THE PEEL-HARVEY ESTUARINE SYSTEM
PROPOSALS FOR MANAGEMENT

REPORT 14 : APPENDIX 2
The Response of the biota to the proposed management measures

Department of Conservation and Environment
Western Australia

Bulletin 242 January 1986

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THE RESPONSE OF THE BIOTA TO THE
PROPOSED MANAGEMENT MEASURES

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INTRODUCTION

The Peel-Harvey Estuarine System Study (1976-80) identified the cause of the macroalgal problem of Peel Inlet and the more recent blue-green algal problem of Harvey Estuary as an abundance of nutrients, especially phosphorus, entering the system from agricultural drainage (Department of Conservation and Environment Report No.9, 1980). Subsequent research aimed at finding appropriate measures to overcome the algal problem resulted in the proposal of a preferred management strategy consisting of 3 measures (Department of Conservation and Environment Bulletin No.170, 1984):

i) Continuation and possible expansion of the present programme of harvesting and removal of accumulating weed;

ii) Modifying present fertilizer practices on the coastal plain to reduce phosphorus levels in agricultural drainage;

iii) Construction of a new channel (Dawesville Channel) to increase flushing of water from Harvey Estuary.

The first of these is a "control" method aimed at reducing the nuisance caused by algal accumulation on the shores of the system. The other two are "preventative" methods which aim to progressively reduce the amount of phosphorus available for algal growth; since phosphorus is the plant nutrient in shortest supply, the total amount of phosphorus entering the system each year largely determines nuisance algal biomass.

The preferred management strategy is expected to greatly reduce the algal problem, but the measures involved, particularly the construction of the Dawesville Channel, will result in significant changes to the salinity regime, tidal dynamics, nutrient levels and turbidity of waters in the system. The expected changes will result in a considerably different environment for estuarine biota, especially in Harvey Estuary. This report is concerned with the effects of these changes on both the nuisance algae and estuarine biota in general.

The changes expected with the two "preventative" methods of the preferred management strategy are discussed in detail in Appendix 3 (Department of Conservation and Environment Bulletin No.195, 1985), and are summarized below.

Modification of fertilizer practices on the coastal plain

In the short term (3-5 years), modified fertilizer practices in the Harvey catchment should lead to a 20-40% reduction in the average concentration of phosphorus in winter river discharge (approximately 90% of riverflow and nutrient loading into the Peel-Harvey occurs in the winter months). In the longer term (5-15 years), if the fertilizer programme continues as hoped and the store of excess phosphorus in agricultural soils is gradually reduced, a 40-60% reduction in average concentration of phosphorus could be achieved. Since about 60% of the phosphorus entering the system comes from the Harvey River and Mayfield Drain, modified fertilizer practices in the Harvey catchment will significantly reduce total phosphorus input, although the amount of winter rainfall will obviously remain important. The fertilizer management programme will also be extended to other catchments affecting the system, and is already operating in the Serpentine catchment.

The Dawesville Channel

i) Salinity - at present the waters of Harvey Estuary become hypersaline in late summer/early autumn, but during winter and early spring are rendered almost fresh by river flow. Peel Inlet undergoes these seasonal variations in salinity to lesser extremes, and marine salinities prevail longer in this water body because it is subject to more exchange with oceanic waters through the Mandurah Channel. The proposed Dawesville Channel will considerably increase exchange between the ocean and Harvey Estuary, which will therefore become more like Peel Inlet - in effect, more "marine". Peel Inlet will be less influenced by oceanic exchange through the Dawesville Channel, but it too will become more marine.

ii) Tidal dynamics - the Peel-Harvey system experiences only small daily tidal fluctuations, and longer-term changes in oceanic water levels caused by wind and barometric effects cause greater changes in water level in the estuaries. However with the Dawesville Channel, up to 50% of coastal daily tidal fluctuations will be experienced. Although mean water level will not change, both daily and seasonal tidal amplitudes will increase. As a result, the total subtidal area (i.e. area that is permanently submerged) will decrease, and intertidal areas (areas alternately inundated and exposed with the incoming and outgoing tide) will increase, and be exposed and inundated more frequently than at present.

iii) Nutrient levels - the increased (three-fold) level of flushing of the system expected with the Dawesville Channel will result in lower nutrient levels in the estuarine system, as nutrient-rich estuarine waters are exchanged with nutrient-poor marine waters. The combination of the Dawesville Channel and modified fertilizer practices should achieve a 50-70% reduction in phosphorus available to algae in Harvey Estuary in the short term.

iv) Turbidity - the turbidity of waters in Peel Inlet is largely determined by phytoplankton blooms, whereas in Harvey Estuary, although phytoplankton blooms also dramatically increase turbidity, waters are generally more turbid than in Peel Inlet because of the suspension of fine sediments by wind-caused waves. With the Dawesville Channel, the lower nutrient levels will result in lower levels of phytoplankton, and increased exchange with the ocean will dilute the phytoplankton even further. Therefore waters will become clearer in both systems. Harvey Estuary will still be more turbid than Peel Inlet, but in the longer term should become progressively less turbid as the fine suspended sediments are also lost through oceanic exchange.

Other minor effects include the possible formation of a tidal delta adjacent to the Channel and the erosion of shores due to wave action associated with increased daily tidal fluctuations.

