Organic pollutants in mussels and sediments of Perth's southern metropolitan coastal waters

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Organic pollutants in mussels and sediments of Perth's southern metropolitan coastal waters

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Summary

The results of a survey conducted in November 1991, of organic pollutants in the marine sediments and the common mussel, *Mytilus edulis*, from the southern metropolitan coastal waters off Perth are presented. Organophosphorus and organochlorine pesticides, polychlorinated biphenyls, aliphatic and polycyclic aromatic hydrocarbons and organotin compounds were analysed in surficial (top 20 mm) sediments from 175 sites and in mussel tissue from 35 sites over an area of 500 km^2. Detectable concentrations of pesticides, polychlorinated biphenyls and aliphatic hydrocarbons were recorded at approximately 5 per cent of the sediment sites and 10 per cent of the mussel sites. Contamination was generally confined to areas within or immediately adjacent to shipping facilities and marinas. By contrast, contamination of sediments and mussels with polycyclic aromatic hydrocarbons and organotin compounds, particularly tributyltin, was widespread throughout the study area. Areas of highest contamination occurred in harbours and boat mooring areas and along the eastern side of Cockburn Sound.

Comparisons with the results of similar Australian and overseas studies indicate that, in general, sediments and mussels from these waters are not significantly contaminated with pesticides, polychlorinated biphenyls or hydrocarbons. In contrast elevated concentrations of TBT in the sediments and mussels are amongst the highest recorded in Australia. A recent study of imposex in the neogastropod *Thais orbita*, found very high frequencies in populations living on intertidal platforms throughout the metropolitan coastal waters of Perth. The high proportion of sites contaminated with TBT and the widespread occurrence of imposex in *Thais orbita*, linked to TBT contamination, is cause for major concern.

1. Introduction

The protected coastal waters off the southern metropolitan coastline of Perth, Western Australia, are utilised for industrial, commercial and recreational purposes. Perth's population is predicted to double to two million people over the next 30 years with most of the associated industrial and urban expansion occurring along the coastal strip (Simpson *et al.*, 1993). As a result, inputs of toxic contaminants to these waters, particularly from sewage discharge, are predicted to increase in proportion to population growth, if current treatment and disposal methods remain in use (Martinick *et al.*, 1992). At the same time a rapid increase in recreational usage of these nearshore waters is predicted to occur (Sherlock, 1994). The *Southern Metropolitan Coastal Waters Study 1991-1994* (SMCWS) was initiated by the Western Australian Department of Environmental Protection to facilitate the development of a comprehensive environmental management strategy for the long-term management of these waters.

Over the past four decades, wastes containing heavy metals, pesticides and hydrocarbons have been routinely discharged into Cockburn Sound and, to a lesser extent Owen Anchorage, from point sources such as industrial and domestic wastewater outfalls and stormwater drains (Martinick *et al.*, 1992). Over the next 30 years the discharge of toxic contaminants from industrial point sources is projected to decrease substantially and diffuse sources such as contaminated groundwater inflow and surface runoff are expected to increase (Martinick *et al.*, 1992). The leaching of tributyltin (TBT) from boat hulls and other marine structures is currently another diffuse source of contaminant input to these coastal waters. Tributyltin has been used as a biocide in antifouling paints since the 1950s and is highly toxic to a wide range of marine biota with detrimental effects occurring at concentrations many times lower than other marine pollutants (Bryan and Gibbs, 1990).

This paper provides a summary of the results of a November 1991 survey of organic contaminants in marine sediments and mussels (*Mytilus edulis*) collected from the southern waters off Perth. The organic contaminants investigated were pesticides, polychlorinated biphenyls, aliphatic and polycyclic aromatic hydrocarbons and organotin compounds, particularly the highly toxic tributyltin. The survey was undertaken to determine the recent history of contaminant inputs to these waters using a common filter-feeding bivalve, as an integrator of contaminant concentrations in the water, and surficial marine sediments collected from the study area. Additional objectives were to identify areas of significant contamination for more detailed follow-up work (Burt *et al.*, 1994) as well as providing a broadscale quantitative baseline for future reference. This study was part of the characterisation phase of the SMCWS.

2. Materials and methods

Marine sediments (175 sites) and the common mussel, *Mytilus edulis*, (sites 1-35) were collected from Perth's southern metropolitan coastal waters (Figure 1). Five sediment cores were collected by SCUBA divers at each site using 25 mm diameter by 70 mm length polycarbonate vials with a small water-release hole in the bottom. Individual cores were taken by carefully pushing the vial into the sediment to minimise disturbance to the sediment surface, and capping the vial underwater. Cores were taken randomly from the corners and centre of a one metre square grid to minimise the effects of small-scale heterogeneity in sediment contamination. Prior to use in the field the vials were soaked in 10 per cent nitric acid for 12 hours, washed in re-distilled methanol, air dried, capped, labelled and placed in sealed plastic bags. Following collection, each core was snap-frozen in dry-ice in the field and transported to the laboratory where all samples remained frozen until analysis. Just prior to analyses the top 20 mm of sediment from each of the five cores were removed, pooled and homogenised. Duplicate analyses were performed on the homogenised sample.

