	
Rawson et al 1993	18 stranded Atlantic bottlenose dolphins found on the SW coast of Florida	Median = 55 Average = 135 Max = 443			
Long et al 1997	18 bottlenose dolphins found dead in South Australia			Median approx 9 Average = 11.4 Max = 38	
	20 common dolphins found dead in South Australia			Median approx 6 Average = 8.2 Max = 36.2	

n.a. not available

The highest liver mercury result for bottlenose dolphins published in the literature is 13,155 mg/kg (dry weight). Although somewhat variable depending on moisture content, liver mercury results expressed on a wet weight basis are approximately 70–80% less than results expressed on a dry weight basis (see Appendix 1 for a comparison between measured wet and dry weights). On this basis a dry weight value of 13,155 equates to about 2630–3945 mg/kg on a wet weight basis. The lower end of this is more than five times the value reported for the dolphin Hilo (465 mg/kg), whereas the high end of the range is more than 8 times this value.

The claim, therefore, that the liver mercury level of 465 mg/kg wet weight found in the dolphin Hilo is the highest ever recorded is clearly incorrect. The issue, however, is whether this value is unusually high for bottlenose dolphins in South Australia and, if so, what is the source. This study was designed, in part, to answer those questions.

SURVEY FINDINGS

Dolphins

Sampling and analysis

Tissue samples were collected from 15 (13 male, 2 female) bottlenose dolphins, *Tursiops truncatus*, that had been found dead in various locations around South Australia over the last decade. The dolphins had been collected and studied by the South Australian Museum and samples of various organs frozen. Male dolphins were chosen because PCB levels in blubber of female dolphins is depleted by lactation on calving (Tanabe et al 1981). The 2 female dolphins were selected because tissue samples from these animals had been used in earlier work and the results were useful for comparison purposes.

Details of the dolphins recorded by the museum, such as tooth condition, sex and length, are given in Appendix 1.

Tooth condition is an index assigned by the South Australian Museum based on tooth pulp cavity closure (Long et al 1997, Kemper and Gibbs 1997). It is roughly proportional to age, with a tooth condition of 1 belonging to a very young or juvenile dolphin, 2–3 to a sexually but not physically mature subadult, and 4 and 5 to an adult. Bottlenose dolphins can live for about 43 years and become physically mature at about 15 years of age (Long 1996).

As PCB, mercury and cadmium are known to accumulate in blubber, liver and kidney respectively (Kemper et al, 1994), these tissues were used, where available, for analysis.

Dolphin tissue was thawed and subsamples taken for analysis. Care was taken to ensure that cross-contamination of the samples did not occur. Samples were placed in sample bottles supplied by the analytical laboratory and frozen in dry ice during transport. The full suite of tissue samples was not available for all dolphins.

The Queensland Health Scientific Services laboratory carried out the analysis of the tissue samples. They are registered by the National Association of Testing Authorities (NATA) for this work.

Samples for mercury and cadmium analysis were digested in acid and analysed by ICPAES (USEPA method 3050A). The limit of determination is 0.01 mg/kg. Samples for PCB analysis were extracted in solvent and analysed by gas chromatography mass spectrometry (USEPA method 8082). The limit of determination is 0.01 mg/kg.

The PCB congeners Arochlor 1260 and 1254 were selected for analysis. These congeners are more heavily chlorinated than some of the other PCB congeners and are therefore likely to persist longer in the environment. Arochlor 1254 is thought to have been the most commonly used PCB, and both Arochlor 1254 and 1260 were found in a previous study of Port River dolphins (Bossley and Burzacott 1999).

PCBs results

Results for PCB as Arochlor 1260 in blubber tissue, sorted in increasing wet weight concentration, are shown in Table 3. Results for Arochlor 1254 were below the limit of determination (ie <0.01 mg/kg wet weight) and are not shown. All results for PCBs in dolphin blubber are given in Appendix 1. Blubber samples were not available from dolphins 3, 8 and 10.

Results are expressed on a wet weight and lipid weight basis. Lipid weight is used in lieu of dry weight for blubber samples.

Table 3: Results for PCB in dolphin blubber.

Dolphin number	Dolphin found	Arochlor 1260 (mg/kg)		Tooth condition	Sex
		wet weight	lipid weight		
3	North Shields	-	-	5	Male
8	Port Lincoln	-	-	2	Male
10	Mount Dutton Bay	-	-	2	Male
6	Port Augusta	0.5	1.5	5	Male
7	American River	0.5	0.76	3	Male
4	Port Lincoln	0.7	1.6	2	Male
13	St Kilda	0.8	1.2	4	Female (Hilo)
5	Port Lincoln	0.9	1.3	4	Male
2	Port Lincoln	1.2	1.5	2	Male
1	Port Lincoln	1.4	2.0	3	Male
15	Port Hughes	1.6	2.0	5	Male
9	Barker Inlet	3.2	3.5	1	Female (Micki)
14	Barker Inlet	8.5	11.3	3	Male
12	Largs Bay*	14.8	39.2	2	Male
11	Largs North	19.5	26.4	5	Male

*Offshore form of bottlenose dolphin

Dolphins 9, 13 and 14 were known to be residents of the Port River estuary area and two of these animals (9 and 14) had elevated levels of PCBs in blubber. The third, dolphin 13 (Hilo) which was a female, had lower PCB levels than other dolphins from the Port River estuary area.

Dolphin milk is very high in lipids (fat), and it is thought that PCBs in blubber are lowered during lactation (Tanabe et al 1981) through transfer to milk. Dolphin 9 (Micki) which was a young dolphin when it died had elevated PCB levels probably through milk from its mother (dolphin 13).

The highest level found was from dolphin 11 (Largs North). Although the level of 19.5 mg/kg was high compared with other dolphins found elsewhere around the

State, it was well below the highest concentration of 1400 mg/kg reported from overseas (see Table 1).

