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AN OVERVIEW OF ENVIRONMENTAL PROBLEMS IN PRINCESS ROYAL HARBOUR AND OYSTER HARBOUR, ALBANY, WITH A DISCUSSION OF MANAGEMENT OPTIONS

Environmental Protection Authority
Perth, Western Australia
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Edited by D.A. Mills

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i ABSTRACT

Between 1962 and 1984, 66 % of the seagrass cover in Princess Royal Harbour (PRH) and 45% in Oyster Harbour (OH), Albany, was lost, probably due to smothering by highly productive algae in a nutrient-enriched environment. If effective management action is not taken, it appears from present trends that seagrass loss will continue, with a corresponding loss of seagrass habitat, sediment stability and water clarity. It is probable that algal blooms will increase in severity and frequency.

Reduction of total inputs of nutrients to the harbours would appear to be the most effective strategy for dealing with these interrelated environmental problems. However, there is an urgent need for systematic data which can yield reliable estimates of the magnitudes of nutrient inputs, and can lead to an identification of the nature, relative importance and distribution of nutrient sources. This information is essential for the formulation of an effective management programme, which may include control of point sources, management of diffuse sources and application of land-use controls.

Marine life in PRH has been contaminated with lead and mercury, which emanated from a local superphosphate plant. In the western end of the harbour, species of crustaceans, molluscs, and at least 11 fish species exceed human health standards for these heavy metals in edible seafood. As a consequence, this part of the harbour has been closed to the public for the taking of seafood. At present, there are no clear signs of natural decrease in contaminant levels, even though heavy metal discharge to PRH effectively ceased in 1984. Lead and mercury (including methyl mercury) are strongly associated with fine organic fractions of the sediments, and with the algae and seagrass. These materials form the base of local food chains. Removal, dispersal, or burial of contaminated algae and fine organics suggest themselves as management strategies. However these materials are interspersed with seagrass, and a major problem is how to remove contaminated organic material without causing considerable further loss of seagrass.

A sustained, coordinated management approach to the Albany waterways and their catchments can best be achieved within a suitable administrative framework, and with reference to carefully formulated policy guidelines. Catchment management should involve state and local government agencies, and the land users. Declaration of a waterways management area would enable improved, direct management of OH and PRH, and related waterways, and should be given careful consideration by appropriate agencies.

Land-use developments and practices taking place in the Albany hinterland are similar to those found elsewhere in southern catchments of Western Australia. It is therefore likely that similar environmental problems are developing in other south coast estuaries and embayments. Arrangements for waterway and catchment management should be flexible enough to deal with the widespread occurrence of these problems, and to pre-empt the emergence of serious environmental problems on a regional scale.

ii ACKNOWLEDGEMENTS

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The major contributors to the report, and the particular sections of it to which they contributed, are listed below. An asterisk denotes principal authorship of a section.

<u>CSIRO, DIVISION OF FISHERIES RESEARCH</u>

Dr H. Kirkman	sections 2*, 7

<u>DEPARTMENT OF AGRICULTURE</u>

Dr J. Yeates	sections 5*, 7*, 11

<u>DEPARTMENT OF FISHERIES</u>

Dr R. Lenanton	section 2

<u>ENVIRONMENTAL PROTECTION AUTHORITY</u>

ESTUARINE IMPACTS BRANCH

Dr R. Humphries	section 4
K. McAlpine	section 4

MARINE IMPACTS BRANCH

Dr D. Mills	sections 1, 3*, 6*, 9, 10, 12
Dr V. Talbot	sections 8*, 9*

<u>UNIVERSITY OF WESTERN AUSTRALIA, CENTRE FOR WATER RESEARCH</u>

J. Cary	section 2, and the photographs
K. Grey	section 9

<u>WATERWAYS COMMISSION</u>

R. Atkins	section 4
Dr B. Hamilton	section 11*

In conjunction with this overview, Dr H. Kirkman prepared a consultant's report (Kirkman 1987) on the decline of seagrasses in Princess Royal Harbour and Oyster Harbour, and their replacement by macroalgae (see Appendix). The Officer-in-Charge of the CSIRO Marine Laboratories, Marmion is thanked for making Dr Kirkman available for this work.

The Department of Marine and Harbours, the Water Authority of Western Australia, and the Albany Port Authority, provided technical information.

Members of the working group on the problem of mercury contamination in Princess Royal Harbour (representing the Health Department, the Department of Fisheries, the Government Chemical Laboratories and the Environmental Protection Authority) commented on a draft of this report. The constructive comments of several Environmental Protection Authority officers, and of Dr E. Hodgkin are appreciated. Dr J. Ottaway, Manager, Marine Impacts Branch of the Authority provided valuable guidance throughout this project.

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1. INTRODUCTION

At its Meeting 396 (18 December 1986), the Environmental Protection Authority was presented with evidence of a major, continuing loss of seagrass cover from Oyster Harbour (OH) and Princess Royal Harbour (PRH), Albany (see Figure 1), accompanied by a major increase in macroalgal biomass. This was attributed to excessive nutrient inputs into the harbours.

The Authority was also provided with a review of lead and mercury contamination of biota in PRH. In certain species of fish, molluscs and crustaceans found at the western end of the harbour, the levels of these contaminants exceed legal health limits applicable in Western Australia for the consumption of seafood by humans. The Minister for Fisheries has closed this area (see Figure 1) for the taking of seafood.

As a consequence of these briefings, the Authority directed its Environmental Investigations Division to:
- engage an independent expert to appraise, interpret and report on the data and evidence of apparently significant changes occurring in the seagrass meadows, and
- prepare an overview report to the Authority, dealing with the various problems affecting these harbours, and the management measures which could be brought to bear on them.

In January 1987, Dr. H. Kirkman, Senior Research Scientist, CSIRO Division of Fisheries Research, and a specialist in seagrass ecology, was requested to examine the seagrass problem. He subsequently completed a detailed consultant's report (Kirkman 1987) entitled 'Decline of Seagrass Beds in Princess Royal Harbour and Oyster Harbour, Albany' (Appendix).

The purpose of the present report is to provide an overview of what is known of environmental problems in the Albany harbours and their catchments, and to recommend approaches to the management of these problems.

Therefore, this report:
- documents the history and present state of the problems,
- identifies the likely causes,
- estimates the probable rates of change of the situation,
- considers probable future environmental outcomes, with and without management action,
- discusses broad management options, and their potential for application to the waterways of Albany and their catchments,
- recommends investigations designed specifically to enable selection and effective implementation of the most appropriate management strategies,
- recommends a programme designed to monitor response of the waterways and catchments to the management adopted,
- discusses the institutional and legislative framework within which such management could be carried out.

2. LOSS OF SEAGRASSES AND PROLIFERATION OF MACROALGAE

There is no doubt that seagrass cover and density have declined in OH and PRH since McKenzie (1962) made initial surveys. Underwater photographs, taken in 1986, show evidence of old, dead rhizomes in the substrate and unhealthy, algae-covered *Posidonia* throughout PRH. Although not so intensively examined, OH appears to have similar problems.

In terms of biomass and area covered, *Posidonia australis* and *P. sinuosa* were the two most important seagrasses in the harbours. Once lost, these species do not usually recolonise in less than 20-30 years. By 1984, 45% and 66% of seagrass cover in OH and PRH respectively had been lost, and there is no evidence to suggest revegetation. Bastyan (1986) reported on this loss of seagrass cover up to 1984, and claimed that seagrasses were being

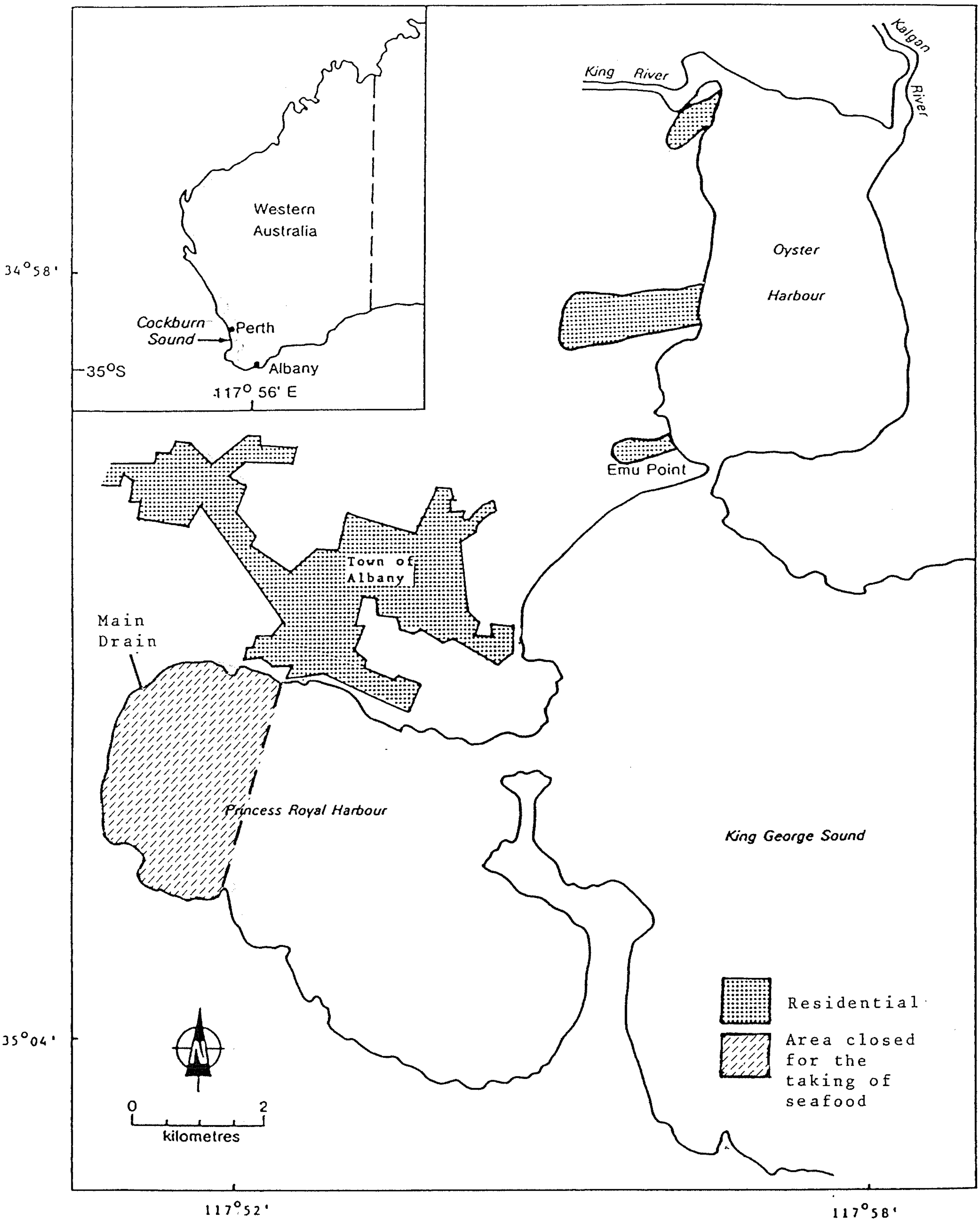

Figure 1. Map showing location of Princess Royal Harbour and Oyster Harbour at Albany.

smothered by epiphytic algae. The seagrass meadows have continued to decline since then.

Figures 2 and 3 show for comparison, a healthy seagrass bed in Frenchman Bay (Figure 2a), a seagrass bed covered with filamentous algae (epiphytic growth) in PRH (Figure 2b), a thick mat of *Cladophora* (benthic algae) on the bed of PRH in an area once covered with seagrass (Figure 3a), and an area of bare sediment in OH which was formerly covered with seagrass (Figure 3b).

From the evidence and experience in other Western Australian bays and estuaries, particularly Cockburn Sound and the Peel-Harvey Estuary, it seems that a major cause of the proliferation of fast growing, highly productive macroalgae, and the decline of seagrass in PRH and OH, could well be high nutrient availability in the water column and sediments. These nutrients (nitrogen and phosphorus) are entering the harbours through drainage of water from agricultural lands, from a fertilizer factory and from other anthropogenic sources, including the town drainage system, food processing plants on the northern shore of PRH, and the sewage treatment works which discharges to King George Sound (near the PRH entrance). There is also a considerable nutrient store in the sediments and organic matter on the bottom of both harbours.

It is unlikely that even an immediate reduction of available nutrient levels in the harbours would enable a return to pristine conditions, which were probably similar to those of King George Sound (KGS). Existing seagrass beds in reasonable condition would probably recover, provided they were not exposed to other environmental impacts, but recolonization of denuded areas by *Posidonia* would be negligible. Other seagrass species would return to at least stabilise sediments, and afford shelter to some juvenile fish and crustaceans. The main colonisers of bare areas in seagrass beds are the small seagrass species, *Halophila ovalis*, *Heterozostera tasmanica* and occasionally *Amphibolis* species.

In terms of habitat for animals or stabilisation for sediments, little is known of the relative value of a *Posidonia* bed compared with a seagrass bed comprising these smaller colonisers. However, Middleton et al (1984) have made comparisons between *Posidonia* and *Zostera*. Information on the relative habitat value of *Posidonia* beds in south-Western Australia compared with seagrass beds comprising the smaller coloniser *Ruppia* is also available (Lenanton 1977, 1982; Scott 1981, and Scott et al 1986).