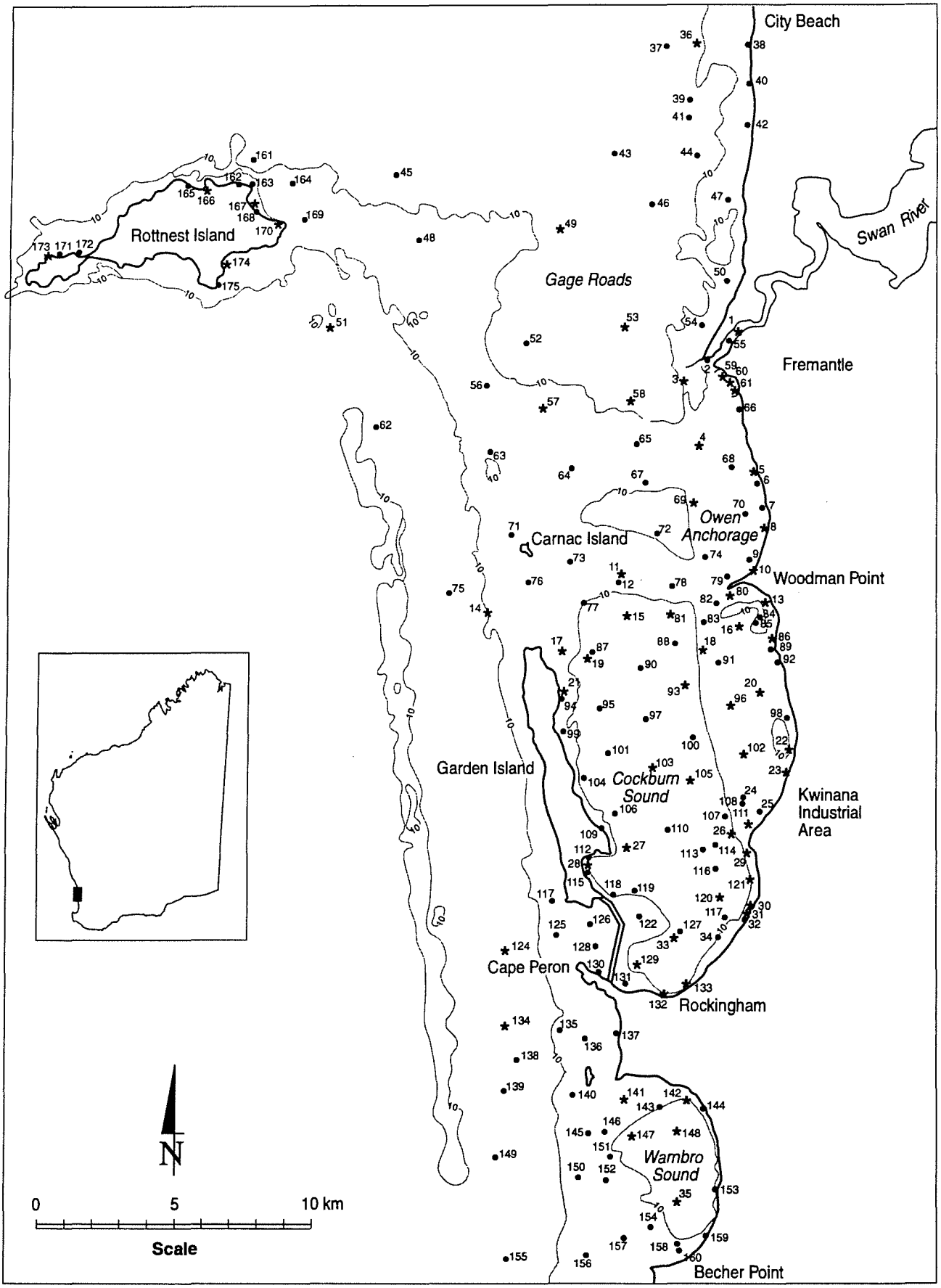

Figure 1. Locality map of the study area showing sediment (sites 1-175) and mussel sampling sites (sites 1-35). Aliphatic and polycyclic aromatic hydrocarbons, pesticides and PCBs were analysed at all sites. Organotin was also analysed in sediments from 64 sites (*) and at all mussel sampling sites except sites 6 & 7.

Pesticide, PCB and hydrocarbon analyses in sediments and mussels collected from all the sites, were carried out at the Chemistry Centre of Western Australia using the methods described in detail by Burt *et al.* (1994). Organochlorine pesticides included aldrin, dieldrin, ∂ and ß chlordane, oxychlordane, heptachlor, heptachlor epoxide, hexachloro benzene (HCB), lindane, p-p'DDE, p-p'DDD, o-p' and p-p'DDT. Organophosphorus pesticides included chlorpyrifos, fenitrothion and maldison (malathion). Analysis for PAHs targeted naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo-(a)anthracene, chrysene and benzo(a)pyrene.

