# Investigation into Tributyltin (TBT) Contamination in Cockburn Sound

## *Summary Report 2006*

*Cockburn Sound Management Council*
*Community Summary Paper*

*February 2006*



COCKBURN SOUND MANAGEMENT COUNCIL

# Background

The Cockburn Sound Management Council (CSMC) is responsible for annual reporting to Parliament on the state of Cockburn Sound which is measured against Environmental Quality Criteria (EQC) established by the *State Environmental (Cockburn Sound) Policy 2005*. The EQC include measures of water quality, sediment quality and biological characteristics, which are used to assess the environmental condition of Cockburn Sound and determine the need for further investigations and/or management.

The CSMC's annual monitoring (commenced in 2001) has reported levels of tributyltin (TBT) in sediments in Jervoise Bay exceeding the Environmental Quality Guideline (EQG) of 5 µg tin/kg (see Note #1), thereby triggering further investigations and assessment against the Environmental Quality Standard (EQS).

The CSMC commissioned Oceanica Consulting Pty Ltd to undertake a study to describe the current state of TBT contamination in Cockburn Sound, identify gaps in the current management response and where necessary, prepare and undertake a research and investigation program to provide information for future decision-making. This paper represents an edited summary of the research to report to the community on this issue.

# Introduction

## Tributyltin (TBT)

TBT compounds have been used in antifouling paints since the early 1960s to prevent, or at least slow, the settlement and growth of marine fouling organisms on ships hulls and other submerged structures (Figure 1). TBT is an extremely effective antifoulant due to its broad spectrum toxicity and ability to persist on vessel hulls.

**Figure 1** **Fouling on hull of Royal Australian Navy (RAN) vessel (Photo courtesy of John Lewis)**

## The need for antifoulants

Fouling can significantly increase the 'drag' on a hull as it travels through the water, with even light fouling able to cause up to a 40% increase in fuel consumption. Therefore an effective antifouling agent can significantly reduce a vessel's fuel consumption (and therefore the generation of greenhouse gases).

## Toxic effects of TBT

Even extremely low concentrations of TBT of 1 to 2 ng/L in seawater can cause chronic (long-term) and acute (short-term) poisoning of non-target species.

The toxic effects are wide ranging and include imposex in shellfish (see overleaf), a reduction in shell growth in the mussel *Mytilus edulis*, and disruption of the ionic regulatory functions of fish. Studies in the United States have shown organotins to accumulate in the livers of marine mammals, causing damage to the central nervous system and reproductive mechanism. Organotins have an endocrine disrupting ability in humans, with the tolerable daily intake (TDI) set at 15 µg/60 kg person/day. The Department of Health has analysed a number of farmed mussels from Cockburn Sound and concluded that negligible concentrations of TBT were present within the shellfish tissues, and that they posed no risk to public health.

*Note #1:*

*TBT results are typically reported in terms of the amount of tin present due to TBT (or DBT/MBT) contamination. Therefore, results reported as ng tin/L of seawater, or as µg tin/kg of sediment or shellfish flesh, do not include the weight of the other components of TBT compounds, such as carbon, oxygen and hydrogen (Luke Baker, pers comm., National Measurement Institute, January 2006). Although it is likely that all results have been reported in this manner, this cannot be confirmed for all historic results. All historic results have been reported as provided in their original documents.*

### Bioaccumulation in marine birds

Seabirds appear to be able to metabolise TBT and to shed the breakdown products through moulting. However, these compounds have been found in the livers and kidneys of cormorants (*Phalacrocorax carbo*) from the North Pacific, Japan and Korea, at concentrations of up to ~300 ng/g wet weight.

TBT and its breakdown products have also been found in the tissues of dead penguins found in the Perth metropolitan area. TBT concentrations of up to 488 ng tin/g and concentrations of DBT (a breakdown product of TBT) up to 637 ng tin/g were recorded.

Whilst there is no evidence to suggest that the death of these birds can be attributed to TBT, it does demonstrate that while these birds can metabolise TBT, bioaccumulation of TBT is occurring in penguins within Perth metropolitan waters.

### Imposex as an indicator of TBT contamination

Imposex is the occurrence of induced male sex characteristics superimposed on normal female gastropods (marine snails) (Figure 2).