If there is no reduction in the levels of available nutrients, and if the present rates of seagrass decline continue, the *Posidonia* beds will die out completely probably in the order of five years. Nuisance algae blooms have been reported in PRH since at least 1975; however, increased eutrophication will result in more frequently occurring blooms of nuisance algae such as *Enteromorpha*, *Cladophora*, *Ulva* and phytoplankton species. Water clarity will be reduced and there may be considerable sediment movement and silting in the harbours.

Other factors which may have contributed to these problems include:

- inputs of directly harmful chemicals contained in agricultural drainage (e.g. herbicides and pesticides), or industrial effluents,
- changes in water quality brought about through activities in the catchments, e.g. decreased water clarity,
- the succession of dredging and reclamation works which has occurred in PRH and along its northern shore, mainly between1951 and 1985. Aerial photographs and local resident reports indicate the occurence of widespread sediment plumes and turbid water in PRH whilst certain of these works were in progress. The resultant decrease in light reaching seagrass plants may have hastened their loss.

3. WATER CIRCULATION, MIXING AND FLUSHING

Concern over excessive algal growth and plant nutrient inputs leads to questions about the physical behaviour of the harbours. How rapidly are nutrient-rich waters mixed and dispersed away from their discharge points? To what hydrodynamic regimes are the

Figure 2a. *Posidonia sinuosa* bed in Frenchman Bay at 6 m depth, February 1987. The dense seagrass meadow is relatively free of epiphytic algae.

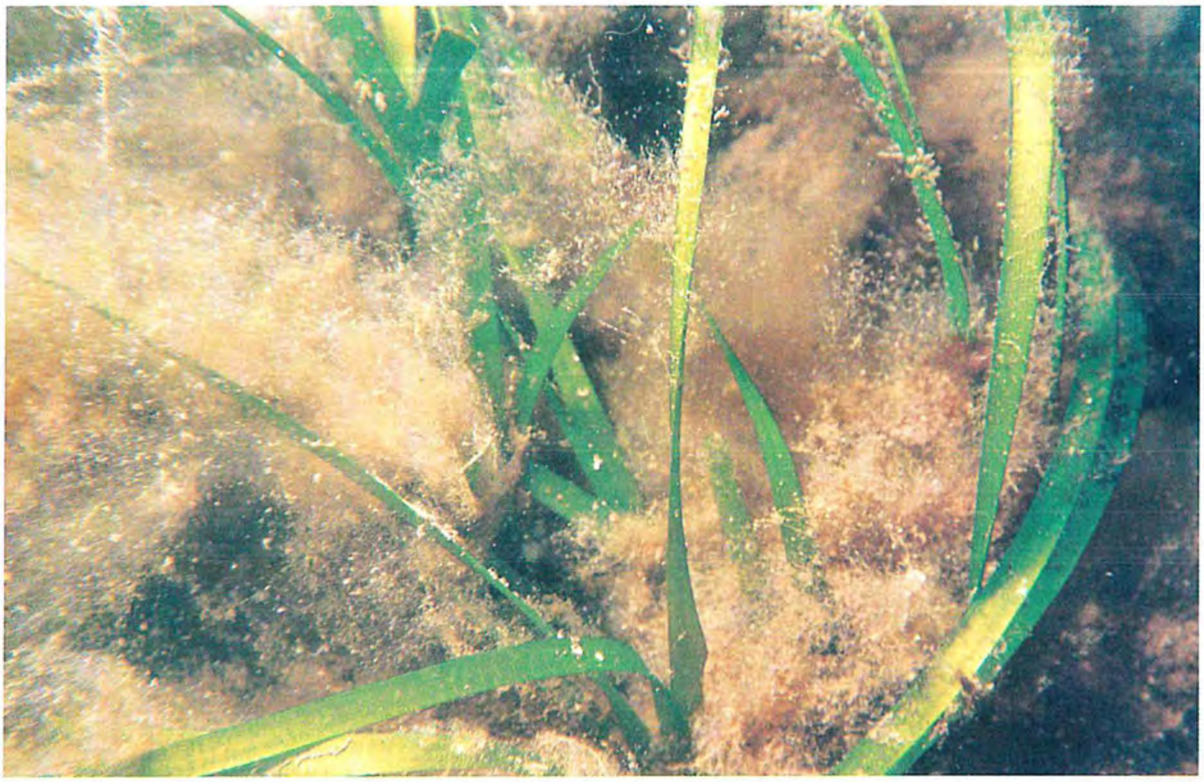

Figure 2b. Filamentous alga (epiphyte) covering *Posidonia sinuosa* in the eastern part of Princess Royal Harbour at 4.5 m depth, November 1986. When the epiphyte reaches this density, growth of the seagrass is impaired through shading effects

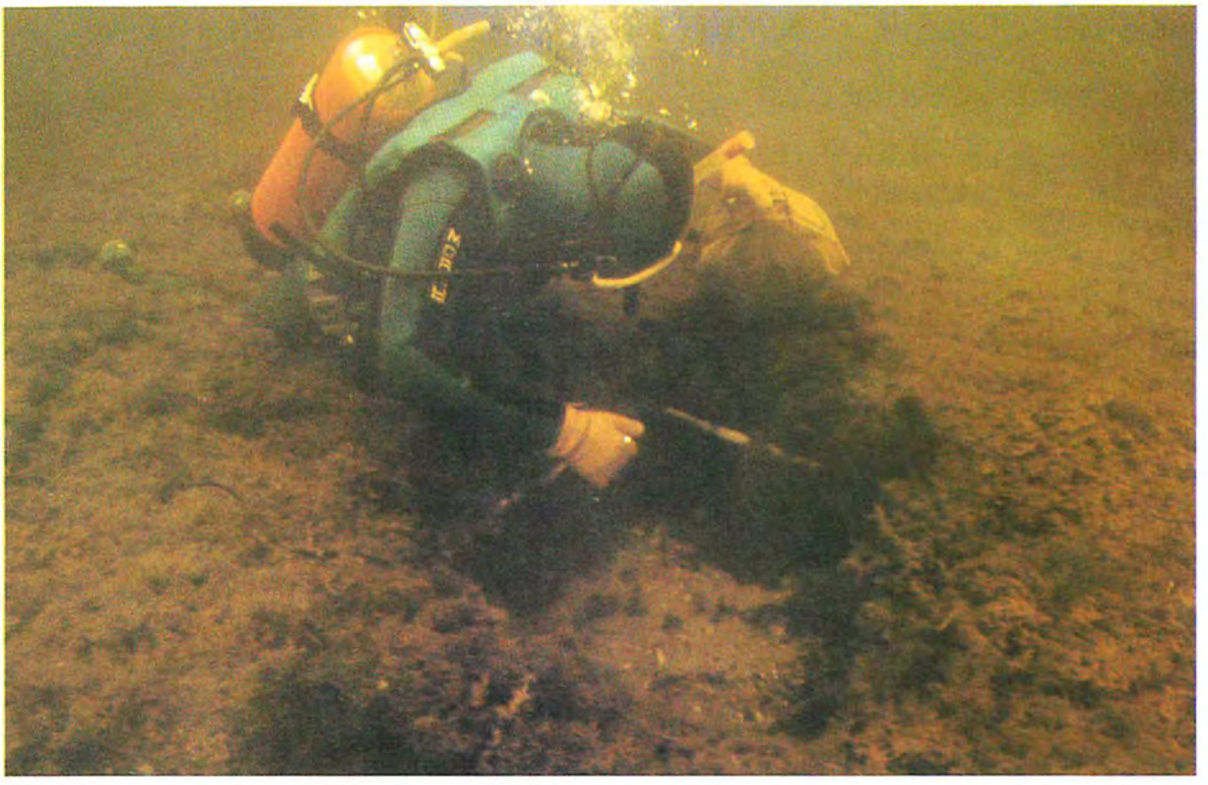

Figure 3a. A mat of *Cladophora* (benthic algae), 0.6 m thick, on the bed of Princess Royal Harbour, at 1.5 m depth, November 1986. Remains of rhizomes and leaf bases found in the sediments indicate clearly that this area was once a seagrass meadow.

Figure 3b. An area of bare sediment (mud and silt) in Oyster Harbour at 2 m depth, November 1986. From seagrass remains found buried in the sediments, this area was also, undoubtedly, a seagrass meadow at one time.

seagrasses and the macroalgae exposed? How efficiently does incoming sea water replace harbour water? What are the flushing rates (including nutrient loss rates) of the harbours?

3.1 PRINCESS ROYAL HARBOUR

Because of the orientation and bathymetry of PRH, north to west winds (common in winter) drive extensive anticlockwise water circulation; south to east winds (common in summer) drive clockwise circulation; and intermittent strong southwesterlies promote two counter-rotating gyres (Mills & Brady, 1985). These circulations are important agents of broad horizontal mixing over most of the PRH basin (depths exceeding 2 m). They can also extend over the western shallows of PRH while the banks and seagrass beds of this margin are submerged.

In calm conditions, daily tidal variations of mean to spring range cause water to jet a distance of up to 2.5 km into PRH from its narrow entrance channel prior to undergoing clockwise circulation and ebbing. This gives rise to significant horizontal mixing over that area of PRH where water depths are 5 m or greater. Elsewhere, tidal current speeds are low, except across the very shallow sandy sill at the outer edge of the western margin, where more rapid water flow is required to accomodate the tidal capacity of the margin.

Under average wind and tidal conditions, horizontal currents are consistently weak (< 0.08 m/s) in a zone of water depths from 2-5 m just off the west and south margins. Typical wave-induced bottom speeds are of similar magnitude. Within this zone Bastyan (1986) reported dense accumulations of *Cladophora*.

Near the base of seagrass meadows, water movement is retarded, and turbulent vertical mixing inhibited. The seagrass beds can therefore trap and store fine organic particulates. Nevertheless, even in very shallow water, appreciable currents can still be generated at the level of the seagrass canopy, and above the meadows when they are fully submerged.

Atkins et al (1980) reported near-shore salinity depressions of several parts per thousand on the western margin during winter periods of freshwater runoff (mainly from agricultural drainage). This implies that the volume flux of harbour water traversing this margin is low, which may be due as much to the extreme shallowness of the margin as to the residence time of its waters. Nutrient-laden waters issuing from these drains are likely to result in relatively high nutrient concentrations over this margin.

In the main (deeper) basin of PRH, volume fluxes of harbour water are higher, and the salinity is generally maintained at about marine levels. Thus effluents from the western drains generally must be highly diluted by the time they have entered the main basin.

The ratio of harbour volume (9×10^7 m^3) to its mean tidal capacity (1.2×10^7 m^3) leads to an estimate of 7 days for the flushing time of PRH, but this assumes complete tidal exchange, which is not the case. Combined tidal movement and wind-forced circulation does promote nett water exchange between PRH and King George Sound, as water flooding into PRH tends to be conveyed away from areas from which exiting (ebbing) water will subsequently be drawn (Mills, unpublished). Given this moderate efficiency of water exchange, a flushing time of about 14 days for PRH is considered more realistic.

The outfall from the Albany No. 1 sewage treatment plant discharges to King George Sound, but is sufficiently close to the PRH entrance to suggest that effluent may at times enter PRH. Drogue trajectories and visual observations of sewage effluent surface slicks confirm this. The significance of nutrient loading to PRH from this source remains to be quantified.

3.2 OYSTER HARBOUR

Very little is known of the hydrodynamics of OH.

The local wind and tide regimes are the most consistent forcing effects governing the horizontal mixing and nett water exchange in OH, which has a mean depth almost equal to that of PRH. It is anticipated that these effects result in typical flushing times for OH similar to those of PRH, namely 10-14 days. Although the annual freshwater flux to OH (mainly from the King River and Kalgan River catchments) is considerably greater than that to PRH, and salinity depressions in OH are probably more prolonged and widespread, the flushing time of OH from freshwater throughput alone is typically several months, except for occasional short periods of very high river flow.

4. NUTRIENT INPUTS TO THE HARBOURS

4.1 PRINCESS ROYAL HARBOUR

Platell (1978) reported on a water quality monitoring investigation conducted by the Government Chemical Laboratories, and concluded that trade wastes were a threat to the recreational amenity of PRH waters, but were not of ecological significance at that time. This study foreshadowed that nutrients in trade wastes and in waters discharging from the main (Robinson Estate) drain could become problems in PRH. It was recommended that better management practices be instituted for the discharge of trade wastes.

On the basis of 13 water quality surveys, conducted on a monthly basis, Atkins et al (1980) reported that nutrient concentrations in the central, deeper basin of PRH were low (with higher nutrient levels found in the waters of the shallow western margin). These levels are low when compared with concentrations found in highly eutrophic estuaries, such as the Harvey; however, the concentrations of phosphate phosphorus and also of ammonia, measured in PRH, are higher than those at Marmion lagoon near Perth, where seagrasses are healthy and abundant (Pearce et al 1985).

The Atkins et al (1980) report identified Borthwicks meat works, the main agricultural drainage network (which also receives stormwater and other effluents from the CSBP fertilizer plant site) and the sewage treatment plant outfall (located in King George Sound, just outside the PRH entrance channel), as potential sources of nutrients to PRH. The study did not include monitoring of input loads, but reviewed the work performed by the Government Chemical Laboratories in 1978.

Preliminary estimates for phosphorus load to PRH, based on the three-monthly instantaneous load and flow measurements of the Government Chemical Laboratories during 1977-8, and a one-off sampling in June 1979 are presented in Table 1.