Approximately 80 g of sediment was extracted three times with equal proportions of acetone:hexane using sonication and a wrist action shaker. A separate subsample was taken to determine dry weight. The extracts were combined, filtered, washed with aqueous sodium sulphate (5%) and the aqueous phase discarded. The organic extract was concentrated to eight ml in hexane ensuring removal of acetone. Two, two ml aliquots were subjected to matrix removal by column cleanup using florisil (5 per cent deactivated) with pentane elution for aliphatic hydrocarbons, and florisil with 1:9 ether:hexane elution for pesticides, PCBs and PAHs respectively. These extracts were filtered through sodium sulphate and concentrated to 10 ml by rotary evaporation under reduced pressure. The aliphatic hydrocarbon fraction was analysis by gas chromatography, flame ionisation detection. The other fraction was treated with tetrabutyl ammonium hydrogen sulphate solution saturated with sodium sulphite to remove sulphur (Jensen *et al.*, 1977). The extract was then divided into two, four ml aliquots for pesticide and PCB determination by electron capture detection (OC) and nitrogen-phosphorous detection (OP). PAH determination was by gas chromatography mass spectrometry .

Mussels were sampled from fixed man-made structures such as posts, jetties and beacons. Divers collected mussels at each site from a standard depth of approximately one metre below mean low water level. About 30 mussels between 40-50 mm in length were selected, scrubbed clean, placed in dry hessian bags, chilled on ice and transported to the laboratory. Mussels were rinsed with methanol before shucking to minimise external sources of contamination. The tissue was removed and rinsed with water and methanol to minimise contamination in mantle fluids. The tissue of about 20 mussels was homogenised to provide a final sample of between 80 and 100 g per site. Five intact mussels were also stored on ice and transported by air to CSIRO's Lucas Heights laboratories for organotin analysis.

Approximately 40 g of homogenised mussel was dried to a powder using anhydrous sodium sulphate and extracted three times with hexane using sonication. The extract was filtered through sodium sulphate and concentrated to 10 ml by rotary evaporation under reduced pressure. Aliquots of 2.5 ml were taken for matrix removal using florisil (5 per cent deactivated) for aliphatic hydrocarbons and gel permeation for pesticides, PCBs and PAHs (A O A C, 1990).

Organotin (monobutyltin, dibutyltin and tributyltin) concentrations in sediment (64 sites) and mussel samples (33 sites, Figure 1) were determined by the CSIRO Centre for Advanced Analytical Chemistry, Lucas Heights, New South Wales according to the methods of Batley *et al.* (1988). Sediment samples were dried for moisture determination and approximately 0.2g digested in cold 50%, methanol and concentrated hydrochloric acid, using an ultrasonic bath to aid extraction of the alkyltins from the matrix. The supernatant liquor was extracted with 0.5%, tropolone in dichloromethane, and the organic layer retained. The alkytins were back-extracted with 0.05 M nitric acid, filtered and diluted for analysis. Five mussels from each site were pooled and homogenised. The organotin compounds were extracted from the homogenate using 50 per cent methanol in 10 M hydrochloric acid in an ultrasonic bath. The supernatant liquor was then extracted with dichloromethane in the presence of tropolone and finally back extracted into nitric acid and filtered for analysis. Sediment and mussel samples were treated with 4 per cent w/v sodium borohydride and the volatile tin hydrides purged from solution and trapped on a packed PTFE column containing 1 per cent OV-101 on Chromasorb-G held at liquid nitrogen temperature. The tin hydrides were then thermally desorbed into the light path of an electrically heated quartz furnace atomic absorption spectrometer.

Procedural blanks, calibration standards and recoveries were run routinely during the analytical programme. Sampling or laboratory equipment which came into direct contact with sediment

and mussel tissue samples was rinsed in methanol and dried at 105°C for 12 hours prior to use. All results are expressed as $\mu g\ g^{-1}$ and were calculated to two significant figures. The limits of detection for sediments and mussels were the same for each contaminant group, apart from PCBs, and are as follows: OC pesticides (0.001 $\mu g\ g^{-1}$); OP pesticides (0.01 $\mu g\ g^{-1}$); aliphatic and polycyclic aromatic hydrocarbons (0.001 $\mu g\ g^{-1}$); tributyltin (0.0005 $\mu g\ g^{-1}$); polchlorinated biphenyls: sediments (0.01 $\mu g\ g^{-1}$), mussels (0.02 $\mu g\ g^{-1}$).