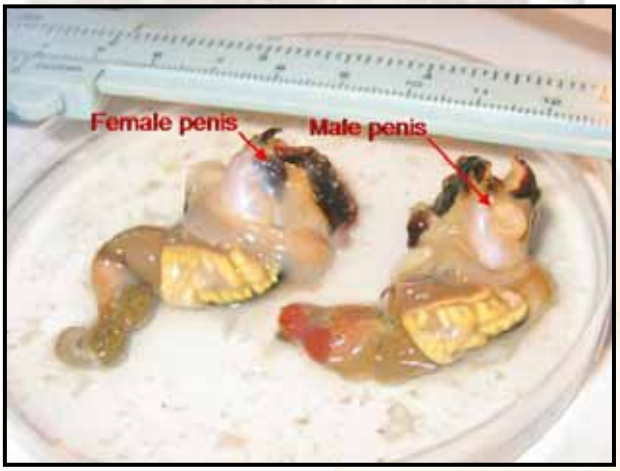


**Figure 2 Female exhibiting imposex (left) and normal male (right) of *Thais orbita* (shell removed)**

The development of imposex is thought to be a result of an increase in testosterone in females, due to inhibition of the normal breakdown mechanism.

Imposex was first reported in the dogwhelk *Nucella lapillus* in the UK, in the 1970s. Since then it has been estimated that up to 150 gastropod species worldwide have been found to exhibit imposex, with five species having been used as bioindicators of TBT contamination in Australia. Many studies have shown a clear relationship between the proximity of populations to sources of TBT (e.g. harbours and marinas) and the degree of imposex they exhibit. Severe imposex development can result in a female's death as blockage of the oviduct can cause aborted egg capsules to build up and eventually rupture the capsule gland.

## Sources of TBT

### Active sources

TBT enters the marine environment via two main routes:

(1) Leaching from the hulls of large (>25 m in length) vessels.

This is determined by the volume of shipping using TBT antifouling paints and the vessels involved (e.g. their size, how recently antifoulant has been applied, how well maintained they are). Paint flakes containing TBT may also fall off vessels hulls.

(2) Hull cleaning and maintenance practices.

TBT from land-based maintenance facilities can enter the marine environment if contaminated wastes are not contained by air (i.e. wind-blown paint flakes, or paint spray), site drainage or groundwater.

Figure 3 shows the input pathways of TBT into coastal waters including the leaching of TBT from commercial vessels, surface runoff, groundwater or drainage discharges from boat yards and release from resuspended sediments. The possible sinks of TBT are shown to include the sorption of TBT onto sediment particles, followed by their sinking, burial and storage in anaerobic (oxygen depleted) sediments, and the degradation of TBT within oxic (well-oxygenated) sediments. Organisms potentially affected by TBT contamination (fish larvae, fish, marine mammals and invertebrates) are also shown.

### Passive sources

TBT can also enter the marine environment following long-term storage and release from sediments.

Although TBT has a half-life in seawater of around six hours, it rapidly adsorbs either to suspended sediments or to the surface microlayer of sediments. TBT is likely to be stored in sediments adjacent to wharfs and slipways, where it has a half-life of 1-5 years (possibly decades within anaerobic sediments), whilst the half-life for paint flakes is unknown. It has been suggested that marine sediments may form a