Table 1. Load estimates (tonnes/yr) of total phosphorus to Princess Royal Harbour.
(NA = data not available)

	June 1979	April 1977-January 1978
Main drain (Frenchman's Bay Road)	35.0	13.0
Borthwicks Abbatoir	2.0	NA
Hunts Canneries	0.5	NA
Albany Woollen Mill	0.3	NA
Total	37.8	13.0

The estimates of loading to PRH from these points ranged from 13 tonnes to 38 tonnes of phosphorus per year. The value of 38 tonnes was derived from the one-off sampling in June

1979. The flow measurement on this occasion approximated the upper limit of the range monitored during 1977-8. From these very few data, the main drain appears to be the predominant source of phosphorus loading to PRH.

Note that nutrient inputs to PRH may have been underestimated, since data on loads from the sewage treatment plant outfall, the town stormwater runoff, groundwater inputs, domestic septic tanks and other minor drains to PRH are not available. In addition, sources such as rock phosphate and fertilizer losses to PRH during handling in the port area (e.g. as wind-blown dust) have not been considered.

The phosphorus load from the sewage outfall to King George Sound was estimated to be 10 tonnes P/yr, based on assumed flow rates per capita, the population connected to the wastewater treatment plant and typical concentrations of total reactive phosphorus in the effluent. Assuming that 40% of this load could enter PRH on the flood tide (which is probably a quite conservative upper limit), the additional phosphorus load to PRH from this source is unlikely to exceed 4 tonnes/yr.

Urban stormwater runoff from the Albany townsite could carry about 1 to 2 tonnes P/yr to PRH. This estimate is based on annual rainfall, urban catchment area (much of it impermeable), and typical phosphorus concentrations found in urban runoff.

Nothing is known of the flux of groundwater entering PRH, nor of the significance of the associated phosphorus load (including contributions from septic tank leachates in unsewered areas). Loads from minor drains to PRH, including private drains servicing the highly fertilized horticultural areas at the western end of the harbour, also require estimation.

In view of all this, a more detailed and systematic programme to evaluate all nutrient loadings to PRH should be instigated as a matter of high priority. One of the aims of this programme should be to obtain a good estimate of the load from the main drainage network to the western end of PRH, and to determine the respective contributions to this load from diffuse agricultural sources, and 'point sources', including the CSBP plant site. An adequate knowledge of the magnitude and distribution of nutrient loadings to PRH is a vital element in determining the most appropriate management strategies.

The fate of the phosphorus entering PRH is not adequately understood, either in terms of availability to the algae, loss to or recycling from the bottom sediments of the harbour, or export to the ocean. Atkins et al (1980) reported low nutrient concentrations in the deeper waters of PRH. Mills (unpublished) estimated that complete water flushing of PRH takes about 14 days. Under these conditions it is possible that sedimentation is an important process in the removal of nutrients from the water column.

4.2 OYSTER HARBOUR

Preliminary estimates of nutrient loading to OH are presented in Table 2. These figures are based on one sampling occasion with incomplete river flow data, and were derived using a set of assumptions drawn from experience in the Peel-Harvey study. Estimates are for the King and Kalgan Rivers only.

The estimated riverine loading of total nitrogen is of the order of 170 tonnes (ranging from 98 to 307 tonnes). The combined riverine phosphorus load per year to OH is estimated to be 22 tonnes (ranging from 14 to 37 tonnes).

These load estimates do not include contributions from the drains on the sandy soils surrounding OH, below the main river catchments, for which no data are currently available. Experience with the Peel-Harvey catchment suggests that high nutrient losses may be expected from such soils. Observations on the Yakamia Creek drain on the western side of OH suggest considerable nutrient loads from horticultural land-use, urban runoff and septic tank leachate.

It is stressed that the nutrient loading estimates presented here are based on most limited data. There is an urgent need for a comprehensive measurement programme, from which reliable estimates of the magnitude and distribution of nutrient loadings to OH can be derived, as precursors to management strategy decisions.

Table 2. Estimates of river flow (m^3/yr), and of total phosphorus and total nitrogen loads (tonnes/yr) to Oyster Harbour.

	King River	Kalgan River	Total
Flow			
mean	47×10^6	45×10^6	92×10^6
min	33	22	55×10^6
max	73	85	158×10^6
Total Phosphorus			
mean	16.5	5.9	22.4
min	11.5	2.9	14.4
max	25.5	11.1	36.6
Total Nitrogen			
mean	61.0	112.0	173.0
min	43.0	55.0	98.0
max	95.0	212.0	307.0

5. THE CATCHMENTS

The location and extent of the catchments of Princess Royal Harbour and Oyster Harbour are shown in Figure 4.

5.1 PRINCESS ROYAL HARBOUR

Preliminary analysis (Section 4.1) indicated that the main drainage network discharging to the western end of PRH is likely to be the most important source of phosphorus input. This network collects runoff from agricultural land in the Robinson Estate and Marbellup-Elleker region, in addition to effluent from local industry. Soils of the area include the Owingup, Dempster and valley soil units (Churchward et al. in press), of which deep sands and duplex soils are used for a variety of farming enterprises (principally beef farming and intensive horticulture, such as potato growing). The area is largely developed (85% cleared) and has an extensive drainage network. The deeper sands and peats, some cleared up to 100 years ago, are likely, because of very low phosphorus retention capacities, to leach significant quantities of phosphorus. Phosphorus application rates are likely to range from 200 kg P/ha/annum (potato crops) to 15-20 kg P/ha/annum (beef farming) as water soluble phosphorus (superphosphate). Nitrogen loss rates are also likely to be high.

5.2 OYSTER HARBOUR

The King and Kalgan rivers were found to provide major nutrient sources to OH.

The King River catchment consists mainly of duplex soils (Redmond, Dempster units) and some valley soils (including peaty sands) on the gently undulating Narrikup plain (Churchward et al. in press) of the east Redmond-Albany-Narrikup area. The sandy soils of these variable units have very low phosphorus retention capacities.

North and east of the Porongorup Range, the Kalgan River catchment soils (heavier duplex

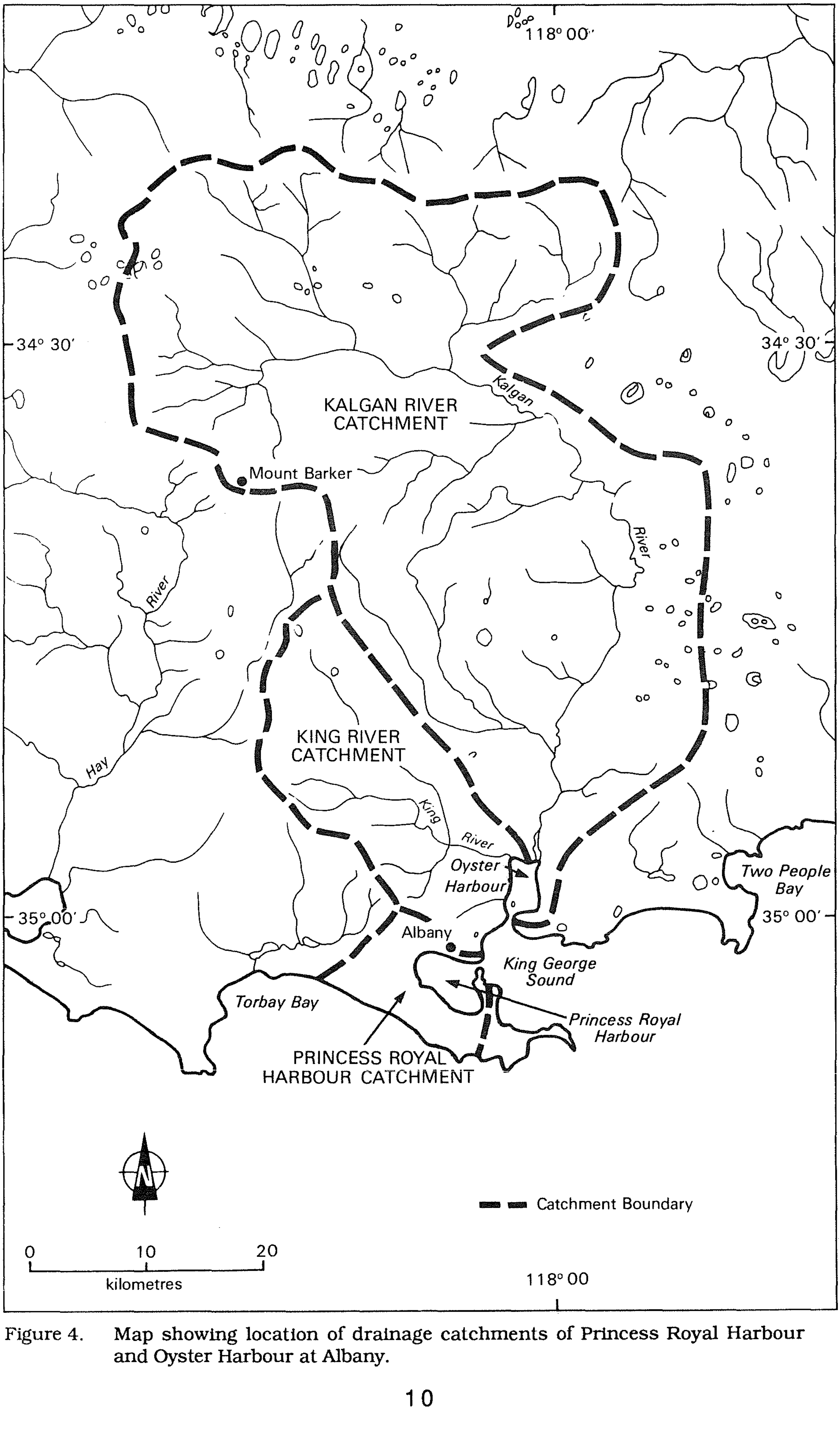

Figure 4. Map showing location of drainage catchments of Princess Royal Harbour and Oyster Harbour at Albany.

soils and loams) have generally higher phosphorus retention. South of the Porongorups (the Narrikup-North Manypeaks-South Stirlings area), soils are similar to those of the King River catchment.

Clearing of the heavier soils near the river banks of the King and Kalgan Rivers dates from the turn of the century, but most of the clearing on the sandy duplex soils has occurred in the last 30 years. About 80% of these are now developed, and are used almost entirely for beef and sheep grazing, with phosphorus application rates typically 15-20 kg/ha/annum as superphosphate. The soils are generally very poorly drained, with the exception of the deeper sand ridges. Further drainage work would be expected to be carried out by farmers in future years.

Phosphorus leaching at a similar rate per hectare to that occurring from the Coolup sands on the Swan Coastal Plain (1-3 kg P/ha/annum) would be expected from the developed sandy duplex soils which receive phosphorus fertilizer applications. Losses as high as those from the deeper Bassendean sands (5-6 kg P/ha/annum) are unlikely except from small areas of deep sand used for beef and sheep farming. Losses from soils of the Kalgan catchment north of the Narrikup Plain are likely to be relatively low. To the east, potential phosphorus losses from the North Manypeaks-South Stirling area soils are likely to be significant, but drainage patterns in this area are rather unclear, and phosphorus applications and rainfall are lower than to the west.

Significant nitrogen leaching losses, originating from biologically fixed rather than fertilizer N (i.e. from subterranean clover pastures), probably occur from most of the soils of all catchments.

6. BROAD MANAGEMENT CONSIDERATIONS

6.1 THE NEED FOR MANAGEMENT

Kirkman (1987) warns that, if available nutrient levels in PRH and OH are not reduced,

- the trend to eutrophication in the harbours will continue,
- blooms of nuisance algae may occur at least annually, and dead plant material will accumulate on the harbour beds,
- existing seagrass beds will continue to decline and may die out completely (possibly within about 5 years) with little chance of recovery,
- water clarity will decrease, and
- more bottom sediments will be exposed, destabilised, and become subject to erosion.

As noted in Section 2, there may be additional causal factors which have been contributing to these problems and which require management.

There is a history of public concern over the state of the Albany waterways, and this concern will increase markedly if the environmental problems become generally more pronounced. Should environmental deterioration in these harbours continue, the tourism and fishing industries, and recreational amenity value for local residents, would be directly affected.

6.2 THE GOAL OF THE MANAGEMENT

A major goal of management actions should be to reduce the amounts and growth rates of nuisance algae (epiphytic and benthic) in PRH and OH to levels at which:

- decline of existing seagrass beds is arrested,
- recolonisation of areas denuded of seagrass beds could be encouraged, and
- nuisance algal blooms can be minimised,

and to achieve this reduction in a manner which is consistent with the maintenance of the regional economy.

6.3 BROAD MANAGEMENT PRINCIPLES

Management experience has already been acquired in dealing with problems of this type in Western Australia, notably in the Peel-Harvey estuarine system and its catchments, and in Cockburn Sound. The broad principles of management applied to these systems provide starting points when considering what may be done to arrest the trends in the Albany region.

These broad principles are to:
- reduce total input of nutrients to PRH and OH waters,
- increase the nett rate of nutrient flushing to KGS, and
- harvest the benthic macroalgae and remove the material from the system.

The reduction of total nutrient inputs may be achieved by:
- reduction of diffuse rural sources, and nutrient losses to drainage,
- control of 'point' sources located either in the catchment or local to the waterbody,
- controls on such land-use developments as clearing, drainage and the establishment of intensive rural industries,
- diversion of nutrient-rich drainage waters away from the harbours, and
- use of wetland vegetation as a nutrient sink.