3. Results

3.1 Pesticides and polychlorinated biphenyls

Detectable concentrations of pesticides were measured in sediment from six sites. The organochlorine pesticides, DDT and dieldrin were detected in Success Harbour (site 60; 0.013 $\mu g\ g^{-1}$, 0.001 $\mu g\ g^{-1}$) and Fremantle Harbour (site 54; 0.005 $\mu g\ g^{-1}$, 0.002 $\mu g\ g^{-1}$). DDT was also detected at sites in the Fremantle Fishing Boat Harbour (site 59; 0.022 $\mu g\ g^{-1}$) and the eastern shelf of Cockburn Sound (site 33; 0.004 $\mu g\ g^{-1}$). Dieldrin (0.002 $\mu g\ g^{-1}$) was detected at site 89 in the Cockburn Sound basin. The organophosphorus pesticide malathion was detected in the Fremantle Harbour (site 54; 0.120 $\mu g\ g^{-1}$) and at site 107 on the eastern shelf of Cockburn Sound (0.010 $\mu g\ g^{-1}$), where fenitrothion was also detected (0.010 $\mu g\ g^{-1}$). Traces of PCBs (< 0.010 $\mu g\ g^{-1}$) were detected at two sites in the basin of Cockburn Sound.

Organochlorine pesticides were detected in mussel tissue at two inshore locations at the northern end of Owen Anchorage adjacent to the Fremantle boat harbours. Chlordane (0.017 $\mu g\ g^{-1}$), DDT (0.002 $\mu g\ g^{-1}$), dieldrin (0.002 $\mu g\ g^{-1}$) and heptachlor (0.002 $\mu g\ g^{-1}$) were detected at site 3 and chlordane (0.005 $\mu g\ g^{-1}$) was detected at site 4. Organophosphorus pesticides and PCBs were not detected in the tissue of mussels at any sites.

3.2 Hydrocarbons

Aliphatic hydrocarbons in sediments were detected at site 54 in Fremantle Harbour (11.8 $\mu g\ g^{-1}$) and two sites (22, 24) on the eastern shoreline of Cockburn Sound (1 μg g-1). Traces (< 1 $\mu g\ g^{-1}$) were detected at sites adjacent to the Swanbourne wastewater outfall (39, 40, 42), Gage Roads (45), Fremantle Harbour (1) and the entrances to Success Harbour (3) and Careening Bay (26). Aliphatic hydrocarbons (>1 $\mu g\ g^{-1}$) were detected in the tissue of mussels from site 18 in Jervoise Bay and site 22 adjacent to the Kwinana industrial area. Traces (< 1 $\mu g\ g^{-1}$) were also detected at sites in the shipping channels (11, 12, 16) and in mussels from the Kwinana industrial area (23, 24, 28, 29).

PAHs were detected in sediments from 60 sites (34%) throughout the study area (Figure 2a) ranging from 0.001 $\mu g\ g^{-1}$ to 3.2 $\mu g\ g^{-1}$. Elevated concentrations of PAHs (>0.10 $\mu g\ g^{-1}$) were detected at 10 sites including the Fremantle harbours (site 2, 0.31 $\mu g\ g^{-1}$; site 54, 3.2 $\mu g\ g^{-1}$; site 58, 0.11 $\mu g\ g^{-1}$); Owen Anchorage (site 9, 0.35 $\mu g\ g^{-1}$); Jervoise Bay marina and launching ramp (site 13, 0.16 $\mu g\ g^{-1}$; site 83, 0.36 $\mu g\ g^{-1}$); Careening Bay (site 112, 0.11 $\mu g\ g^{-1}$; site 27, 0.22 $\mu g\ g^{-1}$) and waters adjacent to the Kwinana industrial area (site 24, 0.18 $\mu g\ g^{-1}$; site 29, 0.35 $\mu g\ g^{-1}$). The most frequently detected PAHs were fluoranthene, pyrene and benzo (a) anthracene.

PAHs were detected in the tissue of mussels from 27 sites (87%) throughout the study area (Figure 2b) ranging from 0.001 $\mu g\ g^{-1}$ to 0.012 $\mu g\ g^{-1}$. The highest concentrations of PAHs were found at site 24 (0.012 $\mu g\ g^{-1}$) and sites 21 and 22 (both 0.010 $\mu g\ g^{-1}$) adjacent to the Kwinana industrial area. The most frequently detected PAH was naphthalene.

3.3 Tributyltin

Organotin compounds were detected in sediments at all 64 sites (Figure 1). TBT was detected at 53 sites (Figure 3a) ranging from 0.001 μg TBT g^{-1} to 1.35 μg TBT g^{-1}. The distribution of sites with relatively low TBT concentrations were generally found at offshore sites or at sites distant from areas of high boat densities. TBT contamination of sediments was highest in harbours (site 60, 1.00 μg TBT g^{-1}; site 59, 1.35 μg TBT g^{-1}; site 58, 0.25 μg TBT g^{-1}), marinas (site 85, 0.27 μg TBT g^{-1}) and in the mooring area at Thomson Bay, Rottnest Island (site 167, 0.20 μg TBT g^{-1}). Concentrations above 0.05 μg TBT g^{-1} occurred at sites in Careening Bay and the northern shore of Owen Anchorage and most of the eastern shore of Cockburn Sound.