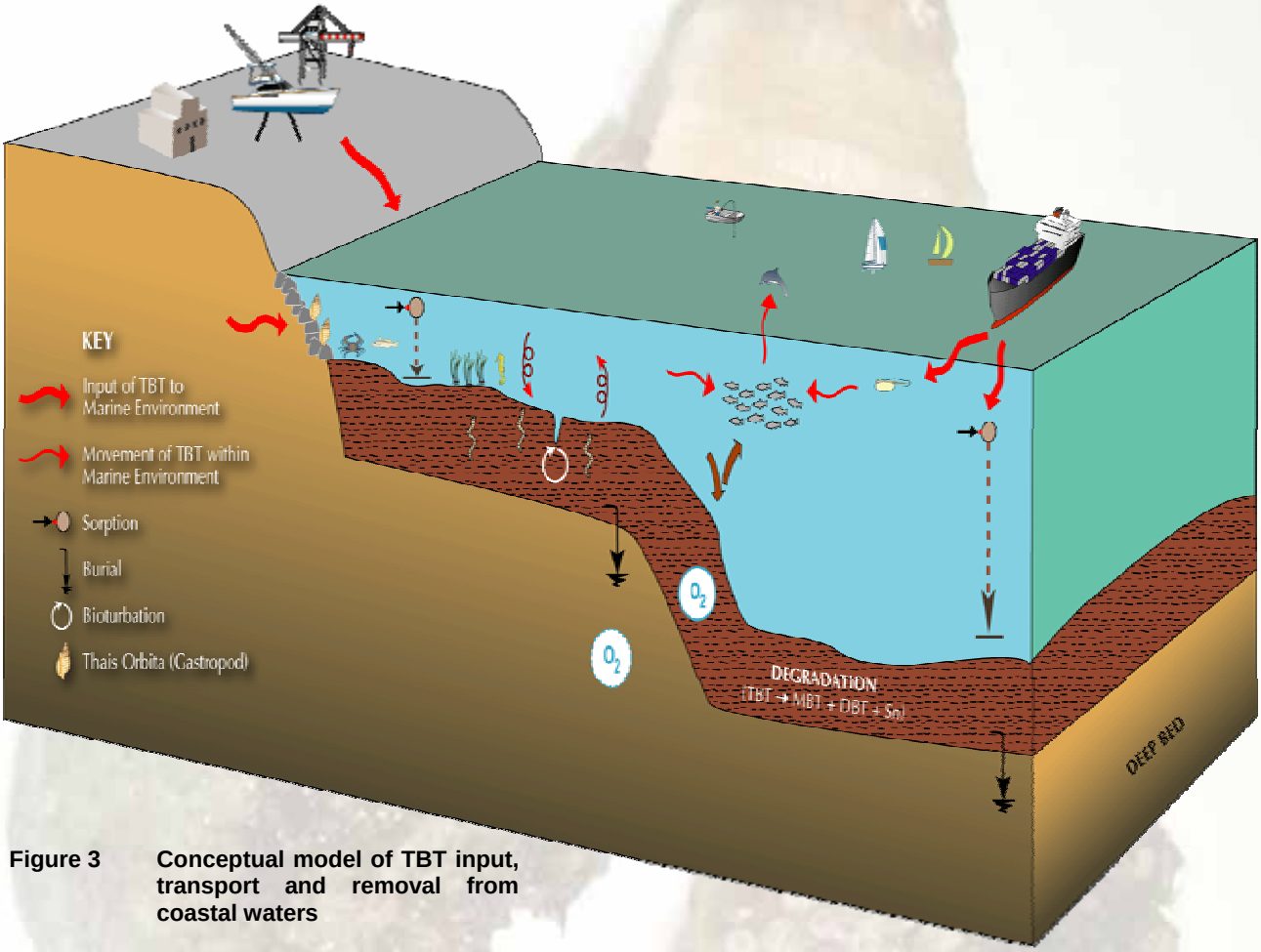


**Figure 3** **Conceptual model of TBT input, transport and removal from coastal waters**

reservoir of TBT a number of years after input has ceased.

Surveys of estuaries around Sydney have shown that although the concentration of TBT in the surface 1-3 cm of sediment has decreased following the partial ban on the use of TBT, the maximum concentration occurs below this depth.

Several studies have shown that TBT concentrations in sediments and coastal waters have remained high in some areas, even 8-10 years after the introduction of regulations to control TBT contamination (refer to section on 'Management Strategies').

TBT contaminated sediments may be periodically resuspended, for example by wave action, dredging or propeller wash, leading to the release of TBT back into the water column.

It is likely that relatively high concentrations of TBT are present in deep sediments in Northern Harbour surrounding the now decommissioned ASI boatyard, and in Southern Harbour resulting from historic shipyard activities (there has been a shipyard at this site since 1970). Elevated levels at depth are also likely to be present adjacent to wharves such as those at Careening Bay on Garden Island, Kwinana Bulk Terminal and James Point.

## Historic Status of TBT Contamination in Cockburn Sound

Past monitoring of TBT contamination in Cockburn Sound has included the monitoring of TBT levels in sediments and mussels, and surveys of imposex levels in *Thais orbita*.

The first extensive survey of TBT contamination in Cockburn Sound was undertaken in 1991 as part of the *Southern Metropolitan Coastal Waters Study* (SMCWS). Sediment TBT concentrations were highest in harbours and boat mooring areas suggesting recreational and commercial boats as a major source. TBT concentrations in mussel tissue reached a maximum of 320 ng TBT/g adjacent to the Jervoise Bay marina. Since then monitoring of TBT concentrations in sediments (Kwinana and Jervoise Bay) and mussels (Careening Bay, Garden Island) has taken place.