There does not appear to be the same scope for increasing the hydrodynamic (and hence the nutrient) flushing rates of the harbours by engineering means, as predicted for the Peel-Harvey estuary. Within each of the Albany harbours, wind-driven circulation promotes broad-scale horizontal mixing, and tidal range is similar to that of the external tide. Thus, tidal flushing would not necessarily be increased by constructing another entrance. Widening or deepening the existing entrance may actually decrease flushing, by lessening the penetration of the tidal flood jet into the harbour. Significant deepening (dredging) in areas of heaviest benthic algae accumulation i.e. in water depths of 2-5 m, may be counter-productive to enhancing flushing of the harbours. A harbour basin of more uniform depth would lead to a reduction in the strength of the wind-driven water circulation, a weakening of horizontal mixing in the harbours, and hence a lowering of flushing efficiency.

Harvesting of algae in the Peel-Harvey estuary removes the immediately objectionable sights and smells experienced by the local residents, but does very little to attack the cause of the problem. In Albany, shoreline accumulations of rotting algae have not yet reached such general nuisance levels, although there have been complaints over isolated incidents. Algae harvesting would diminish the store of nutrients available for recycling to the harbours, and therefore should reduce the flux of recycled nutrients, though to what extent is not known. While the external loads of nutrient inputs remain uncontrolled, however, this management measure would provide temporary improvement at best.

6.4 APPLYING MANAGEMENT TO THE ALBANY REGION

Thus far general approaches have been discussed. It is now necessary to ask how to select from the management principles and to translate them into an action programme which will achieve the desired goal with a minimum of social and economic cost.

The answer to this question must be based on an adequate knowledge of the systems to be managed, and of the causes of the problems. Critical gaps in this knowledge need to be filled by specific investigations. These must yield the information required for detailed design of management programmes, and in time for these programmes to be initiated as quickly as possible.

A sustained, coordinated management approach to the catchments and waterways of the Albany region can best be achieved within a suitable administrative and legislative framework.

7. RECOMMENDATIONS FOR MANAGEMENT

7.1 CONFIRM THE CAUSES AND PRESENT STATUS OF PROBLEMS IN THE HARBOURS, AND MONITOR ENVIRONMENTAL RESPONSE TO MANAGEMENT

There is still a paucity of detailed information relating to the causes of the marine ecological problems seen in PRH and OH. In order to ensure that the correct type and level of management is undertaken, it is necessary to have adequate documentation of these causes and of the present state of the harbours. Such information is also essential to establish a reference point or baseline from which to monitor the response of the harbours to management.

It is therefore suggested that:

- all loadings of nutrients (nitrogen and phosphorus) to the harbours be identified and adequately quantified over an initial one year period, and that the more significant of these loadings be monitored on an ongoing basis
- selected seagrass beds in each harbour, and at a control site in KGS, be monitored regularly (perhaps 3 times per year). Measurements of seagrass beds should include perimeter and biomass, to assess changes in rates of decline, and plant tissue nutrient (N and P) assays, to assess changes in relative nutrient availability. Biomass of epiphytic and benthic algae associated with these beds should also be estimated. Photographic records should be kept
- the size of the nutrient store in PRH and OH bed sediments, and in particular, the degree of recycling of these nutrients and their subsequent availability for algae growth, be investigated
- water quality (at least salinity, temperature, light attenuation, suspended sediments and inorganic N and P) be regularly monitored within each harbour and at a control site over seagrass beds in King George Sound. The water quality monitoring strategy should be 'event-oriented' in the sense that the data should be collected over a complete range of freshwater flow-rates and nutrient input rates
- discharges to the harbours be sampled and analysed to determine whether any chemicals are present at concentrations which could be ecologically harmful, e.g. herbicides and pesticides in agricultural drainage waters, for which initial sampling should be conducted soon after commencement of significant runoff from the catchments. Representative marine plant and animal species should also be sampled and analysed for contamination by these substances
- minimum light requirements for the major species of seagrass in the harbours should be determined and compared with existing light levels reaching the seagrass beds
- in the event of major harbour dredging, light attenuation and sedimentation characteristics should be monitored. These characteristics should be compared for periods of dredging and non-dredging
- other anthropogenic factors which seriously reduce light levels reaching seagrass beds, eg turbid or coloured effluent, should be identified

Most of these activities should yield initial results for input to the management selection and design process within one year. Measurements should be continued for several years however, to establish the longer term response of the harbours to management.

7.2 REDUCTION OF NUTRIENT INPUTS TO THE ALBANY HARBOURS

7.2.1 DEFINE TARGET NUTRIENT LOADINGS TO THE HARBOURS

Target nutrient loadings for PRH and for OH should be derived, at which macroalgal growth would no longer be excessive. This would provide a basis for evaluating the effectiveness of management strategies to reduce nutrient inputs.

7.2.2 REDUCTION OF DIFFUSE SOURCE PHOSPHORUS LOADS

Of the two major nutrients, phosphorus is taken as the target for manipulation through

management of diffuse catchment sources. This is because:
- there is significant biological fixation of atmospheric nitrogen from subterranean clover pastures in all catchments,
- there is potential for the proliferation in the harbours of blue-green algae, some of which are also able to fix nitrogen.

The fertilizer management strategies used to reduce phosphorus losses from the sandy soils of the Peel-Harvey catchment are generally applicable to the Albany region; however, a considerable amount of preliminary technical information is required before a programme could be implemented. The requirements include:
- precise identification and quantification of diffuse source phosphorus loadings to rivers and drains on a sub-catchment basis for at least 1 year (involving upgraded stream and drain flow ratings, as well as nutrient sampling),
- definition of drain and river catchment areas, areas of different soil types, areas of land-use, and drainage densities,
- assessment of the current phosphorus store in catchment soils*,
- assessment of current phosphorus application rates*,
- further verification of soil tests (continuing past and current work by the Department of Agriculture) to determine the relationship between plant productivity and phosphorus levels stored in soil*

Fertilizer practice modification can only achieve phosphorus loss reduction within the constraint of maintaining existing modes of agricultural productivity if past and current phosphorus application has been/is excessive. The rate of phosphorus loss per hectare from catchment soils is an important factor, as the most significant potential reductions in phosphorus loss will come from the highest phosphorus exporting soils. If, as expected, phosphorus loss rates from the Albany region soils are relatively low (compared with the deep sands of the Peel-Harvey catchment), gains per hectare from the implementation of a fertilizer modification campaign are likely to be relatively small. Reduced application rates over a large area will then be necessary to achieve significant reductions in river phosphorus loads. The considerable variability of soils over small areas is also likely to pose difficulties in any fertilizer management programme which may be implemented.

7.2.3 REDUCTION OF POINT SOURCE NUTRIENT LOADS

Point source nutrient loads from industry and intensive agriculture, both locally and from the catchments, require attention at a technical level. This includes:
- precise identification and quantification of point source nutrient loadings to rivers, drains, and directly to the Albany harbours,
- investigation of aspects of the industrial or intensive agricultural production processes relevant to the quantity and quality of effluent streams,
- control of quantity and quality of stormwater runoff from the site, and
- investigation of alternative waste treatment and disposal options, either on an individual plant/site basis, or for combined effluents from a number of sites, treated at a local to regional scale.

In the case of the Albany sewage treatment plant outfall into King George Sound, just outside the PRH entrance channel, it will be necessary to assess not only its nutrient load, but also the percentage of this load that enters PRH.

The larger point source contributors to total nutrient load, and those which are not presently employing 'best possible' means of waste disposal and effluent treatment, offer the greatest potential to achieve overall reductions in nutrient loadings.

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* Note that these activities should be conducted on a paddock-by-paddock basis.

7.2.4 CONTROL OF LAND-USE DEVELOPMENTS

Although the catchment areas are extensively developed, there is still potential to exacerbate the nutrient enrichment problem by allowing further catchment clearing and the installation of further drainage for additional agriculture. The intensification of agricultural industries in the region is likely to be strongly advocated as a stimulus to the economy. It is suggested that:

- a review of current catchment development plans and relevant land-use controls be undertaken immediately,
- consideration be given to applying an interim embargo on further land clearing, drainage of catchment soils and further intensive agricultural or industrial developments without environmental assessment, in order to limit the increase of nutrient loadings to the harbours, and to gain more time to manage the algal problem.
- a catchment management programme involving farmers, industry, and government departments should be established, with the aim of reducing nutrient inputs into the harbours. This should incorporate effective land use controls to regulate future development of intensive agricultural industries and farming. In this context, alternative land uses should be considered.
- investigations should be carried out to identify alternative (to existing), sustainable and productive rural land-uses, which, if implemented, would result in a reduction of nutrient losses from the catchments.

7.2.5 DIVERSION OF AGRICULTURAL DRAINAGE WATERS

This option could be evaluated for PRH, where drainage flows are considerably smaller than for OH. Diversion of peak flows from the main PRH drain may not be economically feasible; however, even partial diversions may result in a significant reduction of annual nutrient load. Such an option need only be considered if the diffuse source nutrient loads to PRH prove to be important, and if major point sources have already been controlled.

The feasibility of diverting drainage flows directly to King George Sound could be investigated. The assimilative and flushing capacity of inner KGS, and the selection of a suitable discharge site to the Sound (so as to avoid re-entry of nutrients to PRH) would need to be considered in this context.

An alternative diversion, westward from the PRH main drainage network to the drainage system discharging to Torbay Inlet, could also be assessed.

7.2.6 USE OF WETLAND VEGETATION AS A NUTRIENT SINK

Nutrients levels in surface drainage waters may be reduced by passing these waters through wetlands prior to their entry to the harbours. Some wetland plant species which take up the nutrients can be harvested to make way for new growth. The implications of creating or modifying wetlands for this purpose requires careful consideration.

Such an approach could be considered for the treatment of nutrients in Yakamia Creek. This creek, which derives much of its nutrient load from town runoff, septic tank leachate and horticulture of nearby lands, discharges to OH. It is of concern both to the Town and Shire of Albany, and is currently under consideration by the Water Authority of Western Australia.

7.3 MANAGED SEAGRASS RECOLONISATION

The feasibility of artificial recolonisation of denuded areas with seagrass could be examined. Initial trials would need to take place in areas which were not subject to epiphytic algal smothering, and trials in the Albany harbours could only proceed after the nutrient enrichment/algal bloom problems were under control.

8. LEAD AND MERCURY CONTAMINATION IN PRINCESS ROYAL HARBOUR

8.1 LEAD CONTAMINATION

CSBP has operated a lead-acid and superphosphate plant at Albany since 1954. An unknown quantity of lead sulphate was dumped around the CSBP property at poorly defined sites. Whilst the company lime-treated some sites in latter years, discharge of lead-contaminated water to PRH, via a drain and an effluent pipe, has resulted in a build up of lead in the biota and sediments of PRH. Because of a lack of information, neither CSBP nor the Environmental Protection Authority has been able to estimate, even very approximately, the quantity of lead which reached PRH. CSBP has acted to stop further lead entering the environment since the discovery of contamination in the harbour. Discharges through the effluent pipe ceased about February 1984, and the pipe was removed in December 1986.

Effectively all effluent and runoff from the plant site is now recycled and lime-treated. During very heavy rains, however, surface runoff from the CSBP agricultural area, containing small traces of lead, may still enter PRH through the drains.

Maximum mean lead levels of 31 mg/kg wet weight were found in one species each of cockles and of mussels. The National Health and Medical Research Council (NHMRC) standard for lead in food is 2.5 mg/kg wet weight. Individual lead levels in cockles of up to 71 mg/kg wet weight have been recorded.

The lead has accumulated in marine vegetation and is most strongly associated with fine organic detritus. Values as high as 80 mg/kg dry weight have been recorded in organic-rich sediments, but a more typical range of values for such sediments is 20-30 mg/kg dry weight.

8.2 MERCURY CONTAMINATION

During the manufacture of superphosphate, mercury is liberated and collected in scrubber fluids. CSBP estimates that it discharged 900 kg of mercury to the environment between 1954-1984. Most of this would have reached PRH: 300 kg of mercury were discharged to the harbour via a drain, between 1954-1969, and 600 kg of mercury were discharged directly to the PRH via the effluent discharge pipe, between 1969-1984. As mentioned above, CSBP stopped discharging effluents through the harbour discharge pipe in early 1984.

Mean mercury concentrations in cockles in the most polluted area of the western end of PRH ranged between 3-15 mg/kg wet weight, with individual values as high as 50 mg/kg wet weight. The NHMRC standard for mercury in seafood is 0.5 mg/kg wet weight.

The main problem, however, is the high concentration of toxic methyl mercury in commercial fish, which necessitated the western end of PRH being closed to fishing. Recent data obtained by the Fisheries Department show that, of the 15 species of fish analysed, 11 exceed the health standard. Mercury concentrations in individual Australian herring and rock flathead are as high as 7.2 and 7.3 mg/kg wet weight, respectively. Most of this mercury is in the form of methyl mercury.

Mercury, in a similar fashion to lead, has accumulated in the marine vegetation and associated detritus in PRH. Total mercury concentrations in sediments of PRH are very low compared with levels generally found in sediments in polluted areas around the world. Average mercury concentrations for mainly inorganic and organic-rich sediments in the most polluted area of PRH are 0.05 and 0.25 mg/kg dry weight, respectively. Values as high as 3.4 mg/kg dry weight have been recorded, however, in the fine organic fractions of PRH sediments.