It is puzzling that dolphin 12 also had elevated levels of PCB in blubber. It is thought (Kemper, pers comm) that this animal is an offshore form of bottlenose dolphin and therefore less likely to be exposed to PCB contamination than inshore forms. The source of PCB contamination is unknown.

There is no clear relationship between the age of the animals and PCB levels in blubber. This relationship may be clouded by an increase in PCB levels in young dolphins from drinking their mothers' PCB contaminated milk.

PCBs are synthetic substances and do not occur naturally in the environment. Therefore detectable levels of PCBs in higher order animals such as dolphins is a matter of concern and indicates exposure to contamination at some time during the life of the animal. The concentration of PCBs likely to cause significant health problems in the animals is not known.

Mercury and cadmium results

Mercury and cadmium results of dolphin liver and kidney samples respectively are shown, sorted on increasing mercury wet weight concentration, in Table 4. Results are expressed on both a wet and dry weight basis. Results expressed as dry weight are preferred for comparative purposes, as moisture content of tissue can vary between samples. All results are given in Appendix 1.

No kidney samples were available for dolphins 1, 2, 8 and 15. No liver sample was available from dolphin 10.

Table 4. Heavy metal results from dolphins.

Dolphin number	Dolphin found	Mercury in liver (mg/kg)		Cadmium in kidney (mg/kg)		Tooth condition
		Wet weight	Dry weight	Wet weight	Dry weight	
10	Mount Dutton Bay	-	-	18.8	83	2
9	Barker Inlet	3.7	14.9	0.2	0.97	1
7	American River	68	265	34.3	179	3
14	Barker Inlet	98	363	0.69	3.3	3
2	Port Lincoln	99	356	-	-	2
8	Port Lincoln	135	446	-	-	2
5	Port Lincoln	163	823	38.7	193	4
4	Port Lincoln	179	755	4.2	28	2
12	Largs Bay*	214	738	2.7	13	2
13	St Kilda	322	1314	4.2	20	4
3	North Shields	426	1657	23.4	114	5
1	Port Lincoln	449	1789	-	-	3
11	Largs North	577	1933	5.4	24	5
6	Port Augusta	653	2573	18.8	109	5
15	Port Hughes	1570	5856	-	-	5

*Offshore form of bottlenose dolphin

Mercury

The highest level of mercury found in this survey was from dolphin 15 which was found at Port Hughes. No cadmium results are available for this dolphin. No cause of death was recorded but the dolphin was physically mature (tooth condition 5). The source of the mercury is not known.

High concentrations of mercury were also measured in dolphins found at Port Lincoln (dolphins 1 and 3), Port Augusta (dolphin 6) and Largs North (dolphin 11).

There appears to be a reasonable relationship between the age of the dolphin (tooth condition) and the concentration of mercury in the liver (Figure 2). The very high result from dolphin 15 of 5856 mg/kg (dry weight) has been excluded from this plot as it is clearly anomalous and has the effect of substantially weighting the regression line upwards. An increase in mercury level in liver with age in dolphins has been observed by others (see Itano et al 1984).

There is no correlation between mercury level and the location where the dolphin was found (the crosses represent dolphins found near the Port River estuary and the squares represent dolphins found elsewhere).

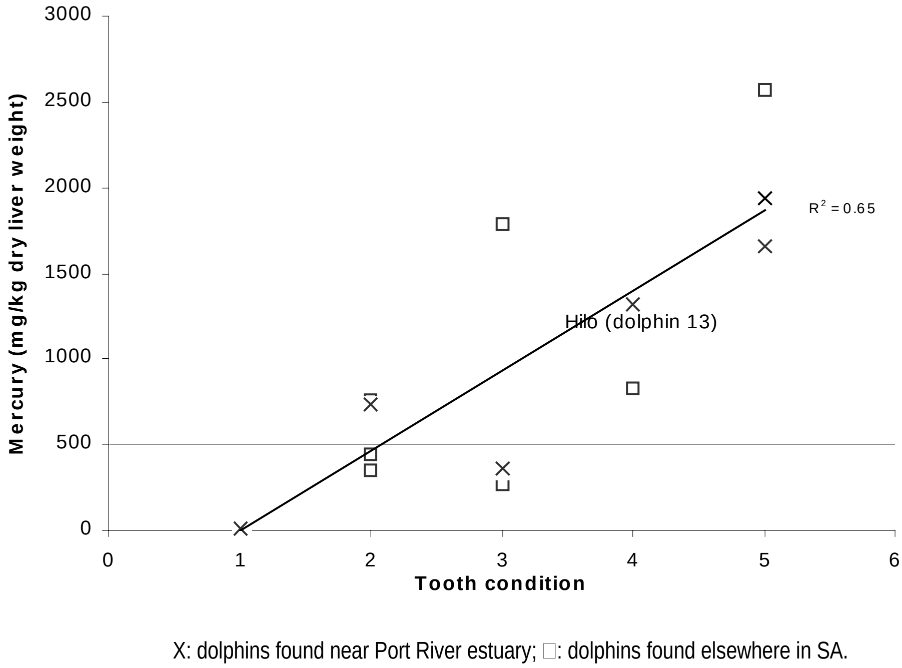


Figure 2 Plot of liver mercury concentrations (dry weight) against tooth condition.

The liver mercury level of 322 mg/kg found in this study from dolphin 13 (known as Hilo or Eleanor Rigby) can be compared with the value reported by Bossley of 465.5 mg/kg from the same dolphin (Bossley 1999). The difference between the laboratory results is probably not significant (the average is about 400 mg/kg wet weight).