## Jervoise Bay summer monitoring

Annual data from Jervoise Bay show that concentrations of TBT in excess of the EQG (5 ng tin/g) have remained in sediments within Northern and Southern Harbour (Figures 4a and 4b).

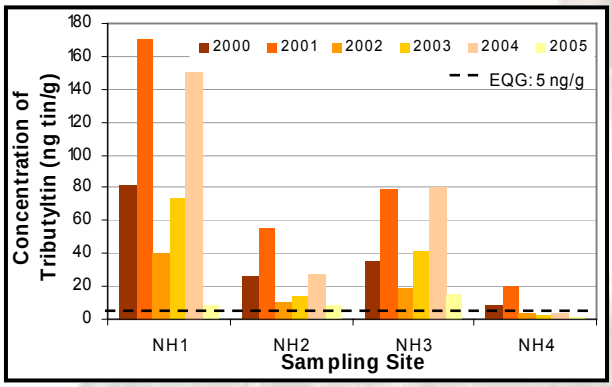


**Figure 4a** **Change in sediment TBT concentrations in Northern Harbour**

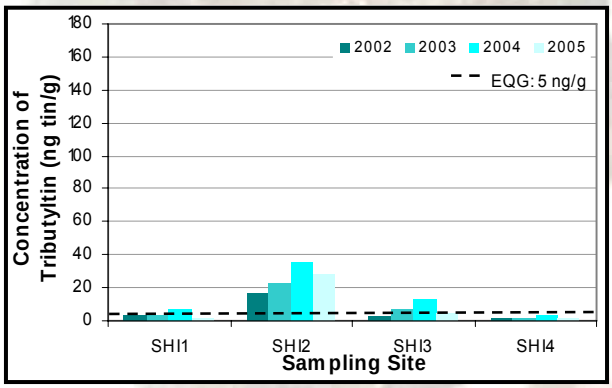


**Figure 4b** **Change in sediment TBT concentrations in Southern Harbour**

## Southern Harbour Shipyard monitoring programme, Jervoise Bay

Under licence conditions the boat maintenance facility in Southern Harbour is required to undertake quarterly sediment, soil and groundwater monitoring.

The June 2005 data show that the sediments at most sites surrounding the Southern Harbour Shipyard facility exhibit TBT concentrations above the EQG. Soil concentrations were generally lower than sediment concentrations, although relatively high levels of TBT were recorded at some sites. Groundwater TBT concentrations ranged from low (<0.002 µg tin/L) to very high (1.620 µg tin/L).

## Department of Defence Monitoring, Garden Island

A program to annually collect and monitor mussels from HMAS Stirling for TBT was established in January 1993, with the number of survey sites gradually increased from five to fifteen. The data show a gradual reduction in mussel tissue TBT loads from the early 1990s. Data from November 2003 and November 2004 suggest that the steady decrease in contamination levels within Careening Bay and surrounding Cockburn Sound waters has continued, though concentrations of TBT in mussel tissue have remained high (>100 ng tin/g wet weight) at some sites.

# Current Status of TBT Contamination in Cockburn Sound

Survey sites were chosen to revisit those populations of *Thais orbita* previously surveyed for imposex: Northern Harbour, Southern Harbour, Challenger Beach, Colpoys Point and Beacon Point. *Thais orbita* is a marine snail that lives just below sea level (Figure 5).

**Figure 5** ***Thais orbita* at James Point**

Additional sites not previously surveyed were also visited within this study (Mangles Bay, James Point and Woodman Point) to try to obtain a more comprehensive distribution of sites within Cockburn Sound (Figure 6) and to measure against the EQS in the High Ecological Protection area.

The choice of sites was limited by the fact that *Thais orbita* only occurs on hard substrate (reefs, rock groynes and breakwaters), and so sampling in Cockburn Sound was confined to those relatively few areas that have suitable habitat for these organisms.