Recent data indicate that the methyl mercury content in contaminated PRH sediments is also primarily associated with the organic fraction of these sediments. The greater proportion of mercury in contaminated fish is found in the methylated form. It is postulated that fish containing the highest levels of methyl mercury frequently feed in areas containing the highest levels of total and methyl mercury in the sediments, that is, in areas which trap fine, organic-rich sediments.

Jackson et al (1986) estimated 3.3 km^2 of PRH to be contaminated with mercury levels in the sediments exceeding 0.1 mg/kg; however, this early work did not recognise the high level of association between mercury and the fine organic fractions of these sediments, and therefore the figures of Jackson et al (1986) should be used with caution.

Talbot et al (1987) conducted further work to identify the source of the mercury pollution, determine the extent of this pollution in PRH sediments and some biota, and understand the major factors controlling dispersion of mercury in the sediments.

Mercury levels in the biota and sediments of PRH have shown no conclusive signs of decreasing since the discharge from CSBP stopped in 1984. A recent set of preliminary measurements, taken in February 1987, indicated that mercury levels in PRH waters (both in the entrance channel and at the western end of the harbour) are extremely low. Estimates based on these data suggest that it may take at least several decades to achieve, by natural water-borne export, a substantial reduction of the total amount of mercury in the harbour.

A reduction of the marine plant and organic detrital mass in the western end of PRH would reduce the availability and supply of methyl mercury to the food chain. The ecological implications of such a reduction would need to be carefully considered.

9. MANAGEMENT OF LEAD AND MERCURY CONTAMINATION

9.1 MANAGEMENT ACTIONS TAKEN

Since the detection of lead and mercury contamination in biota at the western end of PRH, several management actions have been taken:

- a Working Group was established, comprising officers of the Health Department, Fisheries Department, Government Chemical Laboratories, and the then Department of Conservation and Environment, to recommend suitable investigations and monitoring of the mercury problem, and to formulate appropriate management strategies;
- the western portion of PRH was closed by the Minister for Fisheries in March 1984, to the taking of all fish, crustaceans and molluscs, and the area signposted to advise the public accordingly;
- the known inputs of lead and mercury to PRH were effectively eliminated, through cessation of direct effluent discharge to PRH and through on-site treatment and recycling of industrial and storm waters from the CSBP plant;
- programmes to investigate and monitor contamination of fish, cockles, sediments and marine plants were commenced.

9.2 THE PRESENT NEED FOR MANAGEMENT

Since 1984, there has been no significant input of lead and mercury to PRH; however, lead and mercury introduced to the harbour prior to that time still contaminate marine plants, animals and organic matter, particularly in the western end of the harbour.

The heavy metal contamination of edible marine life continues to be a health issue, as the health standards for seafood are still exceeded.

As a consequence of this, professional fishermen and the general public are not permitted to take fish or other edible marine life from the western end of PRH. This has a direct economic impact on professional fishing and tourism in the area, and social and aesthetic impacts on tourism and the general local community.

Monitoring and investigations carried out so far suggest that it may take decades for the heavy metal contamination in fish, cockles and mussels to return naturally to acceptable levels. There is therefore a need to search for active management strategies which can help mitigate the problem.

9.3 BROAD MANAGEMENT OPTIONS

No overwhelmingly effective or single, preferred management method is likely to emerge. A combination of methods will probably need to be applied. Even combined measures should not be expected to yield rapid, obvious results. Small-scale trials will be required to assess the feasibility, cost, efficiency and environmental impact of techniques proposed. Monitoring programmes already being conducted should be continued.

9.3.1 MANIPULATION OF FINE ORGANIC MATTER AND MARINE PLANTS

Fine organic fractions of sediments in the western end of PRH are most highly contaminated with lead and mercury. The living plant matter, seagrasses and algae, also contain significant concentrations of these metals. The fine organic matter and the living plants are at the base of the local marine food chains. Hence, these materials seem to be the most logical targets for active management of the heavy metal contamination problems. General management strategies could include removal, dispersal or burial.

It should be noted that, in the most contaminated areas, seagrasses, algae and fine organic detritus are closely interspersed. Organic-rich sediments are to be found trapped at the base of existing seagrass and algae beds. Hence, management action directed at the fine organics or the algae entails a risk of damage to the seagrass, and possible further loss. The seagrasses are attached plants. which provide valuable shelter and habitat, and stabilise the sediments. The loss of seagrass beds is regarded as a serious environmental problem for these reasons, and also because recolonisation and recovery by seagrasses takes place very slowly. Benthic algae on the other hand are unattached, can grow quickly to the extent that they can form nuisance blooms, and their communities are less sensitive to direct physical disturbance.

The task is to identify effective management techniques which in themselves do not generate further significant environmental damage to the remaining seagrass communities.

9.3.1.1 Removal of Fine Organic Matter and Algae

The removal of benthic algae from the most contaminated area at the western end of PRH is one way of approaching the mercury problem; however, it has been estimated that removal of 10 000 tonnes of algae would be necessary to abstract only about 1 kg of mercury, which probably represents less than 1 % of the total mass of mercury in PRH. Since the most contaminated algae are found interspersed with seagrass, a method of algae collection which minimises loss or damage to these seagrasses would therefore be required.

A device such as the underwater "harvester", used in the Peel Inlet to collect algae, could be considered. Such a machine would need to be modified to operate at depths of up to 3 metres. Reportedly, this harvester can be operated in a manner which does not destroy seagrass; however, this aspect would require early monitoring should a weed harvester be used in PRH.

Other techniques of algae collection, such as some form of bottom netting, could be investigated in PRH. Small-scale field trials would be required to determine the most appropriate equipment and procedures, and whether it could be a cost-effective method of collection.

A method involving suction of fine detrital and plant material from the bottom, and subsequent collection, concentration and removal could also be considered. Again, preliminary trials would be required to develop such a technique, and to monitor its environmental effects.

Weed and dead seagrass accumulations on the western beaches of PRH could be removed in a bid to ease the mercury contamination problem. However, generally these accumulations are not very extensive and they occur intermittently. Since they can be washed back into PRH on high tides, heavy equipment would need to be available for deployment on an irregular, unscheduled basis. The use of front end loaders to remove accumulations of weed on beaches in the Peel Inlet has led to minor beach erosion problems, because much sand is collected and lost to the system along with the algae. Weed is taken from beaches of the Peel Inlet in order to remove the objectionable sights and smells of decomposing algae, which are of considerable concern to the local residents. In PRH, the aesthetic impacts of weed accumulations are not as great. From past observations and chemical analyses, removal of weed accumulations from beaches in PRH would not remove significant quantities of lead and mercury from the system.

Proposals have been advanced for the dredging of areas of mercury contamination. As has been pointed out, the most contaminated areas are characterised by organic-rich sediments often associated with remaining seagrass beds. Major dredging operations in these areas would probably destroy the seagrass beds, and could alter the environment to the extent that *Posidonia* would never recolonise.

9.3.1.2 Suspension and Dispersal of Fine Organic Matter

An alternative management strategy could be to disturb and suspend fine organic sediment fractions and algae in the most contaminated areas in the western end of PRH, at times when they would most likely be dispersed away from these areas by water movements. A series of small-scale trials would be required:

- to find a way of suspending the fine organic matter, without damaging the seagrass,
- to monitor the extent of transport and dispersion of the fine organics under various conditions of wind and tide, and
- to assess whether such a dispersion and lowering of peak mercury levels in organic-rich sediments would in fact lead to a more rapid reduction in mercury levels in the edible marine life.

9.3.1.3 Burial of Organic Matter

Uncontaminated sand could be dredged and spread on highly contaminated areas, in order to bury the organic-rich contaminated sediments and isolate them from the food chains. It is possible that such actions could have serious impacts (e.g. smothering) on the seagrasses. Bioturbation of the sediments could eventually bring the contaminated material back to the surface, and hence this action could well increase the time for mercury levels to drop below health limits.

The Government Chemical Laboratories have investigated the option of applying iron filings to mercury contaminated sediments, to chemically immobilise the mercury prior to covering these areas with uncontaminated sand. This method also suffers from the problem that iron and contaminated sediments could eventually be worked to the surface. Also, field trials have shown that the iron produces a very noticeable colouration of the overlying sands. Major practical difficulties with large scale field application indicate that this method will not solve the problem.

9.3.2 MANIPULATION OF BIOTA

Several management options have been advanced in relation to the edible biota.

It has been suggested that, in areas where the cockles are most highly contaminated with lead (in shallow waters and on predominantly sandy sediments), they could either be ploughed into the sediments, or hand-collected for disposal. This may be a relatively inexpensive exercise. Since levels of lead decrease down the sediment column, ploughing in these sandy areas may tend to bury the most contaminated sediments. After recolonisation by cockles has occurred, monitoring could be conducted to determine whether the new cockles were accumulating lead to the same extent as the present ones.

The option of fishing out the western end of PRH would be difficult and costly. It would have only short term benefits, unless repeated at regular intervals, since fish recolonising the area would accumulate mercury. Also, there would seem to be little advantage in opening an area to the public from which the fisheries resource had been substantially removed.

Allowing fishing for selected species which are known to be within the health limits is another option. It does nothing to solve the contamination problem, however, and it increases the probability that people will catch and consume other fish species which exceed health limits for mercury. Even with regard to the selected species, there would always be an element of doubt in the minds of people until the area is unrestricted and fully opened.

9.3.3 CONTINUED CLOSURE OF WESTERN PRINCESS ROYAL HARBOUR

As indicated above, it appears that the health issues associated with heavy metal contamination of edible marine life in the western end of PRH may not naturally recede for many years, possibly decades, given present trends as determined by monitoring programmes since 1984. Heavy metal pollution of the harbour occurred over a period of about thirty years, and rapid, non-destructive, cost-effective management solutions are not readily apparent. Further work and small-scale field trials may identify active management options which can help shorten the time required for reduction of mercury contamination to levels below the specified health standards. Until this reduction is achieved, it will probably be necessary for the western end of PRH to remain closed.

9.4 SUGGESTIONS

The management options most worthy of further investigation are:
- removal of benthic algae from the PRH system, and
- suspension and dispersal of fine organic matter.

10. EDUCATION, EXTENSION AND PUBLIC PARTICIPATION

State government departments and agencies, shire and town councils, industry, community and special interest groups, and the general public, should be informed about the environmental problems discussed in this report. This can be achieved through education and extension programmes. These groups should be encouraged to participate in the management process by implementing improvements in industry, farming, public utility and general land-use practices.

The causes and nature of the environmental problems, and the management approaches being pursued, could also be effectively explained through the local media.

11. INSTITUTIONAL ARRANGEMENTS FOR MANAGEMENT

11.1 MANAGEMENT NEEDS

Two related management areas can be identified:
- The Catchments. Many of the problems in the waterways can be attributed to land-use practices in the catchments; for example, leaching of nutrients and siltation. Thus, effective management of the total catchment, or at least those parts which most affect the waterways, is vital. Catchment management, which involves a number of state government agencies, local government, and the land users, is in its infancy in Western Australia, but must be seen as a priority and one of the challenges for the State over the next 5 to 10 years.
- The Waterways. Management of the waterways and associated foreshores must include catchment management, and also a whole series of additional measures specific to the waterbody. These can include such actions as control of point discharges, clean up operations, provision of facilities, monitoring and inspection.

The two areas noted above have been separated because it is believed that one body alone cannot effectively or realistically provide overall management control. This section contains a series of suggestions for management, which together could lead to an overall management approach for both the waterways and the catchments. These suggestions were presented as advice to the Environmental Protection Authority.

11.2 AGENCY ROLES

11.2.1 ENVIRONMENTAL PROTECTION AUTHORITY

11.2.1.1 Policy

The Environmental Protection Authority could consider the development of an overall policy (set out as an Environmental Protection Policy) for waterway and catchment management. The policy would be applicable to a range of catchments, and could be prepared jointly with the State Planning Commission, to include land-use zoning considerations. It should set out aims for management, and appropriate institutional arrangements for implementation.

11.2.1.2 Research

It is suggested that the Environmental Protection Authority should remain the lead agency to coordinate and where appropriate carry out research on estuarine and marine systems, as a basis for advice to Government on strategies to pre-empt, resolve, or ameliorate environmental problems. In the case of OH and PRH, the Authority should co-ordinate appropriate studies (suggested in this report). Other bodies, such as the Waterways Commission, might more appropriately carry out routine and baseline monitoring, and inspections.

11.2.1.3 Pollution Control

The Environmental Protection Authority should continue its endeavours to control point sources of pollution through the powers of the Environmental Protection Act 1986, at least until an appropriate waterways management authority is established at Albany. At that time responsibility for licencing and control of point source discharges could be delegated to that body.

Non-point source discharge is more complex, and an overall strategy is required. As stated above, the Authority should take the lead role in recommending the most appropriate approach to Government through the development of an Environmental Protection Policy.

11.2.1.4 Environmental Impact Assessment

Any proposal which, if implemented, may have a significant effect on the environment, must be referred to the Environmental Protection Authority for assessment. In this matter, decision-making authorities have no discretion regarding referral.

The scope of environmental impact assessment is wide; for example, it is not limited to referral of single development projects, but includes amongst other things, programmes, plans and changes in land-use.

In instances where the Authority decides that a proposal should be assessed 'formally' (i.e. under Part 4 of the Environmental Protection Act 1986), the Minister for the Environment has a role in the setting of conditions under which the project may proceed. In this way environmental management controls can be placed on projects which are enforceable under the Act.