The following points are relevant when considering the mercury level in dolphin 13:

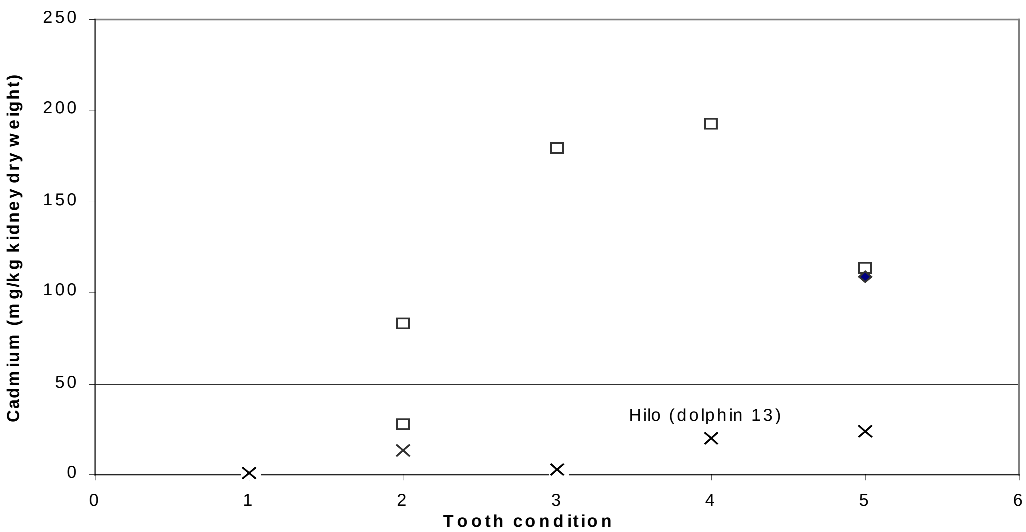
- Mercury can occur naturally in the environment and fish taken from pristine areas can contain significant levels of mercury. Mercury in liver tissue of dolphins is not necessarily indicative of pollution. A mature dolphin consumes approximately 10 kg of fish per day and therefore there is considerable potential for bioaccumulation of naturally occurring mercury in the liver of dolphins with age.
- There are five dolphins out of 15 in this survey with liver mercury concentrations higher than dolphin 13 (see Table 4). Some of these dolphins were found in areas where mercury contamination from pollution would be unlikely, however, the range of the animals is unknown.
- When compared on an age basis, the liver mercury concentration of dolphin 13 appears to be close to the expected level for a South Australian bottlenose

dolphin (see Figure 2). Insufficient information is available from the scientific literature to determine background levels for bottlenose dolphins as a function of age and hence it cannot be determined whether this "expected" level is elevated compared with levels in dolphins from unpolluted environments.

- There does not appear to be any significant correlation between the locality in which dolphins are found and mercury levels in liver.
- The mercury level in dolphin 13 was well below the highest level reported in the scientific literature and levels reported in dolphins found in polluted environments elsewhere around the world.

Cadmium

The kidney cadmium results are shown in Table 4. There is no overall correlation with tooth condition. The data do, however, appear to separate into two distinct groups with the dolphins found in the vicinity of the Port River estuary having generally lower levels than dolphins found elsewhere in South Australia (Figure 3). Within each group there is a correlation with tooth condition.



X: dolphins found near Port River estuary; □: dolphins found elsewhere in SA.

Figure 3 Plot of kidney cadmium concentrations (dry weight) against tooth condition.

This difference may be the result of Port River estuary dolphins having a lower proportion of squid in their diets compared than dolphins from elsewhere (Bossley, pers comm) and squid are known to accumulate cadmium (Long 1996).

Cadmium, like mercury, can occur naturally in the environment and cadmium found in kidney tissue from dolphins does not necessarily indicate exposure to pollution sources.

Sediment

Sampling and analysis

Sediment samples were collected from 26 sites in and around the Port River estuary (Figure 4). The sites included a number of stormwater drain sumps, stormwater drains, wetlands outlets, and sites in the estuary. Map co-ordinates of the sites are given in Appendix 2.

Stormwater drain sumps are gross pollutant traps at the ends of some drains. They are designed to trap larger pollutants before the stormwater discharges into the Port River. They are cleaned out regularly (approximately every 3 months) by the local council, and consequently heavy metal and PCB contamination at these sites indicates recent pollution.

Samples collected from stormwater drains consisted of residual sediment left in the concrete channel of the drain. Heavy metal or PCB contamination of these samples indicates recent pollution as, after time, the sediment is moved along the drain by stormwater flow and is eventually discharged into wetlands or the river.