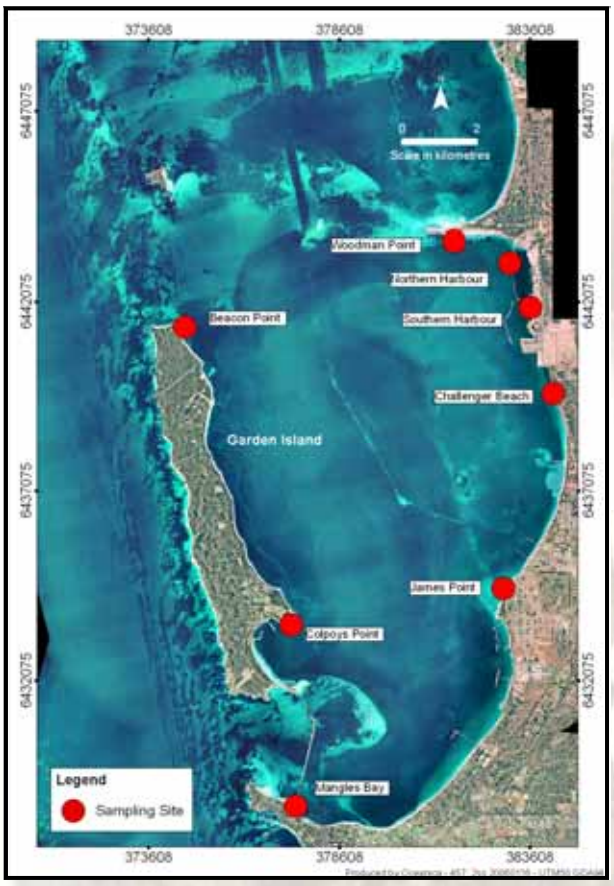


**Figure 6** **Location of survey sites**

## Methods

### *Thais orbita* collection

The *Manual of Standard Operating Procedures (Cockburn Sound)* suggests the collection of one hundred individuals at each site. However, within this study the collection of fifty individuals for imposex determination was attempted. The change in sample size was made due to the relatively low abundance of individuals within Cockburn Sound and followed an examination of the results from previous studies. Other workers considered that the collection of thirty to fifty individuals would be sufficient to obtain accurate imposex data.

Data were collected on the size frequency distribution, sex ratio, incidence of imposex (percentage of females exhibiting imposex), relative penis size and vas deferens sequence index of each population.

At sites at which 50 animals could not be found, those animals found within 1½ hours were collected, with a sub-sample sent for tissue analysis and the remainder analysed for imposex development.

### Sediment sampling and analysis

Sediment samples were taken at each site at which sufficient numbers of *Thais orbita* were found, following the method outlined in the *Manual of Standard Operating Procedures (Cockburn Sound).*

## Results

### Sediment data

Only sediments within Jervoise Bay Southern Harbour exhibited TBT contamination in exceedance of the EQG. All other sediment samples, with the exception of those from Northern Harbour and one replicate from Colpoys Point, exhibited TBT concentrations below the reporting limit (Table 1).

**Table 1** **Median TBT Concentrations in Sediment Samples**

| Site | Median TBT Concentration (ng tin/g) |
|---|---|
| ***Reporting Limit*** | ***0.5*** |
| ***EQG*** | ***5.0*** |
| Colpoys Point | 0.5 |
| James Point | 0.5 |
| **Southern Harbour** | **107** |
| Northern Harbour | 3.7 |
| Woodman Point | 0.5 |

*Note: Exceedance of EQG highlighted in red*

### Data from *Thais orbita*

#### Tissue TBT concentration

Animals from James Point and Woodman Point exhibited the lowest concentration of TBT within their tissues (2.7 and 3.8 ng tin/g respectively) while animals from Northern Harbour and Southern Harbour exhibited the highest concentrations (80 and 66 ng tin/g respectively).

#### Abundance

No individuals of *Thais orbita* could be found after an hour of searching at Challenger Beach, Mangles Bay and Beacon Point. Fifty individuals could not be found at James Point and Southern Harbour (Table 2). The relative scarcity of animals at these sites could be a result of natural changes in the environment (for example increased sedimentation or a shift in the intertidal community), naturally high mortality rates within this species, inhibition of normal reproduction due to imposex development, seasonal migration (this is the first study within Cockburn Sound conducted during winter) or potentially a response to the removal of significant numbers of individuals for historic imposex assessment.

## Incidence of imposex

The EQS was exceeded at each of the sites surveyed (Table 2).

**Table 2 Abundance and imposex occurrence in *Thais orbita* populations**

| Site | No. of Individuals | EQS | Imposex (%) |
|---|---|---|---|
| Colpoys Point | 56 | ≤10 | 100 |
| James Point | 25 | ≤10 | 89 |
| Southern Harbour | 26 | ≤10 | 100 |
| Northern Harbour | 55 | ≤10 | 100 |
| Woodman Point | 50 | ≤5 | 90 |

*Notes: Exceedances of EQS highlighted in red*
*Woodman Point is within the High Protection Area*

The incidence of imposex at Colpoys Point, Southern Harbour and Northern Harbour was ≥99% when these sites were previously surveyed (1993 and/or 1998/99).