Organotin compounds in mussel tissue were detected at 96 per cent of the 35 sites, indicating that these substances are widely distributed in the waters of the study area. TBT was detected in mussel tissue at 29 sites (Figure 3b) ranging from 0.003 μg TBT g^{-1} to 0.33 μg TBT g^{-1}. The lowest TBT concentrations (< 0.0005 μg TBT g^{-1}) were generally found at offshore sites or at sites distant from areas with high boat densities. The highest concentrations occurred at site 18 (0.32 μg TBT g^{-1}) adjacent to the Jervoise Bay marina and site 1 (0.16 μg TBT g^{-1}) in the Fremantle Harbour.

4. Discussion

4.1 Pesticides and PCBs

Pesticides and PCBs in sediments and mussels were detected at less than 2 per cent of the sites and most of these sites were within or near ports and marinas. Comparisons with similar Australian and overseas studies indicate that these waters are not significantly contaminated with these substances (Table 1). The most likely source of organochlorine pesticides in harbours is from urban drains discharging either directly into the harbours or in the case of the Fremantle Harbour discharging upstream into the Swan River. The presence of the organophosphorus pesticides, maldison and fenitrothion, detected in sediments from Fremantle Harbour and adjacent to the grain loading facility in Cockburn Sound, is probably related to the spillage of grain treated with these pesticides (P. Rutherford, pers. comm.). While organophosphorous pesticides, especially chlorpyrifos, can persist in marine sediments (Readman *et al.*, 1992) the results of this survey suggest current usage levels are unlikely to result in significant environmental impacts in the near future.

4.2 Hydrocarbons

Compared with the concentrations of hydrocarbons found in sediments (2 - 26 μg g^{-1}, Sleeter *et al.*, 1980, Botello *et al.*, 1983) and mussels (0.8 - 2 μg g^{-1}, Risebrough *et al.*, 1983) in overseas studies, the southern waters off Perth are relatively uncontaminated with aliphatic hydrocarbons. Since the late 1970s, the concentrations of aliphatic hydrocarbons in sediments and mussels in Cockburn Sound and Owen Anchorage have generally decreased and the formerly widespread distribution of contaminated sites has contracted to the vicinity of harbours, marinas and areas along the eastern shelf of Cockburn Sound (Chegwidden, 1979; Alexander *et al.*, 1979). The distribution of aliphatic hydrocarbons in the study area suggests the source is primarily related to shipping activity.

PAHs are ubiquitous in sedimentary environments with background levels of between 0.010 μg g^{-1} to 0.015 μg g^{-1} in deep sea sediments (Hites *et al.*, 1980). In this study, PAHs in sediments and mussels were found throughout the study area however the concentrations were generally low and unlikely to be biologically significant (CEPA, 1994 Rainio et al., 1986). The highest PAH concentrations were recorded at sites located in harbours, marinas and the eastern