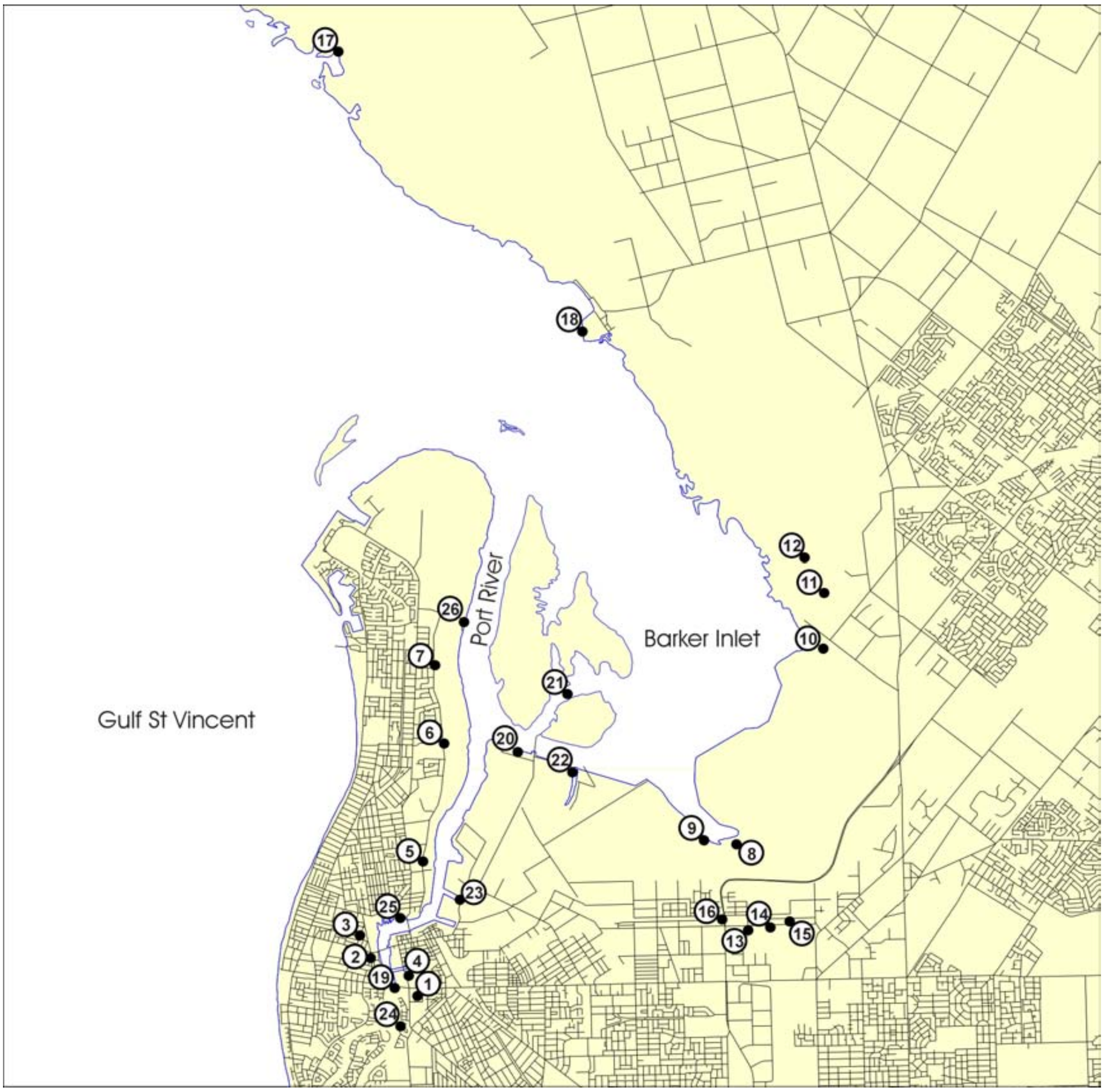
Samples collected from the Port River estuary and wetlands were taken with a spade and these samples could contain historical rather than recent pollution.

Samples were collected over three separate days: 18, 20 and 25 August 1999. Stainless steel sampling equipment was used, and the equipment was washed in distilled water and hexane after each sample was collected. At each site the sample was homogenised by thorough mixing in a tray before it was sealed in a sample container, which had been provided washed and ready for use by the analytical laboratory. Sample containers were iced and dispatched to the laboratory for analysis.

The Queensland Health Scientific Services laboratory analysed the samples. They are registered by the National Association of Testing Authorities (NATA) for these analyses. Samples for heavy metal analysis were digested in acid. Mercury was analysed using cold vapour atomic absorption spectrometry (limit of determination (LOD: 0.2 mg/kg), cadmium was analysed using flame atomic absorption spectrometry (LOD: 1 mg/kg) and other heavy metals were analysed using ICPAES (copper LOD: 5 mg/kg, chromium LOD: 10 mg/kg, lead LOD: 10 mg/kg, zinc LOD: 10 mg/kg, nickel LOD: 5 mg/kg).

Samples for PCB analysis were refluxed with solvent followed by sulfur cleanup and analysis using gas chromatography mass spectrometry. The limit of determination for Arochlor 1260 and 1254 is 10 ug/kg.

Heavy metals and PCBs tend to adsorb more readily on finer grain size sediments but the availability of PCBs decreases with higher sediment organic content (ANZECC 1999). The samples were therefore analysed for total organic carbon and grain size. Total organic carbon was analysed by the Queensland Health Scientific Services laboratory, and grain size analysis was undertaken by the Soil and Concrete Laboratory (SA Water).



Site	Description	Site	Description	Site	Description
1	Drain sump: Clemantina Drive, West Lakes	10	Dry Creek: near Globe Derby Park	19	Port River: Bower Rd
2	Drain sump: Hart St, Ethelton	11	Little Para River: mouth	20	North Arm: by shipyards
3	Drain sump: Carlisle St, Glanville	12	Bolivar STW: storm water & overflow drain	21	Angas Inlet: Garden Island Yacht Club
4	Drain sump: Hack St, Port Adelaide	13	Stormwater drain: Dunstan Rd drain	22	Magazine Creek Wetland outfall
5	Drain Sump: Elder Rd (Lulu), Birkenhead	14	Stormwater drain: Hindmarsh/Enfield/ Prospect drain	23	Port River: No. 1 dock
6	Drain sump: Mersey St, Port Adelaide	15	Stormwater drain: north arm east drain	24	Drain sump: Port Road drain into West lakes
7	Drain sump: Hamilton St, Port Adelaide	16	Stormwater drain: South Road drain	25	Port River: Off Jenkins St, Birkenhead
8	Barker Inlet Wetlands outlet	17	Bolivar STW: outlet weir	26	Port River: Off Veitch Rd
9	North Arm Creek by Wingfield dump	18	St Kilda foreshore: by playground		

Figure 4: Map showing sediment sampling sites

PCB results

Criteria used to assess concentrations of PCBs in sediment are from the draft Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 1999). Using these criteria, PCB concentrations exceeding 23 ug/kg, expressed on a dry weight basis, are classified as high.