## Relative Penis Size and Vas Deferens Sequence

The extent to which a gastropod population is affected by imposex can also be described in terms of the relative penis size (RPS) and the vas deferens sequence (VDS). Relative penis size (RPS) is defined as the mean bulk of the female penis expressed as a percentage of the mean bulk of the male. The vas deferens sequence (VDS) describes the development of the vas deferens, with stages running from 0 (no development), through to stage 6 (female penis approaching size of a male, vas deferens fused and proliferating).

The RPS was lowest at Woodman Point, suggesting a minimal influence of TBT, and highest at Colpoys Point and Northern Harbour, indicating a greater influence of TBT contamination (Figure 7).

The RPS has remained relatively constant at Colpoys Point and Southern Harbour, but has increased at the Northern Harbour since 1993 and 1998/99 (Figure 8).

The VDS was found to be high (≥ stage 4) in the majority of females at all sites. In contrast to the RPS data, Woodman Point exhibited the highest VDS (most severe influence of TBT) and Colpoys Point exhibited the lowest VDS (least severe influence of TBT). It is not known why the RPS and VDS results indicate different severities of impact at some sites.

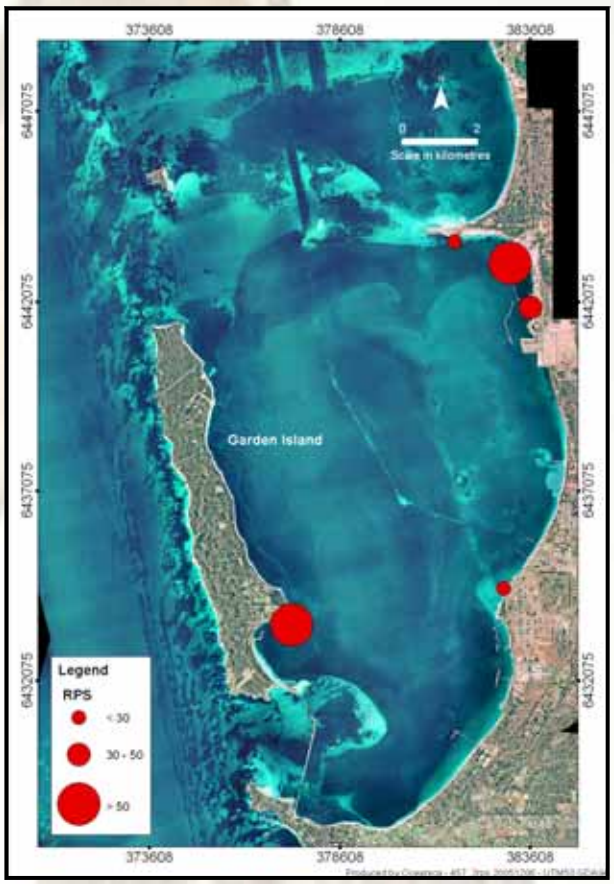


**Figure 7 Relative Penis Size (RPS) results**

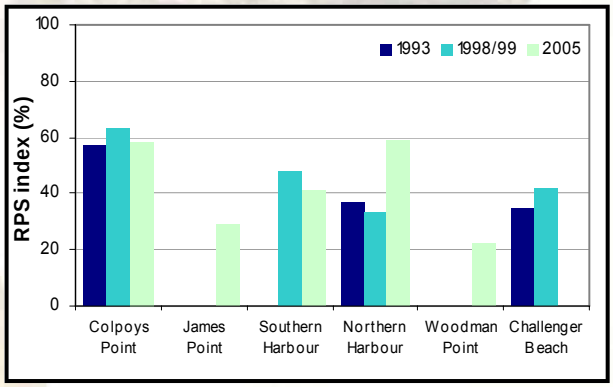


**Figure 8 RPS index recorded from Cockburn Sound sites since 1993**

## Aborted eggs

Severe TBT contamination resulting in a VDS of 5 or greater can cause blockage of the oviduct which means that the female is no longer able to lay eggs. Over time aborted egg capsules build up in the capsule gland and eventually cause it to rupture, which will result in the animals' death.

Aborted eggs were seen within three females from Colpoys Point, three females from Northern Harbour and one female from Southern Harbour. This indicates that the reproduction of populations of *Thais orbita* at these sites is being inhibited by TBT contamination.