11.2.2 WATERWAYS COMMISSION

Government has called for a report on the need for, and desirability of management of waterways in Western Australia (other than the Swan, Peel and Leschenault waterways). Particular attention will be paid to the situation at Albany in the report, as for over 10 years there has been local pressure to form a waterways management area there.

If the Government accepts that a waterways management area should be declared, then the Waterways Commission, in conjunction with the local government authorities, could take responsibility for the normal waterways management functions. At Albany, particular emphasis would need to be placed on control of point source discharges, and management of excess algal growth and heavy metal accumulations in the harbours.

Consideration is being given to the declaration of a regional waterways management area. This could initially comprise the waterways of Albany and Denmark, with provision for future expansion along the south coast to include other waterways likely to experience similar problems to those at Albany, and to require similar management approaches.

11.2.3 ALBANY PORT AUTHORITY, DEPARTMENT OF MARINE AND HARBOURS DEPARTMENT OF FISHERIES, AND THE HEALTH DEPARTMENT

The Port of Albany is an important factor in the regional economy. The Albany Port Authority manages this use of the waterway.

The harbours are extensively used for commercial and recreational navigation. An appropriate level of maritime facilities is required. The Department of Marine and Harbours has a role in the management of such facilities.

The Fisheries Department regulates commercial and recreational fishing.

The Health Department investigates human health issues arising in waterways, and elsewhere in the environment. It determines health standards, and makes recommendations concerning health issues to other management agencies.

11.2.4 LOCAL GOVERNMENT AND THE STATE PLANNING COMMISSION

Planning and development controls are best carried out through local government Town Planning Schemes and development approval procedures. Environmental assessment of developments likely to affect waterways can be carried out under existing procedures.

The State Planning Commission is opening a regional office in Albany. Accordingly, improved interaction in land-use planning should result. Regional planning initiatives should include issues relating to catchment management and control of undesirable developments/activities.

11.2.5 DEPARTMENT OF AGRICULTURE

Phosphorus leaching losses from areas of agricultural fertiliser application can best be addressed by an approach similar to that used in the catchment of the Peel-Harvey estuarine system on the Swan Coastal Plain. Voluntary restraint in phosphorus fertiliser use may be achieved if past and current fertiliser application is shown to have been excessive. In this case, recommendations for reduced rates of fertiliser use may be made by gathering and applying sound agronomic and economic information. Statutory control of fertiliser use may be inappropriate, because of variations in fertiliser requirements for individual paddocks, and practical difficulties with enforcement.

A realistic means of achieving voluntary restraint in fertiliser use is through the declaration of Soil Conservation Districts, and the formation of Soil Conservation Advisory Committees within the catchments, under the provisions of the Soil

Conservation Act.

A large fertiliser management programme, similar to that on the Peel-Harvey catchment, cannot be conducted with the existing funding and staffing of the Department of Agriculture. Expertise and experience developed from the Peel-Harvey study is applicable, but suitable arrangements, both institutional and financial, for application of such a programme to the catchments of Oyster Harbour and Princess Royal Harbour, would be required.

Control of land clearing, protection of existing vegetation and provision for revegetation may also be appropriate. Such actions should be coordinated through the Departments of Agriculture, Conservation and Land Management, the local councils and the State Planning Commission.

11.2.6 DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

The management role of this Department will be of particular significance in catchments which contain large areas of crown land, state forest, or conservation reserves.

11.2.7 WATER AUTHORITY OF WESTERN AUSTRALIA

The Water Authority is responsible for the collection, conveyance, treatment and disposal of sewerage effluent and industrial waste to safeguard community health and protect the environment.

Discussions with officers of the Water Authority indicate a more limited role for that agency in catchment management than was the situation with the former Public Works Department, although this will vary depending on the value of the catchment as a water resource. The Water Authority will continue to monitor stream flows to determine water resource capacities and carry out flood management studies. However research on the dynamics of catchments and waterways will be limited, and implementation of flood management strategies will be left to planning authorities, especially within local government.

Application of the delegated pollution control powers of the Environmental Protection Authority has yet to be clarified.

11.2.8 DEPARTMENT OF REGIONAL DEVELOPMENT AND THE NORTH WEST

A prime objective of this Department is to plan, coordinate and facilitate the economic and social development of the non-metropolitan regions of Western Australia. The Department has recently been involved with the Great Southern Region Economic Study (Department of Regional Development and the North West 1986). An awareness of regional environmental issues should be fostered throughout the region, and incorporated within such studies. Development plans should be consistent with the sustainability of the region's natural resources. In particular, the environmental pressures placed on the region's waterways by developments in the catchments should be recognised, and developments fostered which will minimise these pressures.

11.3 FUTURE DIRECTIONS

Declaration of a waterways management area would enable improved, direct management of OH and PRH and related waterways. Such a declaration may be linked with Government acceptance of recommendations on waterways management for a number of areas in the State.

In the meantime, and even if a waterways management area is created, the Environmental Protection Authority will continue to coordinate research and appropriate studies. Additionally, the Authority could consider the development of an Environmental Protection Policy for catchment and waterway management.

Overall management of the catchments of OH and PRH (and the catchments of other waterways) is complex. In some cases, control of localised discharges may best be achieved through land use planning controls, or pollution controls. In other instances, a broader approach through the provisions of the Soil and Land Conservation Act may be more appropriate.

Development of an Environmental Protection Policy is one avenue that could be used to define an acceptable approach. Of particular interest is the role that the Department of Agriculture might undertake in overall catchment management, which is vital to the future condition of OH and PRH (and a number of other estuaries and embayments in the State).

12. WIDER MANAGEMENT IMPLICATIONS

It should be noted that land-use developments and practices taking place in the Albany hinterland are similar to those found in other southern catchments of Western Australia. It is therefore likely that similar environmental problems are developing in several south coast estuaries and embayments. Appropriate investigations and management programmes are required to cope with and where possible to pre-empt these problems. Institutional arrangements for waterways and catchment management should be flexible enough to deal with the widespread occurrence of these issues.

13. REFERENCES

ATKINS, R P, IVESON, J B, FIELD, R A and PARKER, I N (1980), A Technical Report on the Water Quality of Princess Royal Harbour, Albany, Bulletin No 74 Department of Conservation and Environment, Perth, Western Australia, 67pp.

BASTYAN, G R (1986), Distribution of Seagrasses in Princess Royal Harbour and Oyster Harbour, on the South Coast of Western Australia, Technical Series 1, Department of Conservation and Environment, Perth, Western Australia, 50pp.

CHURCHWARD, H M, McARTHUR, W M, SEWELL, P L and BARTLE, G A (1987), Landforms and Soils of the South Coast and Hinterland of Western Australia, Northcliffe - Manypeaks, Technical Report, CSIRO Division of Water Resources Research. (in press)

DEPARTMENT OF REGIONAL DEVELOPMENT AND THE NORTH WEST, (1986), Final Report of the Great Southern Region Economic Study, Volume 1, Summary and Profile. 72pp.

JACKSON, M, HANCOCK, D, SCHULZ, R, TALBOT, V and WILLIAMS, D (1986), 'Rock phosphate: the source of mercury pollution in a marine ecosystem at Albany, Western Australia', Marine Environmental Research **18**, 185-202

KIRKMAN, H (1987), Decline of Seagrass Beds in Princess Royal Harbour and Oyster Harbour, Albany. Technical Series No 15, Environmental Protection Authority, Perth, Western Australia, 11pp.

LENANTON, R C J (1977), 'Aspects of the ecology of fish and commercial crustaceans of the Blackwood River estuary, Western Australia', Fisheries Department, Western Australia, Fisheries Research Bulletin **19**, 1-72

LENANTON, R C J (1982), 'Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of South-Western Australia', Australian Journal of Marine and Freshwater Research **33(5)**, 881-900.

McKENZIE, K G (1962), Oyster Harbour: a Marginal Environment, PhD thesis, University of Western Australia (two volumes).

MIDDLETON, M J, BELL, J J, BURCHMORE, D A, POLLARD, D A and PEASE, B C (1984), 'Structural differences in the fish communities of *Zostera capricorni* and *Posidonia australis* seagrass meadows in Botany Bay, New South Wales', Aquatic Botany **18**, 89-109.

MILLS, D A and BRADY, K M (1985), Wind-Driven Circulation in Princess Royal Harbour: Results from a Numerical Model, Bulletin No 229, Department of Conservation and Environment, Perth, Western Australia, 39pp.

PEARCE, A F, JOHANNES, R E, MANNING, C R, RIMMER, D W and SMITH, D F (1985), Hydrology and Nutrient Data off Marmion, Perth, 1979-1982, CSIRO Marine Laboratories Report No 167.

PLATELL, N (1978), Water Quality Monitoring Survey of Princess Royal Harbour, Albany. Report of Investigations No 19 Government Chemical Laboratories, Perth, Western Australia.

SCOTT, J K (1981), 'The seagrass fauna of Geographe Bay, Western Australia', Journal of the Royal Society of Western Australia **63**, 97-102.

SCOTT, J K, DYBDAHL, R and WOOD, W F (1986), The Ecology of *Posidonia* Seagrass Fish Communities, Technical Series No 11, Department of Conservation and Environment, Perth, Western Australia, 44pp.

TALBOT, V, WILLIAMS, D and COLLETT, D (1987), Mercury in Sediments and Selected Biota, Environmental Note, Environmental Protection Authority, Perth, Western Australia.

APPENDIX

Decline of Seagrass Beds in
Princess Royal Harbour
and Oyster Harbour,
Albany, Western Australia

Hugh Kirkman
CSIRO Division of Fisheries Research
Marmion WA 6020

Environmental Protection Authority
Perth, Western Australia

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ii SUMMARY

Since 1962, seagrass cover and density have declined markedly in Oyster Harbour and Princess Royal Harbour (PRH), Albany. Underwater photographs, taken in 1986, have shown evidence of old, dead rhizomes in the substrate and unhealthy, algae-covered *Posidonia* throughout PRH. Oyster Harbour, although not so intensively examined, appears to have similar problems.

In terms of biomass and area covered in both harbours, *Posidonia australis* and *P sinuosa* were the two most important seagrasses. By 1984, 46% and 66% of seagrass cover in Oyster Harbour and PRH respectively had been lost, and there is no evidence to suggest revegetation. Bastyan (1986) reported on this loss of seagrass cover to 1984, and claimed that seagrasses were being smothered by epiphytic algae. The seagrass cover has continued to decline since then.

From the evidence and experience in other Western Australian bays and estuaries, particularly Cockburn Sound and Peel-Harvey Estuary, the decline of seagrass and proliferation of fast growing, highly productive macroalgae is caused by high nutrient levels in the water. These nutrients (nitrogen and phosphorus) are entering the embayments through drainage water from agricultural lands, from a fertiliser factory near PRH and from other anthropogenic sources. At this stage there is probably a considerable nutrient store in both harbours. This store is mainly organic nitrogen and phosphorus compounds associated with sediments and organic detritus on the bottom. It would be difficult and very expensive to remove this organic material from either harbour.

If the input nutrient loads were reduced immediately, there would probably be no return to the original pristine conditions, which were probably similar to those of nearby King George Sound. Existing seagrass beds in reasonable condition may recover, but revegetation by *Posidonia* would be negligible. Plant colonisers would appear, and at least stabilise sediments and afford shelter to some juvenile fish and crustacea. The main colonisers in bare areas in seagrass beds are the small seagrass species, *Halophila ovalis*, *Heterozostera tasmanica* and occasionally *Amphibolis* species. Information on the relative habitat value of *Posidonia* beds in south-Western Australia compared with the seagrass beds comprising the smaller coloniser *Ruppia* is available in Lenanton (1977, 1982), Scott (1981), and Scott *et al* (1986); while comparisons between *Posidonia* and *Zostera* were made by Middleton *et al* (1984).

If the nutrients loads are not reduced, the *Posidonia* beds will die out completely, eutrophication will occur, and blooms of nuisance algae such as *Enteromorpha*, *Cladophora* and *Ulva* will develop more frequently. Water clarity will be reduced and there may be considerable sediment movement.

Artificially revegetating denuded areas with *Posidonia* has not been attempted in Australia. Vegetative and reproductive propagules can be obtained easily, but to anchor them and successfully rehabilitate seagrasses in these harbours could prove very costly.

1. TERMS OF REFERENCE

In response to a request by the former Department of Conservation and Environment (now integrated into the Environmental Protection Authority), this report has been prepared to cover the following terms of reference:

. Examine existing data and information regarding distribution of seagrass meadows in Princess Royal Harbour and Oyster Harbour and comment on the reliability.

. Evaluate the nature and magnitude of the changes reported by Bastyan (1986).

. Consider and describe the likely situations in these harbours in the future (perhaps 2, 5, 10 and 20 year scenarios), if present apparent trends continue.

. Describe and comment on the implications of the worst possible scenario developing (for example, effective loss of all seagrass meadows from either or both harbours).

. Comment on possible management options to halt or reverse present trends.

. Consider and predict the likely situations in these harbours (perhaps 2, 5, 10 and 20 year scenarios), if immediate actions are implemented to significantly reduce anthropogenic influences (including nutrient inputs) on marine communities in the harbours.