Arochlor 1260 was detected at four sites as shown in Table 5. The concentration at all sites is classified as high using the classification criteria described above. Arochlor 1254 was not detected at any of the sites surveyed. All the data are listed in Appendix 2.

Arochlor 1260 is a more heavily chlorinated PCB congener with a very long breakdown period and is therefore likely to be more persistent in the environment.

Table 5: Sites at which high concentrations of PCBs were found.

Site	Site description	Arochlor 1260	Total organic carbon	Grain size of sediments (% of sample)		
		(ug/kg)	(% C)	<75 um	75 um – 2 um	>2 mm
7	Drain sump: Hamilton St, Port Adelaide	75	9.9	13	70	17
9	North Arm by Wingfield dump	95	11.9	88	11	1
12	Bolivar STW: storm water & overflow drain	25	6.4	84	14	2
16	Stormwater drain: South Road drain	40	3.4	83	15	2

The results from the two drains (sites 7 and 16) indicate recent contamination as the sediment from these sites is unlikely to have been there for a long time.

The results from the Hamilton Road drain are particularly surprising as the catchment is small and only a small proportion of the grain size is less than 75 microns. If the results from this site were normalised for grain size (ANZECC 1999), the effective concentration of Arochlor 1260 could be substantially higher.

The Bolivar site (site 12) is more likely to be historical contamination possibly from trade waste discharge into the sewer during the 1960s and 1970s. The North Arm site (site 9) could be historical contamination but is worth further investigation.

Heavy metal results

Mercury and cadmium

Criteria used to assess concentrations of mercury and cadmium in sediment are summarised below (ANZECC 1999, expressed on a dry weight basis):

	Mercury	Cadmium
• Low:	<0.15 mg/kg	<1.5 mg/kg
• Moderate	0.15–1 mg/kg	1.5–10 mg/kg
• High	>1 mg/kg	>10 mg/kg

None of the sites sampled showed high concentrations of cadmium. Sites at which high concentrations of mercury were found are given in Table 6 (expressed on a dry weight basis). All the data are listed in Appendix 2.

Table 6: Sites at which high concentrations of mercury were found

Site	Site description	Mercury	Grain size of sediments (% of sample)		
		(mg/kg)	<75 um	75 um – 2 mm	>2 mm
8	Barker Inlet Wetlands outlet	1.8	88	10	2
9	North Arm by Wingfield dump	1.6	88	11	1
19	Port River: Bower Rd	1.2	70	29	1
21	Angas Inlet: Garden Island Yacht Club	2.4	38	43	19
25	Port River: Off Jenkins St, Birkenhead	4.6	12	64	24

The highest concentrations of mercury were found in sediments taken from site 21 (Angas Inlet by the Garden Island Yacht Club) and site 25 (in the Port River by the Birkenhead Bridge near boat construction activities adjacent to Jenkins St). The grain size at these sites was distributed to the coarser fractions. Normally heavy metals are associated with small grain size and, if the results were normalised to grain size (ANZECC 1999), the results from both these sites would be expected to increase substantially, particularly from site 25.

Although it is possible that the elevated levels of mercury at these 5 sites could be the result of historical pollution from past practices, recent pollution cannot be excluded.

Moderate levels of contamination of mercury and cadmium were found in samples collected from two stormwater drains: site 6 (Mersey St Port Adelaide) and site 16 (South Road drain). This indicates recent contamination, although the levels detected are not at concentrations that would cause serious concern.

Lead and zinc

Criteria used to assess concentrations of mercury and cadmium in sediment are summarised below (ANZECC 1999, expressed on a dry weight basis):

	Lead	Zinc
• Low:	<50 mg/kg	<200 mg/kg
• Moderate	50–220 mg/kg	200–410 mg/kg
• High	>220 mg/kg	>410 mg/kg

Sites at which high concentrations of lead or zinc were found are given in Table 7 (expressed on a dry weight basis). All the data are listed in Appendix 2.

Table 7: Sites at which high concentrations of lead or zinc were found.

Site	Site description	Lead (mg/kg)	Zinc (mg/kg)	Grain size of sediments (% of sample) <75 um	75 um – 2 mm	>2 mm
1	Drain sump: Clementina Drive, West lakes	150	**520**	41	54	5
2	Drain sump: Hart St, Ethelton	**410**	**410**	4	92	4
3	Drain sump: Carlisle St, Glanville	**370**	**510**	2	88	10
4	Drain sump: Hack St, Port Adelaide	210	**860**	3	96	1
5	Drain Sump: Elder Rd (Lulu), Birkenhead	130	**510**	1	90	9
6	Drain sump: Mersey St, Port Adelaide	**400**	**2200**	14	70	16
7	Drain sump: Hamilton St, Port Adelaide	**300**	**570**	13	70	17
8	Barker Inlet Wetlands outlet	**350**	**780**	88	10	2
9	North Arm by Wingfield dump	**260**	**1100**	88	11	1
13	Stormwater drain: Dunstan Rd drain	16	**650**	12	78	10
14	Stormwater drain: Hindmarsh/Enfield/ Prospect drain	38	**500**	51	45	4
16	Stormwater drain: South Road drain	**270**	**1000**	83	15	2
19	Port River: Bower Rd	**300**	**940**	70	29	1
20	North Arm: by shipyards	**300**	**7000**	47	48	5
21	Angas Inlet: Garden Island Yacht Club	**380**	**660**	38	43	19
24	Drain sump: Port Rd drain into West lakes	**260**	**690**	2	90	8
25	Port River: Off Jenkins St, Birkenhead	**1200**	**1900**	12	64	24

Note: High concentrations shown in bold

Seventeen of the sites sampled had high concentrations of lead or zinc or both. Twelve of these 17 sites are stormwater drains, and high lead and zinc concentrations would be expected in the sediment samples from road runoff. The drain sumps are designed as gross pollutant traps and trap coarser grain size sediments. Finer grain sediments likely to contain higher levels of lead and zinc are presumably flushed into the Port River estuary during storm events.