### Impacts within younger individuals

The only females not exhibiting any signs of imposex development were relatively small animals (shell length ≤ 5.23 cm) found at Woodman Point (two animals) and James Point (one animal). This suggests that these sites exhibit the lowest TBT contamination of all the sites surveyed. However, it is recognised that conclusions cannot be drawn from such a small dataset (three individuals).

The development of imposex is thought to occur at a young age and is irreversible. If individuals develop imposex early in life, then continue living for several years (*Thais orbita* is a long-lived species, living ≥ 10 years) before they are surveyed, the imposex results obtained could be an indicator of past TBT contamination.

If the contamination status has decreased during the last two to five years, it might be expected that the younger animals, developing under conditions of reduced TBT exposure, may exhibit less well developed signs of imposex than older animals. To investigate this, animals from each population were grouped into two categories; 'small' and 'large' and the RPS index for each group determined (Figure 9).

The resultant grouping showed that the smaller animals at all sites except Northern Harbour exhibited an RPS index less than that calculated for the larger animals. This suggests that there has been a decrease in the degree of TBT contamination at Colpoys Point, James Point, Southern Harbour and Woodman Point, with younger animals less severely affected than older animals.

**Figure 9** **Variation in shell size within Southern Harbour population**

## Management Strategies

### International

A global ban on the use of organotin antifouling systems will be introduced in 2008 by the International Maritime Organisation (IMO), subject to ratification by member states; meaning that after that date no vessels should be painted with TBT containing paint unless sealed to prevent it leaching into the environment.

Many countries implemented restrictions on the use of TBT paints in the 1980's, and the majority of studies have indicated gastropod populations to be showing a reduction in imposex since the introduction of these measures.

It is likely that national restrictions, together with the development of alternative paints in response to the expected ban, are likely to remove TBT-based paints from use within most countries prior to 2008.

### Australia

The Australian Pesticides and Veterinary Medicines Authority (APVMA) has cancelled the registration on antifouling paint containing tributyltin. Use of these products was banned on 31 July 2003.

The Royal Australian Navy has introduced additional restrictions on TBT usage, with no TBT paints applied since 1 January 2003 and many vessels under 40 m in length being required to use alternate antifoulants including copper-based materials.

### Western Australia

The Department of Environmental Protection (DEP) introduced legislation controlling the use of TBT-based paints in 1991. Under this legislation the use of TBT paints on vessels less than 25 m in length was prohibited and the leaching rate of TBT paints was limited to 4-5 µg/cm$^2$/day. Further controls on TBT contamination affect the management of dry docks, slipways and hardstands.

The Environmental Regulation Branch of the Department of the Environment (DoE) has responsibilities which include the licensing of facilities involved in the use or removal of TBT paints.

### Cockburn Sound

Of the boat building and maintenance facilities adjacent to Cockburn Sound (Figure 10), only one is licensed for the removal of organotin compounds. This facility is involved in the hydroblasting of the hulls of Australian and

offshore-registered vessels. Measures to control the input of TBT into the marine environment have been incorporated into the DoE licence conditions of this shipyard since 2000.

**Figure 10** **Ship at maintenance facilities in Jervoise Bay, Cockburn Sound**

Current licence conditions for this facility manage the potential for contamination through a number of requirements including:

a. All abrasive blasting and metal coating of structures treated with TBT is undertaken on a hardstand area;
b. Fully enclosed and weather proof temporary structures are constructed and maintained when abrasive blasting and metal coating of structures is undertaken on unsealed surfaces; and
c. Spent abrasive and abraded material is cleaned up after every blasting operation and disposed of at a licensed facility.

The DoE has advised the CSMC that it is currently reviewing the licence of the Southern Harbour shipyard, associated with TBT, and is working towards improvements on site. Following the exceedances of the EQG noted in 2005, the DoE will continue to meet with senior management from the Southern Harbour shipyard to discuss ongoing management of the site. Further, the DoE intends to request that a plan for upgrading the site be developed. The main aim of the upgrade will be to eliminate existing pathways for contaminants reaching Cockburn Sound.

Other ship fitters and builders in the area are not licensed, and as such are not permitted to clean the hulls of large vessels (> 25 m).

## Conclusions

With respect to TBT inputs from shipping movements, the phasing out of TBT-based paints on vessels is already well regulated at the state, national and international level while licence conditions set for the Southern Harbour shipyard (DoE Kwinana-Peel Regional Office) control the painting, cleaning and disposal of TBT paints, and site monitoring at the local level.