2. DESCRIPTION OF THE AREA

Bastyan (1986) has described the general and biological characteristics of Princess Royal Harbour (PRH) and Oyster Harbour. Mills and Brady (1985) described the physical features, particularly relating to water circulation in PRH, and Atkins et al (1980) described chemical aspects of water in PRH. Each harbour is connected to King George Sound by a narrow channel. There are small beds containing at least five species of *Posidonia* just outside the mouth of Oyster Harbour and at Gull Rock (Figure 1), and extensive seagrass meadows growing to at least 17 m depth in Frenchman Bay and Barker Bay. King George Sound has a maximum depth of about 20 m, contains a few small islands and many reef areas, and is open to the Southern Ocean to the east and southeast.

Salinities over the *Posidonia* beds in the two harbours range from 31 parts per thousand to 35 parts per thousand (Bastyan, 1986). Oyster Harbour has two inflowing rivers whose catchment areas are farmed extensively.

The following seagrass species are found in King George Sound:

Posidonia australis		"australis" complex
P sinuosa		" "
P den Hartogii		"ostenfeldii" complex
P robertsoneae		" "
P kirkmanii		" "
P ostenfeldii	(drift only)	" "
Heterozostera tasmanica		
Halophila ovalis		
Amphibolis antarctica		
A griffithii		

Figure 2a. *Posidonia sinuosa* bed at 15 m depth in Frenchman Bay, January 1987. Note dense, healthy seagrass.

Figure 2b. *Posidonia australis* bed at 1.5 m depth in Frenchman Bay, January 1987. Note dense, healthy seagrass, relatively free of epiphytes.

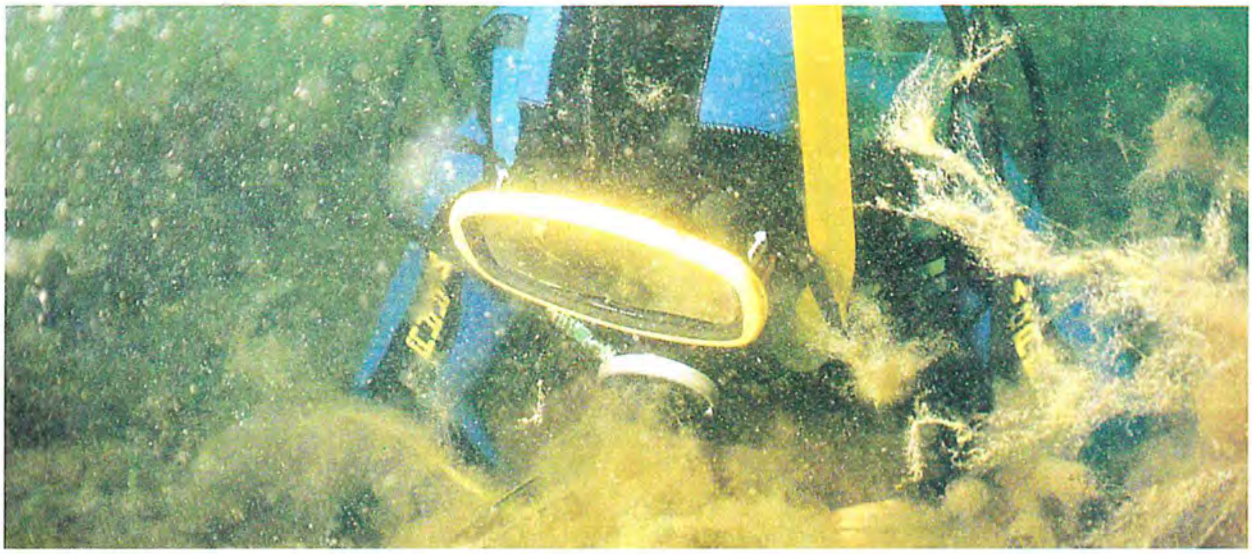

Figure 2c. Filamentous alga (epiphyte) covering *Posidonia sinuosa* in the eastern part of Princess Royal Harbour, 4.5 m depth, November 1986. Note seagrass is almost totally covered with alga.

Figure 3a. *Posidonia australis* and *P sinuosa* in the western end of Princess Royal Harbour, 1.5 m depth, November 1986. Note seagrass here is very sparse, probably due to the quantity of smothering benthic algae.

Figure 3b. Diver examining remains of seagrass leaf - bases and rhizomes dug out from under the sand. This indicated a seagrass bed once covered the site. Photograph taken in the eastern end of Princess Royal Harbour, 4.5 m depth, November 1986.

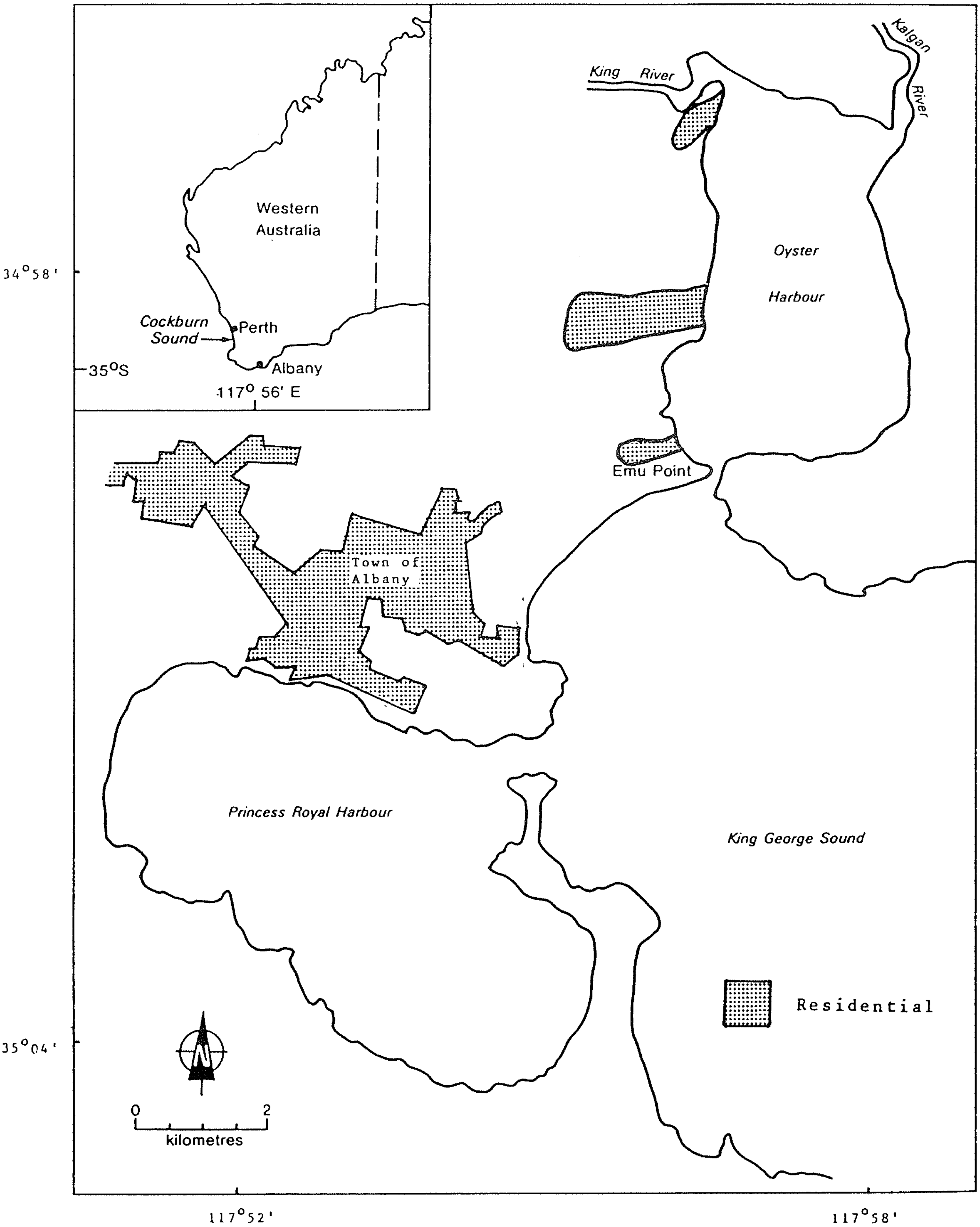

Figure 1. Map showing location of Princess Royal Harbour and Oyster Harbour at Albany.

P australis and *P sinuosa* are found in PRH and Oyster Harbour. The only other seagrass mentioned by Bastyan (1986) was *Amphibolis griffithii*.

3. SEAGRASS BIOLOGY

Altogether six species of *Posidonia* are found in King George Sound. These have been divided, by Kuo and Cambridge (1984), into two complexes - "australis" and "ostenfeldii". The members of the "ostenfeldii" complex (Kuo and Cambridge, 1984) are not likely to occur in sheltered bays as they are generally found in swell conditions. Other seagrasses, *H tasmanica*, *H ovalis* and *A antarctica*, are often associated with blowouts in *Posidonia* beds (Kirkman, 1985).

In most years the members of the "ostenfeldii" complex are prolific producers of seed in November, but these species of *Posidonia*, once established, do not rapidly produce horizontal rhizomes and spread. They do, however, send vertical roots deep into the sandy substrate so that they are well anchored and form multi-branched clumps. The growth form of these species is evident when a mature meadow is observed. The seeds have usually settled on the lee side of swell-formed ripples in the sand, and after three years or more, the meadow looks as though it has been planted in rows. Seedlings are quite robust and are reliant on the seed testa for at least a year after germination.

P australis and *P sinuosa* do not anchor as firmly as the species in the "ostenfeldii" complex, and *P sinuosa* does not flower as prolifically as the other *Posidonia* species. No one has yet attempted to recolonise seagrass beds with *Posidonia* seedlings, although a successful attempt at vegetative propagation in the Mediterranean with *P oceanica* has been made (Cooper, 1980). *P oceanica* has a different growth form from the Australian *Posidonia*, therefore, a method similar to Cooper's may not be successful. *Thalassia testudinum* seedlings have been used to revegetate areas of lost seagrass in the Carribbean, but this has proved very expensive (Thorharg, 1985, 1986).

Kirkman (1985) has shown that, within the eight years of his records, *P sinuosa* and *P australis* do not recover in blowouts or artificial clearings. There is ample evidence from other *Posidonia* beds that recovery is extremely slow, if it occurs at all. A clearing made for the extraction of fibre from *Posidonia* beds in Spencer Gulf in 1917 has not been recolonised (Clarke, pers comm), nor have the tracks made by an amphibious vehicle through a *Posidonia* bed during the Second World War in Botany Bay. Kirkman (1985) has shown that blowouts may be recolonized by *Halophila ovalis*, *Heterozostera tasmanica* or even the seedlings of *Amphibolis*. These colonizers may spread rapidly but may be short lived due to their being smaller and less well anchored and therefore more susceptible to removal by storms.

4. BENEFITS OF SEAGRASS BEDS

It is well known that seagrass beds located in Australian coastal environments provide important nursery areas for juvenile fish and crustaceans, many of which are commercially important (Pollard, 1984; Young 1978). Some of the more important commercial species that utilise seagrass beds are representatives of the flathead, trevally, bream, whiting, Australian salmon, mullet and leatherjacket families (Lenanton, 1977; Middleton *el al* 1984; Robertson, 1977, 1982, 1984).

Seagrass beds stabilise the sediments on which they grow (Thorhaug, 1986). The tough, deep rhizomes of *Posidonia sinuosa* and *P australis* prevent mass sand movement and erosion while the leaf blades act as baffles to water movement. Increased accretion may cover existing beds with sand more rapidly than they can grow out of it; the consequence of this is smothering and later death of these beds (Kirkman, 1978).

Seagrass leaf blades modify water currents causing suspended particles to sink to the bottom. These suspended particles may be organic in origin thus adding to the available food for animals living in the seagrass. Therefore as seagrass beds disappear it can be expected that water clarity will decrease, thus reducing the depth limits of the remaining beds.

5. CONSIDERATIONS

5.1 EXAMINE EXISTING DATA AND INFORMATION REGARDING DISTRIBUTION OF SEAGRASS MEADOWS IN PRINCESS ROYAL HARBOUR AND OYSTER HARBOUR AND COMMENT ON THEIR RELIABILITY

There is no doubt that the extent of seagrass beds in PRH and Oyster Harbour has declined since McKenzie (1962) reported on the area. Since then aerial photographs have not been very reliable without extensive field work to evaluate what is seagrass and what is macroalgae. It appears, from underwater photographs taken in PRH in November 1986, that large areas of seagrass have either been replaced by beds of *Cladophora* or have been covered by this macroalgae (Photograph 1). The deeper seagrass beds seem worst affected. Bastyan (1986) shows no seagrass in the centre of PRH and a reduction in seagrass bed area in the deeper parts of Oyster Harbour.

Aerial photographs taken in 1984 were used by Bastyan (1986). Both these, and those taken in 1985, do not allow accurate comparisons to be made between the earlier 1977 and 1982 photography because:

- The water clarity is poor compared with that of King George Sound where seagrass beds can easily be seen.

- There is no way to distinguish seagrass from accumulations of algae in the two harbours, nor can the area covered by dead rhizomes be distinguished from that covered by live seagrass. Underwater photography along three transects in PRH taken in November 1986 showed that most seagrass was covered, to some degree, with filamentous algae. These photographs also showed the *Posidonia* beds to be in very poor condition. The densest beds in PRH, in 1.5 m of water (Figure 3a), were less dense than beds in 15 m in nearby Frenchman Bay (Figure 2a).