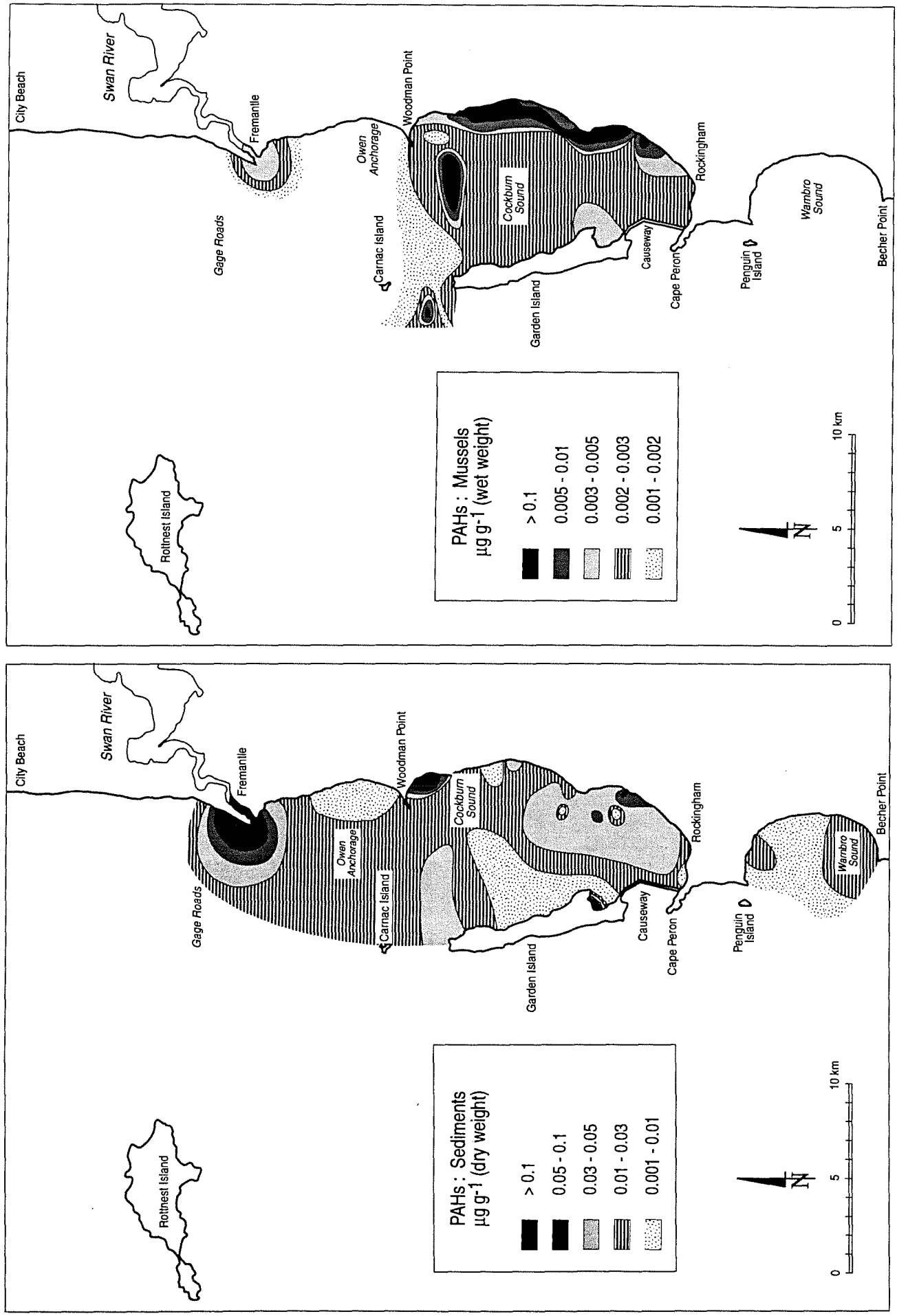

Figure 2. Distribution of polycyclic aromatic hydrocarbons in sediments (a) and mussels (b) throughout the study area.

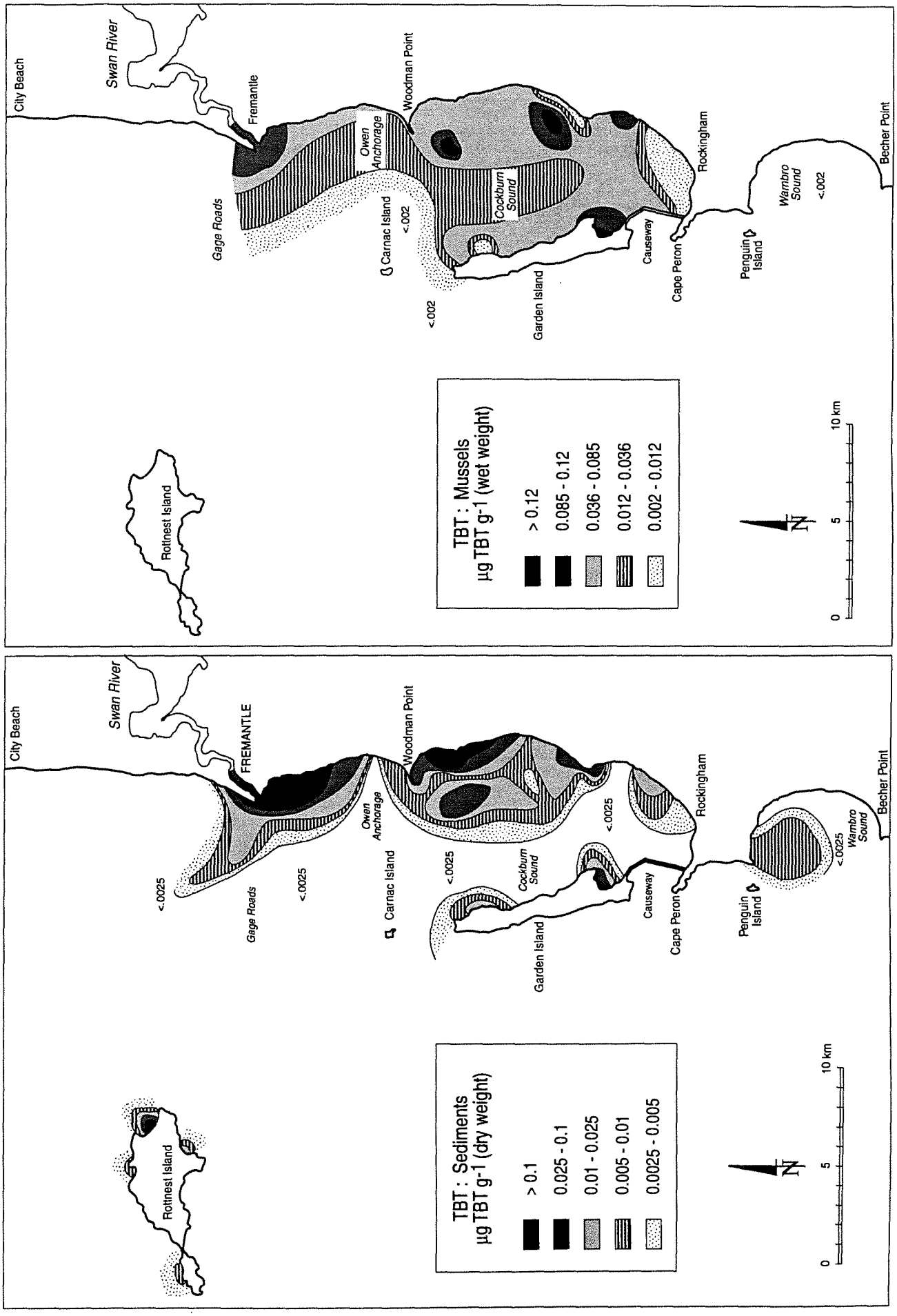

Figure 3. Distribution of tributyltin in sediments (a) and mussels (b) throughout the study area.