There are also effective annual monitoring programs within Jervoise Bay and Careening Bay, currently the two known 'hot spots' of contamination, with an EQG against which to assess environmental quality.

It is likely that the high incidence and severity (RPS and VDS) of imposex observed at most sites is a function of the longevity of *Thais orbita* (≥ 10 years) combined with slightly elevated TBT concentrations within areas of Cockburn Sound due to storage in sediments and inputs from the Southern Harbour Shipyard facility and commercial vessels entering Cockburn Sound (Figure 11). The higher imposex levels (incidence of imposex and RPS) recorded at Colpoys Point, Southern Harbour and Northern Harbour compared to James Point and Woodman Point are likely to be due to their proximity to contaminated sediments within the harbours.

**Figure 11** **Commercial vessel berthed in Cockburn Sound**

# Where to from here?

## Recommended approach

It is likely that management effort would be best directed at addressing the continued input from ship maintenance facilities, which could include stricter controls on operations or a need for site remediation, and close monitoring of activities which could result in further inputs to the marine environment.

Following the rigorous control of active sources of TBT a risk-based decision framework would need to be developed for sediment assessment and management, with sediment remediation works only likely to be warranted in cases of severe contamination.

It is recommended that the CSMC liase with relevant authorities to facilitate the implementation of the management initiatives outlined below:

1. Stricter controls on ship maintenance facility operations (through a review of DoE issued licence conditions) to ensure that pathways for TBT into the marine environment are appropriately managed;
2. Close monitoring of activities which could result in further inputs to the marine environment (e.g. dredging of contaminated sediments);
3. Continue environmental monitoring to assess severity of contamination, and record any decreases in contamination through time;
4. Co-ordinate the commissioning of periodic imposex surveys to record the severity of impacts from TBT contamination; and
5. If contamination 'hot spots' persist, consider site remediation options if soil contamination is acting as a source of TBT into Cockburn Sound. Assess sediment rehabilitation works if sediment contamination persists and is acting as a source of TBT into Cockburn Sound, though this should be seen as a 'last resort' option.

## Reporting against Environmental Quality Criteria

The value of imposex indices as an indicator of TBT-induced environmental effects, and as a method of tracking changes with time in environmental contamination, is well documented. However, the EQS as it stands could be improved, with consideration of temporal trends in TBT contamination rather than simply the comparison of data against the predetermined thresholds of 5% and 10%. The EQS also takes the incidence of imposex as a contemporary measure of TBT contamination, while evidence suggests that a significant lag time may exist between the indicated severity of environmental contamination and the actual degree of environmental contamination.

Given the longevity of TBT contamination and impacts, it is likely that:

(a) The EQS (imposex measurements) for high and moderate protection will not be met for over two decades, even given a total ban in 2008; and
(b) The EQG (TBT in sediments) will be met first.

To allow the reporting of decreasing TBT contamination within Cockburn Sound, as has been documented worldwide following the partial bans imposed on TBT use, and would be expected in Cockburn Sound, interpretation of the EQS could be undertaken in light of previous data. If the incidence of imposex has been found to decrease between sequential surveys, then this information could be carried through in the reporting framework. Such an approach would be particularly appropriate to TBT given that comprehensive management responses already exist at the international, national, state and local levels. Under such a scheme, the CSMC could coordinate the commissioning of periodic surveys to collect imposex data for comparison against the EQS.

## Management of *Thais orbita* populations

It is suggested that the CSMC could act as a 'gate keeper' for future imposex studies, thereby controlling the frequency at which *Thais orbita* populations are destructively sampled to prevent over-exploitation and possible extinction of the Cockburn Sound populations. Given the current limited abundance of *Thais orbita* within Cockburn Sound, the number necessary for imposex determination and the lag time between contamination and measured response, it is recommended that surveys be undertaken not more than once every four to six years.

## Alternatives to TBT

Copper-based compounds, generally with booster biocides, are the primary alternative to TBT paints. However many of these compounds can be detrimental to marine life and the DoE are currently undertaking a risk analysis of these compounds in Cockburn Sound.

This Community Paper is a summary of the Technical Report:

Oceanica Consulting Pty Ltd, 2005. *Investigation into Tributyltin (TBT) Contamination in Cockburn Sound*. Prepared for Department of the Environment by Oceanica Consulting Pty Ltd. Report No. 457/1.

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Individuals of the gastropod *Thais orbita* (photograph courtesy of Kim Sylva)

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