The loss of 0.8 km^2 of seagrass in PRH between 1981 and 1984 does not appear to be a great decline in seagrass cover. However if it is realised that nearly all the seagrass in PRH is covered by filamentous algae, and that this may have been included as seagrass bed in Tables 1 and 3 in Bastyan (1986), then it may be supposed that the expected life of these beds is limited. Without a complete field programme of underwater tows, and checks of aerial photography, it is not possible to define the rate of seagrass bed decline since 1984. Personal experience indicates that the future rate of decline will accelerate.

5.2 EVALUATE THE NATURE AND MAGNITUDE OF THE CHANGES REPORTED BY BASTYAN (1986)

The Bastyan report (1986) is a valuable document describing the seagrass beds and the reduction in seagrass cover in PRH and Oyster Harbour between 1962 and 1984, since it makes good use of aerial photographs and *in situ* observations along fixed transects. Aerial photography for 1985 is now available.

It is unfortunate that Bastyan's report (1986) did not compare the harbours with healthy seagrass beds from nearby. King George Sound has healthy beds with at least five *Posidonia* species, and four other species. Records of their depth limits, distribution and biomass would have been useful as comparisons with the two harbours where seagrasses are declining. Figure 2b shows *Posidonia australis* growing in 1.5 m of water in Frenchman Bay. A comparison of the species and biomass of epiphytes within the two harbours, with those in King George Sound, may have led to a statement as to whether epiphyte loads were unusually heavy or different in Bastyan's study area.

The cover by either seagrass or algae at the western end of PRH is not mentioned in Bastyan's (1986) report, yet there is a large vegetated area visible in each aerial photograph. In fact, this area is covered mainly by *P australis* with large patches of *Amphibolis antarctica* along the edges of the *P australis*. In the very shallow shoreward side of this bed, *Ruppia* sp is found in small quantities growing on the edges of the *A antarctica* clumps. *Heterozostera tasmanica* also grows with the other species. This area of seagrass is probably the healthiest in the harbour: it is not smothered by macroalgae, even though a drain from a potato-growing area flows into PRH close by. This may be because the macroalgae cannot tolerate the high ultraviolet light present in such shallow water. Another alternative for the lack of macroalgae in otherwise ideal conditions is that, being so shallow, wind blown waves can remove any epiphytic growth. It is notable, however, that where the Elleker Road Drain enters PRH there is bare sand.

Bastyan (1986) also states that there has been a considerable increase in algal growth in both harbours and suggests that high nutrient inputs are responsible for this. *Cladophora prolifera* accumulation is a symptom of eutrophication of the water in the Peel-Harvey Estuary (Gordon et al, 1981). Since *Cladophora* has accumulated in both Princess Royal Harbour and Oyster Harbour, Bastyan's suggestion seems well-founded.

5.3 CONSIDER AND DESCRIBE THE LIKELY SITUATIONS IN THESE HARBOURS IN THE FUTURE (PERHAPS 2, 5, 10 AND 20 YEAR SCENARIOS), IF PRESENT APPARENT TRENDS CONTINUE. DESCRIBE AND COMMENT ON THE IMPLICATIONS OF THE WORST POSSIBLE SCENARIO DEVELOPING (FOR EXAMPLE, EFFECTIVE LOSS OF ALL SEAGRASS MEADOWS FROM EITHER OR BOTH HARBOURS).

If the *Posidonia* beds of PRH and Oyster Harbour are lost and the nutrient input into these harbours continues, the water quality and substrate will change considerably. Although flushing rates in both these harbours are greater than for the Peel-Harvey Estuary, they may be slow compared with King George Sound. A further build up of macroalgae could also be expected at Albany. Blooms of algae such as *Cladophora*, *Enteromorpha* and *Ulva* may occur. Dead plant material could consequently accumulate on the bottom and act as a nutrient store. There would probably be very little export of these nutrients to King George Sound because of the slow flushing rates. The waters of these two enclosed harbours would have all the problems of eutrophic waters. If the apparent trends continue all seagrass beds will disappear in the order of about 5 years. There will be no recovery and blooms of algae will occur at least every summer. Sand movement within the harbours may fill in dredged channels within 20 years while erosion along the edges of both harbours will commence as soon as seagrasses disappear. It may even be possible for such large amounts of nutrients to be released that King George Sound seagrass beds are also affected. The above considerations cover the worst possible scenario.

5.4 COMMENT ON POSSIBLE MANAGEMENT OPTIONS TO HALT OR REVERSE PRESENT TRENDS

In considering the results and conclusions from the study of seagrass decline in Cockburn Sound, near Perth (Cambridge and McComb, 1984; Cambridge et al, 1986; Silberstein et al, 1986), and the results of Bastyan's (1986) report, it appears reasonable to assume that excess nutrients in PRH and Oyster Harbour has indirectly caused the decline in seagrass density and cover. Silberstein et al (1986) suggest that seagrass loss in Cockburn Sound may be attributed to enhanced epiphyte loads following nutrient enrichment.

The amount of phosphate phosphorus, in the water of PRH determined by Atkins et al (1980), is higher than that at Marmion lagoon near Perth where seagrasses are healthy and abundant (Pearce et al, 1985). There is also a peak in winter that does not occur near Perth. Ammonia concentrations reported by Atkins et al (1980) are also higher than for waters near Perth. The nitrate concentrations in PRH are similar to those of coastal waters near Perth.

It is apparent that, to prevent further loss of seagrass, the nutrient load entering the harbours must be reduced to levels below some critical amount yet to be determined. The concentration of phosphorus and nitrogen must be such that the algal blooms are not sustained. Reduction of run-off nutrient load in the Peel-Harvey Estuary has been facilitated by farmers in the catchment area using slow release fertiliser, and in Cockburn Sound by the exclusion of industrial and urban wastes. If nutrient inputs are reduced, into the Albany harbours, it would be appropriate to instigate a monitoring programme to determine the response of the marine plant communities.

Once nutrient levels in the water column have been reduced sufficiently to prevent blooms of epiphytic algae growing on the seagrass, a possible management option would be some form of artificial revegetation of the seagrass areas. Natural colonisation of seagrass may take up to two orders of magnitude longer than artificial recolonisation (Thorhaug, 1986). Seagrasses could be replaced either as vegetative turfs or as seedlings, replanted throughout the damaged areas. As the most likely method to succeed is the transplanting of seedlings, which are readily available in summer, the first restoration attempt should be to investigate the possibility of growing *Posidonia* seedlings in the damaged seagrass areas. A detailed procedure and methodology for revegetation would have to be the subject of a separate study.

5.5 CONSIDER AND PREDICT THE LIKELY SITUATIONS IN THESE HARBOURS (PERHAPS 2, 5, 10 AND 20 YEAR SCENARIOS), IF IMMEDIATE ACTIONS ARE IMPLEMENTED TO SIGNIFICANTLY REDUCE ANTHROPOGENIC INFLUENCES (INCLUDING NUTRIENT INPUTS) ON MARINE COMMUNITIES IN THE HARBOURS

The vital question is - will the seagrasses return if nutrient input is reduced to levels at which algal blooms do not occur?

As stated earlier, *Posidonia australis* and *P sinuosa* are extremely slow to revegetate areas denuded of seagrass. Possibly the colonisers *Halophila ovalis* or *Heterozostera tasmanica* can successfully establish to a level where full cover is achieved, because both Oyster Harbour and PRH are relatively well protected from large storms. Nevertheless, these plants will never provide the biomass of a *Posidonia* meadow.

6. CONCLUSIONS

The fact that Bastyan (1986) did not mention *Halophila ovalis*, *Heterozostera tasmanica* and *Amphibolis antarctica* may be significant. These species usually colonise areas where *Posidonia* has been lost naturally. Their absence may be indicative of unsuitable areas for seagrass, thus adding further evidence to the suggestion that PRH and Oyster Harbour are now unhealthy habitats for seagrasses.

Experience from the Peel-Harvey Estuary should be used in solving the problems in PRH, and particularly in Oyster Harbour where farming practices in the catchment area may be adding to the nutrient load of the two rivers which discharge into the harbour.

One other consideration not mentioned by Bastyan (1986) is that a decrease in salinity may kill *Posidonia*. This is particularly applicable in Oyster Harbour into which two rivers, with extensively cleared catchments, empty, thus causing a greater freshwater input than previously. In Cockburn Sound, where large areas of seagrass have also died out, the possibility that increased freshwater input was responsible was not investigated, since there is no appreciable freshwater input into that Sound.

If present trends continue, both PRH and Oyster Harbour will become increasingly eutrophic, blooms of macroalgae will occur more commonly, and all the significant seagrass beds will be lost. As a direct result of seagrass loss, erosion and accretion will occur and valuable nursery areas for juvenile fish and crustacea will be lost. Water turbidity will increase and the blooms of macroalgae will cause problems in the harbours and on their beaches.

7. REFERENCES

Atkins, R P, Iveson, J B, Field, R A and Parker, I N (1980), A Technical Report on the Water Quality of Princess Royal Harbour, Albany, Department of Conservation and Environment, Perth, Western Australia, Bulletin 74, 67pp.

Bastyan, G R (1986), Distribution of Seagrasses in Princess Royal Harbour and Oyster Harbour, on the South Coast of Western Australia, Department of Conservation and Environment, Perth, Western Australia, Technical Series 1, 50 pp.

Cambridge, M L and McComb, A J (1984), 'The loss of seagrasses in Cockburn Sound, Western Australia. 1. The time course and magnitude of seagrass decline in relation to industrial development', Aquat Bot **20**, 229-243.

Cambridge, M L, Chiffings, A W, Brittan, C, Moore, E and McComb, A J (1986), 'The loss of seagrass in Cockburn Sound, Western Australia. 2. Possible cause of seagrass decline', Aquat Bot **24**, 269-285.

Cooper, G (1980), Implantation de *Posidonia oceanica* et recifs Alveoles, Cahier no 4, Jardinier de la mer, Provence-Corse a Giens, 110pp.

Gordon, D M, Birch, F B and McComb, A J (1981). 'Effects of inorganic phosphorus and nitrogen on the growth of an estuarine *Cladophora* in culture', Bot Mar **24**, 93-106.

Hodgkin, E P and Lenanton, R C (1981), Estuaries and coastal lagoons of south Western Australia in B J Neilson, and L E Cronin, 'Estuaries and Nutrients', The Humanana Press, 307-321.

Kirkman, H (1978), 'Decline of seagrass in northern areas of Moreton Bay, Queensland', Aquat Bot **5**, 63-76.

Kirkman, H (1985), 'Community structure in seagrasses in southern Western Australia', Aquat Bot **21**, 363-375.

Kuo, J and Cambridge, M L (1984), 'A taxonomic study of the *Posidonia ostenfeldii* complex (Posidoniaceae) with description of four new Australian seagrasses', Aquat Bot **20**, 267-295.

Lenanton, R C J (1977), 'Aspects of the ecology of fish and commercial crustaceans of the Blackwood River estuary, Western Australia', Fish Res Bull West Aust, **19**, 1-72.

Lenanton, R C J (1982), 'Alternative non-estuarine nursery habitats for some commercially and recreationally important fish species of south-Western Australia', Aust J Mar Freshwater Res, **33(5)**, 881-900.

Middleton, M J, Bell, J J, Burchmore, D A, Pollard, D A and Pease, B C *(1984), 'Structural differences in the fish communities of* Zostera *capricorni* and *Posidonia australis* seagrass meadows in Botany Bay, New South Wales', Aquat Bot **18**, 89-109.

Mills, D A and Brady, K M (1985), Wind-Driven Circulation in Princess Royal Harbour: Results from a Numerical Model, Department of Conservation and Environment, Perth, Western Australia, Bulletin 229, 39pp.

Pearce, A F, Johannes, R E, Manning, C R, Rimmer, D W and Smith, D F (1985), Hydrology and Nutrient Data off Marmion, Perth, 1979-1982, CSIRO Marine Laboratories, Report 167.

Pollard, D A (1984), 'A review of ecological studies on seagrass - fish communities, with particular reference to recent studies in Australia', Aquat Bot **18**, 3-42.

Robertson, A I (1977), 'Ecology of juvenile King George Whiting *Silloginodes punctatus* (Cuvier and Valenciennes, Pisces: Perciformes) in Western Port, Victoria', Aust J Mar Freshwater Res **28**, 35-43.

Robertson, A I (1982), 'Population dynamics and feeding ecology of juvenile Australian salmon *(Arripis trutta)* in Western Port, Victoria', Aust J Mar Freshwater Res **33**, 369-75.

Robertson, A I (1984), 'Trophic interactions, between the fish fauna and macrobenthos of an eelgrass community in Western Port, Victoria', Aquat Bot **18**, 135-153.

Scott, J K (1981), 'The seagrass fauna of Geographe Bay, Western Australia', J R Soc West Aust **63**, 97-102.

Silberstein, K (1985), The Effects of Epiphytes on Seagrasses in Cockburn Sound, Department of Conservation and Environment, Perth, Western Australia, Bulletin 135, 63pp.

Silberstein, K, Chiffings, A W and McComb, A J (1986), 'The loss of seagrass in Cockburn Sound, Western Australia. 3. The effect of epiphytes on productivity of *Posidonia australis* Hook F', Aquat Bot **24**, 355-371.

Thorhaug, A (1985), 'Large-scale seagrass restoration in a damaged estuary', Mar Pollut Bull **16**, 55-62.

Thorharg, A (1986),'Review of seagrass restoration efforts', Ambio **15**, 110-117.

Young, P C (1978), 'Moreton Bay, Queensland: A nursery area for juvenile Penaeid prawns', Aust J Mar Freshwater Res **29**, 55-75.