The results indicate that lead and zinc pollution is a significant issue at most of the sites sampled.

The highest concentration of lead was found at site 25 (in the Port River by the Birkenhead Bridge near boat construction activities adjacent to Jenkins St). Lead and zinc are used in boat construction (eg lead in the keel of yachts), and this is a likely source of contamination.

The highest concentrations of zinc were found at sites 6 (Mersey St drain), 25 and 20 (North Arm at the junction with the Port River by shipyards). Ship and/or boat construction and repair at sites 25 and 20 are likely to contribute the zinc contamination of sediments. The source of zinc contamination at the Mersey St drain site is unknown, but the level is probably too high to be entirely due to road runoff.

Copper, nickel, chromium

Criteria used to assess concentrations of copper, nickel and chromium in sediment are summarised below (ANZECC 1999, expressed on a dry weight basis):

	Copper	**Nickel**	**Chromium**
• Low:	<65 mg/kg	<21mg/kg	<80 mg/kg
• Moderate	65–270 mg/kg	21–52 mg/kg	80–370 mg/kg
• High	>270 mg/kg	>52 mg/kg	>370 mg/kg

None of the sites sampled had high concentrations of chromium. Sites at which high concentrations of copper or nickel were found are given in Table 8 (expressed on a dry weight basis). All the data are listed in Appendix 2.

Table 8: Sites at which high concentrations of copper or nickel were found.

Site	Site description	Copper (mg/kg)	Nickel (mg/kg)	Grain size of sediments (% of sample)		
				<75 um	75 um – 2 mm	>2 mm
14	Stormwater drain: Hindmarsh/Enfield/ Prospect drain	**280**	38	51	45	4
19	Port River: Bower Rd	**460**	36	70	29	1
20	North Arm: by shipyards	**3200**	**64**	47	48	5
21	Angas Inlet: Garden Island Yacht Club	**370**	22	38	43	19
25	Port River: Off Jenkins St, Birkenhead	**1200**	32	12	64	24

Note: High concentrations shown in bold

Five sites have high copper concentration and one site has a high nickel concentration. Three of these sites are associated with ship or boat building activities or a marina where maintenance and repair of boats is carried out. It is likely that contamination of the sediments at these sites is caused by these activities.

Of the other sites, one is adjacent to the effluent discharge for the Port Adelaide Sewage Treatment Works. Copper occurs at elevated concentrations in wastewater due to the corrosion of domestic hot water services and pipes, and the findings at this site are therefore not surprising.

The other site is a stormwater drain with a large catchment area covering industrial areas in the northern suburbs of Adelaide. Elevated copper concentrations at this site are also not surprising.

Fish

A number of Black Bream and Yelloweye Mullet were netted from the upper Port River area in early October 1999. Fillets (muscle tissue) of the fish were analysed for heavy metals in accordance with Standard A12 of the Food Standards Code (ANZFA, 1997) to determine suitability for human consumption.

The fish samples were analysed by the Queensland Health Scientific Services laboratory. Tissue for lead and cadmium analyses were digested in nitric acid and hydrogen peroxide and analysed by flame atomic absorption spectrometry. The limit of determination is 0.5 mg/kg for lead and 0.05 mg/kg for cadmium. Samples for mercury determination were digested in a mix of nitric, sulfuric and hydrochloric acids and analysed by cold vapour atomic absorption spectrometry. The limit of determination is 0.01 mg/kg. All samples were analysed as submitted and results are expressed on a wet weight basis as required by the standards code.

The results of the survey are given in Appendix 3 and summarised in Table 9 (expressed on a wet weight basis).

Table 9: Summary of results from fish survey

Fish type	No. fish collected	Mercury (mg/kg)		Cadmium (mg/kg)		Lead (mg/kg)	
		Average	Max	Average	Max	Average	Max
Black Bream	11	0.11	0.22	0.06	0.08	<0.5	<0.5
Yelloweye Mullet	10	0.027	0.05	<0.05	<0.05	<0.5	<0.5
Limit for food*		0.5			2**		0.5

* Standard A12 of Food Standards Code
** Limit for molluscs (no limit specified for fish)

The results show that both the Black Bream and Yelloweye Mullet caught from the Port River comply with Standard A12 of the Food Standards Code (ANZFA, 1997). In most cases they are below the standard by a factor of about 5 or more. The fish are therefore safe to eat.

These results are comparable with levels of heavy metals found in these, or similar, types of fish collected from South Australian waters (Olsen 1983, Long 1996).

CONCLUDING REMARKS

This study had three objectives:

- Assess PCB, mercury and cadmium in blubber, liver and kidney tissue samples respectively from dolphins found dead in various locations around South Australia to determine if the levels of these pollutants found in the Port River dolphins were unusually high compared with dolphins found elsewhere around South Australia.
- Determine possible sources of contaminants in and around the Port River estuary by undertaking a survey of sediments for PCBs and heavy metals in stormwater drains, sumps and other sites.
- Determine if fish caught in the Port River met food standards for heavy metals and were safe to eat.