shoreline in Cockburn Sound. The highest concentration of PAHs in sediments was in Fremantle Harbour were the PAH concentration was 3.2 μg g^{-1}, approaching the levels of 3.8 μg g^{-1} to 6.8 μg g^{-1}, considered to cause deleterious biological effects (CEPA, 1994). The highest concentration of PAHs in mussel tissue was 0.012 μg g^{-1} and is within the range of concentrations in mussels from waters that are considered to be uncontaminated (ie. 0.05 μg g^{-1} to 0.14 μg g^{-1}; Rainio *et al.*, 1986).

Two- and three-ring PAHs, naphthalene to anthracene, are most likely related to petrogenic hydrocarbon spillages such as diesel and fuel oil, whilst four- and five-ring compounds, fluoranthrene to benz (a) pyrene, are primarily produced as a result of fossil fuel combustion (Bates *et al.*, 1984; Boehm and Farrington, 1984). The distribution and profile of PAHs in sediments and mussels of Cockburn Sound suggest that the origins of these contaminants are shipping activity, associated with the Kwinana industrial area and HMAS Stirling in Careening Bay and direct discharge into these waters from industrial and municipal outfalls respectively.

Table 1. Reported concentrations of organochlorine pesticides and PCBs in sediments and mussels (*Mytilus edulis*).

Location	Organochlorines		PCBs	Reference
	non DDT	DDTs		
	Sediment μg g^{-1} (dry weight)			
Gulf of Mexico, 1986	<0.0001 - 0.020	<0.0001 - 0.450	<0.0001 - 0.190	Sericano, 1990
1987	<0.0001 - 0.089	<0.0001 - 3.270	<0.0001 - 3.730	Sericano, 1990
SMCWS, 1991	<0.001 - 0.002	<0.001 - 0.022	<0.010	This study
	Mussels μg g^{-1} (wet weight)			
California Harbour		0.007 - 0.130	0.032 - 0.190	Riseborough *et al.*, 1983
North Californian Coast	-	0.001 - 0.007	0.001 - 0.006	Riseborough *et al.*, 1983
Middle & North Adriatic	-	0.036 - 0.065	0.075 - 0.133	Picer *et al.*, 1978
Scotland	<0.001 - 0.413	<0.003 - 0.064	0.010 - 1.200	Cowan, 1981
SMCWS, 1991	<0.001 - 0.021	<0.001 - 0.002	<0.010	This study

4.3 Tributyltin

Elevated concentrations of TBT in mussels and sediments were found throughout the study area and contamination was highest in harbours, marinas and boat mooring areas (Figure 3). Similar patterns have been found in numerous other Australian and overseas studies (eg Batley *et al.*, 1992; EPA, 1990; IMO, 1994; Maguire, 1987; Maguire *et al.*, 1986; Langston *et al.*, 1987; Quevauviller *et al.*, 1989). The concentrations of TBT in sediments and mussels from the southern waters off Perth are relatively high in comparison with similar Australian and overseas studies (Table 2). Sediments at approximately 20 per cent of the sites are moderately to very highly contaminated according to a classification of Waite *et al.* (1991). Similarly nearly

Table 2. Reported concentrations of TBT in sediments and mussels (*Mytilus edulis*). (*) Concentrations expressed as dry weight and converted to wet weight by dividing by five (Page and Widdows, 1991).

Sediment				
Location	**Year**	**Statistic**	**Sediment concentration (μg TBT g^{-1}; dry weight)**	**Reference**
Australia				
SMCWS				
Study area	1991	Range	0.001 - 1.350	This study
Harbours/marinas	1991	Range	0.050 - 1.350	This study
Cockburn Sound	1987	Range	0.050 - 0.790	EPA, 1990
	1991	Range	<0.001 - 0.055	This study
Careening Bay	1987	Range	ND - 0.600	EPA, 1990
	1991	Max	0.040	This study
Jervoise Bay	1987	Range	0.030 - 13.130	EPA, 1990
	1991	Range	0.050 - 0.270	SMCWS
Overseas				
San Diego Bay, USA	1988-90	Range	0.002 - 0.080	Valkirs *et al.*, 1991
Toronto Harbour, Canada	1985	Range	ND - 4.410	Maguire and Tkacz, 1985
Mussels				
Location	**Year**	**Statistic**	**Mussel concentration (μg TBT g^{-1}; wet weight)**	**Reference**
Australia				
SMCWS				
Study area	1991	Range	<0.001 - 0.330	This study
Harbours/marinas	1991	Range	0.100 - 0.170	This study
Cockburn Sound	1987	Range	0.030 - 0.300	EPA, 1990
	1991	Range	<0.001 - 0.330	This study
Careening Bay	1987	Range	0.070 - 2.820	EPA, 1990
	1991	Max	0.125	This study
Jervoise Bay	1987	Range	0.340 - 0.400	EPA, 1990
	1991	Range	0.050 - 0.330	This study
Corio Bay, Vic		Max	0.080	NFA, 1993
Overseas				
Puget Sound, Pacific	1992	Median	0.115	IMO, 1994
Galeston Bay, Gulf of Mexico	1992	Median	0.394	IMO, 1994
Coastal waters, USA			0.001 - 0.310 *	Wade *et al.*, 1988
Pacific coast USA	1986	Range	0.005 - 1.080	Short & Sharp, 1989
San Diego Bay, USA	1988-90	Range	0.03 - 0.390	Valkirs *et al.*, 1991