The study found that:

- PCB (Arochlor 1260) levels in blubber samples from dolphins found in the vicinity of the Port River were substantially higher than from dolphins at other sites around the State. The levels in the Port River dolphins were, however, well below most levels reported in the scientific literature over the last 10 years on dolphins found elsewhere around the world, and about 80 times less than the maximum value reported.
- PCBs (Arochlor 1260) were detected in sediment samples from four sites in the area, with at least two of these likely to be the result of recent contamination.
- Mercury levels found in liver samples from Port River dolphins were not unusual compared to those found in dolphins elsewhere around the State. There was no significant correlation between the locality in which dolphins were found and mercury levels in liver.
- Cadmium levels in kidney samples from the Port River dolphins were generally lower than in dolphins found elsewhere around South Australia. This may be related to the cadmium levels in their diet.
- Elevated levels of mercury were found in sediment samples taken from 5 sites. The contamination at some of these sites could have been due to past practices, but the possibility of recent contamination cannot be excluded.
- Monitoring of sediment showed that 17 of the 26 sites samples had high lead and zinc concentrations. The source of the lead and zinc is likely to be road runoff and indicates that more needs to be done to stop these pollutants from entering the river.
- Other contaminants found at high levels in the survey include copper at five sites and nickel at one site. Most of the high copper results, and the high nickel result, were near ship or boat building activities, or areas where boats are repaired or maintained. These activities need to be investigated.
- Testing of fish caught in the Port River for mercury, cadmium and lead found that they met food standards and are safe to eat. Levels were comparable with levels found in similar fish caught elsewhere in South Australia.

In response to these findings the EPA is undertaking an audit of industries in the area to locate the source of the PCB and mercury pollution, and is investigating practices at some shipyards and marinas to reduce pollution from these activities.

ACKNOWLEDGEMENTS

The Environment Protection Agency would like to thank the Department of Human Services for permission to use the results from the fish survey undertaken in October 1999.

Assistance provided by Dr Cath Kemper and Ms Martine Long from the South Australian Museum in preparing dolphin tissue samples, and Ms Pat Harbison in collecting sediment samples, is gratefully acknowledged.

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APPENDIX 1: HEAVY METALS AND PCBS IN DOLPHINS

Dolphin number	Museum reference	Where dolphin was found	Mercury in liver		Cadmium in kidney		Arochlor 1260 in blubber		Arochlor 1254 in blubber		Sex	Tooth condition	Body length
			wet weight (mg/kg)	dry weight (mg/kg)	wet weight (mg/kg)	dry weight (mg/kg)	wet weight (mg/kg)	lipid weight (mg/kg)	wet weight (mg/kg)	lipid weight (mg/kg)			
1	92.002	Port Lincoln	449	1789	-	-	1.4	2.0	<0.2	<0.3	male	3	227
2	94.033	Port Lincoln	99	356	-	-	1.2	1.5	<0.2	<0.3	male	2	223
3	99.133	North Shields	426	1657	23.4	114	-	-	-	-	male	5	219
4	95.106	Port Lincoln	179	755	4.2	28	0.7	1.6	<0.2	<0.3	male	2	238
5	94.008	Port Lincoln	163	823	38.7	193	0.9	1.3	<0.2	<0.3	male	4	226
6	99.101	Port Augusta	653	2573	18.8	109	0.5	1.5	<0.2	<0.3	male	5	212
7	99.063	American River	68	265	34.3	179	0.5	0.76	<0.2	<0.3	male	3	231
8	94.076	Port Lincoln	135	446	-	-	-	-	-	-	male	2	225
9	98.114	Barker Inlet	3.7	14.9	0.2	0.97	3.2	3.5	<0.2	<0.3	female	1	170
10	97.016	Mount Dutton Bay	-	-	18.8	83	-	-	-	-	male	2	237
11	97.100	Largs North	577	1933	5.4	24	19.5	26.4	<0.2	<0.3	male	5	232
12	98.102	Largs Bay	214	738	2.7	13	14.8	39.2	<0.2	<0.3	male	2	270
13	98.101	St Kilda	322	1314	4.2	20	0.8	1.2	<0.2	<0.3	female	4	221
14	98.098	Barker Inlet	98	363	0.69	3.3	8.5	11.3	<0.2	<0.3	male	3	205
15	89.058	Port Hughes	1570	5856	-	-	1.6	2.0	<0.2	<0.3	male	5	225

APPENDIX 2: HEAVY METALS AND PCBS IN SEDIMENTS

Sediment monitoring sites

Site	Description	Easting	Northing
1	Drain sump: Clemantina Drive, West lakes	0271673	6140207
2	Drain sump: Hart St, Ethelton	0270540	6140360
3	Drain sump: Carlisle St, Glanville	0270570	6141260
4	Drain sump: Hack St, Port Adelaide	0271488	6140572
5	Drain Sump: Elder Rd (Lulu), Birkenhead	0271629	6142691
6	Drain sump: Mersey St, Port Adelaide	0271883	6144890
7	Drain sump: Hamilton St, Port Adelaide	0271636	6146318
8	Barker Inlet Wetlands outlet	0277250	6143332
9	North Arm Creek by Wingfield dump	0276489	6143529
10	Dry Creek: near Globe Derby Park	0278610	6147025
11	Little Para River: mouth	0278565	6148053
12	Bolivar STW: storm water & overflow drain	0278176	6148674
13	Stormwater drain: Dunstan Rd drain	0277555	6141760
14	Stormwater drain: Hindmarsh/Enfield/ Prospect drain	0277952	6141833
15	Stormwater drain: north arm east drain	0278290	6141963
16	Stormwater drain: South road drain	0277075	6141935
17	Bolivar STW: outlet weir	0269245	6157512
18	St Kilda foreshore: by playground	0273939	6152610
19	Port River: Bower Rd	0271251	6140331
20	North Arm: by shipyards	0273214	6144804
21	Angas Inlet: Garden Island Yacht Club	0274053	6145927
22	Magazine Creek Wetland outfall	0274222	6144490
23	Port River: No. 1 dock	0274222	6142023
24	Drain sump: Port Road drain into West Lakes	0271394	6139631
25	Port River: Off Jenkins St, Birkenhead	0271278	6141626
26	Port River: Off Veitch Rd	0272114	6147146

Results of sediment survey

Note: All results expressed on a dry weight basis

Site	Site description	Mercury (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Copper mg/kg)	Chromium (mg/kg)	Nickel (mg/kg)	Arochlor 1254 (ug/kg)	Arochlor 1260 (ug/kg)	Total organic carbon (% C)	Grain size of sediments (% of sample)		
												<75 um	75 um – 2 mm	>2 mm
1	Drain sump: Clemantina Drive, West lakes	0.6	<1.0	150	520	50	30	20	<10	<10	2.8	41	54	5
2	Drain sump: Hart St, Ethelton	<0.2	<1.0	410	410	39	14	8	<10	<10	1.6	4	92	4
3	Drain sump: Carlisle St, Glanville	<0.2	<1.0	370	510	34	10	18	<10	<10	1.7	2	88	10
4	Drain sump: Hack St, Port Adelaide	<0.2	<1.0	210	860	60	14	8	<10	<10	0.4	3	96	1
5	Drain Sump: Elder Rd (Lulu), Birkenhead	<0.2	1	130	510	35	160	16	<10	<10	0.8	1	90	9
6	Drain sump: Mersey St, Port Adelaide	<0.2	4	400	2200	120	22	14	<10	<10	14.6	14	70	16
7	Drain sump: Hamilton St, Port Adelaide	<0.2	<1.0	300	570	170	16	16	<10	75	9.9	13	70	17
8	Barker Inlet Wetlands outlet	1.8	2	350	780	120	84	34	<10	<10	4.6	88	10	2
9	North Arm Creek by Wingfield dump	1.6	8	260	1100	230	140	44	<10	95	11.9	88	11	1
10	Dry Creek: near Globe Derby Park	<0.2	<1.0	30	78	10	20	10	<10	<10	0.7	36	63	1
11	Little Para River: mouth	<0.2	<1.0	26	300	34	68	26	<10	<10	1.8	93	6	1
12	Bolivar STW: storm water & overflow drain	0.8	2	28	340	140	120	28	<10	25	6.4	84	14	2

Note: All results expressed on a dry weight basis

Site	Site description	Mercury (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Copper mg/kg)	Chromium (mg/kg)	Nickel (mg/kg)	Arochlor 1254 (ug/kg)	Arochlor 1260 (ug/kg)	Total organic carbon (% carbon)	Grain size of sediments (% of sample)		
												<75 um	75 um – 2 mm	>2 mm
13	Stormwater drain: Dunstan Rd drain	<0.2	1	16	650	85	40	16	<10	<10	2.7	12	78	10
14	Stormwater drain: Hindmarsh/Enfield/ Prospect drain	0.4	<1.0	38	500	280	70	38	<10	<10	1.2	51	45	4
15	Stormwater drain: north arm east drain	<0.2	<1.0	10	400	58	20	10	<10	<10	1.2	8	70	22
16	Stormwater drain: South Road drain	0.2	1	270	1000	94	80	28	<10	40	3.4	83	15	2
17	Bolivar STW: outlet weir	<0.2	<1.0	10	100	76	70	12	<10	<10	4.3	34	65	1
18	St Kilda foreshore: by playground	<0.2	<1.0	<10	20	6	10	6	<10	<10	0.9	33	58	9
19	Port River: Bower Rd	1.2	7	300	940	460	240	36	<10	<10	7.9	70	29	1
20	North Arm: by shipyards	0.6	<1.0	300	7000	3200	56	64	<10	<10	3	47	48	5
21	Angas Inlet: Garden Island Yacht Club	2.4	<1.0	380	660	370	58	22	<10	<10	2.8	38	43	19
22	Magazine Creek Wetland outfall	0.4	<1.0	40	190	71	28	14	<10	<10	1.9	72	27	1
23	Port River: No. 1 dock	0.4	<1.0	60	200	44	16	8	<10	<10	1.2	-	-	-
24	Drain sump: Port Road drain into West lakes	<0.2	1	260	690	66	40	10	<10	<10	0.4	2	90	8
25	Port River: Off Jenkins St, Birkenhead	4.6	<1.0	1200	1900	1200	60	32	<10	<10	1.9	12	64	24
26	Port River: Off Veitch Rd	<0.2	<1.0	30	120	41	20	12	<10	<10	1.3	5	81	14

APPENDIX 3: HEAVY METALS IN FISH

Note: All results are expressed on a wet weight whole fish basis.

Type of fish	Location where caught	Sample number	Mercury (mg/kg)	Cadmium (mg/kg)	Lead (mg/kg)
Black Bream	Upper Port River	1	0.08	<0.05	<0.5
	Upper Port River	2	0.07	<0.05	<0.5
	Upper Port River	3	0.02	<0.05	<0.5
	Upper Port River	4	0.08	0.06	<0.5
	Upper Port River	5	0.09	0.08	<0.5
	Upper Port River	6	0.15	0.07	<0.5
	Upper Port River	7	0.08	<0.05	<0.5
	Upper Port River	8	0.15	0.06	<0.5
	Upper Port River	9	0.22	0.07	<0.5
	Upper Port River	10	0.09	0.06	<0.5
	Upper Port River	11	0.22	<0.05	<0.5
Yelloweye Mullet	Upper Port River	1	0.05	<0.05	<0.5
	Upper Port River	2	0.03	<0.05	<0.5
	Upper Port River	3	0.01	<0.05	<0.5
	Upper Port River	4	0.02	<0.05	<0.5
	Upper Port River	5	0.05	<0.05	<0.5
	Upper Port River	6	0.01	<0.05	<0.5
	Upper Port River	7	0.04	<0.05	<0.5
	Upper Port River	8	0.02	<0.05	<0.5
	Upper Port River	9	0.01	<0.05	<0.5
	Upper Port River	10	0.03	<0.05	<0.5