25 per cent of the mussel sites would be classed as moderately contaminated with concentrations likely to cause mussels physiological stress, according to a classification by Page and Widdows (1991). Furthermore, the concentrations of TBT in mussels from site 1 in Fremantle Harbour (0.16 μg TBT g^{-1}) and site 18 adjacent to the Jervoise Bay Marina (0.33 μg TBT g^{-1}) exceeded levels suggested by the World Health Organisation (0.15 μg TBT g^{-1} wet weight) for the consumption of food containing this substance (WHO, 1990).

A study of *Conus* (family Conidae) at Rottnest Island in 1991 found 80 per cent of the females from seven species displayed evidence of the reproductive disorder imposex or imposed male sexual characteristics (Figure 1; Kohn and Almasi, 1993). A recent examination of preserved specimens from the Western Australian Museum, collected in 1975 from the same sites on the island, showed no evidence of imposex (F. Wells, pers. comm.). Imposex in molluscs has been linked to TBT contamination in many parts of the world (eg Oehlmann *et al.*, 1991). A recent study of the neogastropod *Thais orbita*, found the occurrence of imposex to be very high in populations living on intertidal platforms throughout the metropolitan coastal waters of Perth (Field, 1993). The frequency of imposex in these populations correlated significantly with the concentration of TBT in mussels at the same or nearby sites. Spatially, there was a strong correlation between the frequency of imposex and the distance of sites to boating and shipping facilities. The high proportion of sites in Perth's southern metropolitan coastal waters with elevated concentrations of TBT and the widespread occurrence of imposex in *Thais orbita* is cause for major concern.

National legislative restrictions on the use of organotin antifouling paints on boats have generally been effective in reducing concentrations in waters used predominantly by small boats. However recent studies in the United Kingdom suggest that in coastal waters used by large vessels, exempt from legislative restrictions, reductions in TBT contamination have been comparatively small (IMO, 1994). The use of organotin antifouling paints was restricted in Western Australia from 1 July 1991 although existing stocks were allowed to be sold during the period to 31 December 1991. Boats registered in Western Australia under 25 metres in length were banned from using organotin antifouling paints and vessels over 25 m were restricted to the use of paints with leaching rates less than 5 μg TBT cm^{-2} of hull area day^{-1} (EPA, 1990). Thus at the time of this survey (November 1991) it is unlikely that the legislative restrictions had had any significant effect on TBT contamination of Perth's southern waters. A follow-up survey undertaken in February 1994 will provide a basis for reviewing the effectiveness of the management measures currently implemented.

4.4 Summary and conclusions

Detectable concentrations of pesticides, polychlorinated biphenyls and aliphatic hydrocarbons were recorded at approximately 5 per cent of the sediment sites and 10 per cent of the mussel sites. Contamination was generally confined to areas within or immediately adjacent to shipping facilities and marinas. By contrast, contamination of sediments and mussels with polycyclic aromatic hydrocarbons and organotin compounds, particularly tributyltin, was widespread throughout the study area. Areas of highest contamination occurred in harbours and boat mooring areas and along the eastern side of Cockburn Sound.

Comparisons with the results of similar Australian and overseas studies indicate that, in general, sediments and mussels from these waters are not significantly contaminated with pesticides, polychlorinated biphenyls or hydrocarbons. In contrast elevated concentrations of TBT in the sediments and mussels are amongst the highest recorded in Australia. A recent study of imposex in the neogastropod *Thais orbita*, found very high frequencies in populations living on intertidal platforms throughout the metropolitan coastal waters of Perth. The high proportion of sites contaminated with TBT and the widespread occurrence of imposex in *Thais orbita*, linked to TBT contamination, is cause for major concern.

Since the early to mid-1980s discharge of toxic pollutants to Cockburn Sound and surrounding waters has decreased substantially (Martinick *et al.*, 1993), following recommendations from the Cockburn Sound Environmental Study (DCE, 1979). The results from this current study suggest that management measures implemented over this period, such as relocation of the Woodmans Point domestic wastewater outfall to Sepia Depression and improved industrial wastewater treatment processes, have been effective in reducing the contamination of Cockburn Sound by organic pollutants.

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