It should be emphasized that it is impossible to predict exactly how such changes will affect the estuarine flora and fauna, and the degree of uncertainty increases when moving for instance, from plant to herbivore to carnivore, since the effect on any one organism also depends indirectly on the responses of the organisms it feeds upon. However given sufficient information, it is possible to predict changes on a general descriptive level with a reasonable degree of confidence. The effects of the preferred management strategy on estuarine flora and fauna have been predicted using information gained from research in both the Peel-Harvey estuarine system and a number of other southwestern Australian estuaries. It should also be emphasized that statements made here are in the light of physical and chemical changes predicted so far by computer modelling, and as more information becomes available, the effects on estuarine flora and fauna can be better evaluated. Furthermore, predictions concerning the Dawesville Channel do not include immediate effects such as those associated with construction and dredging of the Channel.

EFFECTS ON THE NUISANCE ALGAE

The two types of algae that grow at nuisance levels in the Peel-Harvey estuarine system, large green algae (macroalgae or "weed"), and the microscopic blue-green alga *Nodularia spumigena*, are influenced to different degrees by different environmental factors, and so their responses to the preferred management strategy are best discussed separately.

Nodularia

The growth of this blue-green alga is favoured at salinities from about 5 to 30 ppt. It requires the element phosphorus in the form of an available nutrient compound, but unlike most other algae, is not dependent on a combined form of nitrogen in the water column, since it has special cells known as heterocysts that can use nitrogen gas dissolved in the water. The poor growth of *Nodularia* at salinities less than 5 ppt or above 30 ppt appears to be related to the inability of the heterocysts to efficiently fix nitrogen at these salinities. *Nodularia* also grows best at relatively low light levels (light levels greater than approximately 5% of full sunlight are inhibitory), and at temperatures from 16 to 30°C (Huber, 1986 a, b).

Conditions in Harvey Estuary during spring and early summer are presently ideal for this species; salinities are low, phosphorus levels are high, temperatures are favourable, and light levels are relatively low due to suspended sediments. In Peel Inlet conditions are less favourable since salinities return to marine levels (35 ppt) more rapidly, light levels are higher, and concentrations of nitrogen compounds in the water are high enough to lessen any competitive advantage *Nodularia* may have over other phytoplankton (diatoms and dinoflagellates) which cannot use nitrogen derived from the atmosphere.

With the implementation of the preferred management strategy, the salinity regime of the Harvey Estuary will become more like that of Peel Inlet, phosphorus levels in the water column will be considerably reduced, and water clarity will improve. Consequently, the period when salinities are favourable for *Nodularia* growth will be considerably shortened, the lower phosphorus levels will only be able to support smaller blooms, and light levels will be less favourable. Thus, if *Nodularia* blooms do occur, they will be of lesser magnitude and considerably shorter duration, and will be still further diluted due to increased exchange with the ocean.

Macroalgae

It is worth mentioning that the so-called "nuisance" macroalgae are a nuisance in human terms only. As far as estuarine ecology is concerned, the macroalgae provide a rich food source, and cover from predators for many estuarine animals, including crabs, prawns and the juveniles of commercially important fish.

Unlike Nodularia, the nuisance macroalgae tolerate the broad range of salinities experienced in the estuarine system, and the change in salinity regime with the Dawesville Channel is unlikely to do anything beyond allowing a few marine species (which cannot tolerate periods of low salinity) to establish. Critical factors affecting the growth of macroalgae with the implementation of the preferred management strategy will be the changes in nutrient levels and turbidity of the water.

Before the 1960's, nutrient levels in Peel-Harvey waters were too low to support nuisance levels of macroalgae, but since then nutrient levels have increased considerably. Recent research suggests that macroalgal populations in Harvey Estuary and western Peel Inlet depend on nutrients from the Harvey River, and those in eastern Peel Inlet on nutrients from the Serpentine and Murray rivers. However more than sufficient supplies of nutrients are available to support large macroalgal populations, and growth is probably now controlled more by light than by nutrient supply. Nodularia and other phytoplankton blooms have made the water so turbid during spring and summer (the main growing period for macroalgae), that these macroalgae receive insufficient light for maximum growth. The generally higher turbidity levels in the waters of Harvey Estuary are the main reason why that water body does not experience nuisance levels of macroalgae, except north of Dawesville.

Predictions on the effects of the management strategy are complicated by the possible role that the considerable bank of nutrients in estuarine sediments may play. Even though water column nutrient levels will be considerably decreased, the benthic algae may be sustained by nutrients released from underlying sediments, and it is difficult to predict precisely how long sediment nutrient reserves in the Peel-Harvey will take to deplete. Thus in the short-term the improvement in water clarity expected with the preferred management strategy may lead to an increase in macroalgal biomass in Peel Inlet, perhaps to levels similar to those experienced in the late 1970's, and macroalgal accumulations may well occur further south in Harvey Estuary.

In the longer term, as sediment nutrient reserves deplete, macroalgal levels should decrease in both Peel Inlet and Harvey Estuary. However macroalgal populations in eastern Peel Inlet may take longer to respond. Although modelling studies indicate that the Dawesville Channel will improve flushing (and therefore reduce nutrient retention) equally in Peel Inlet and Harvey estuary, eastern Peel macroalgal populations appear to depend on nutrients from the Murray and Serpentine Rivers, and a reduction in macroalgal growth in that area will also depend upon a reduction in nutrient (especially phosphorus) loading from the relevant catchments.

OTHER AQUATIC PLANTS

Aside from Nodularia and macroalgae, other types of totally aquatic plants that will be affected by the Dawesville Channel are phytoplankton, benthic diatoms and seagrasses. Phytoplankton are microscopic plants that are suspended in the water, and in addition to Nodularia, there are two other groups of phytoplankton important in the Peel-Harvey estuarine system; diatoms and dinoflagellates. Benthic diatoms are microscopic plants that live on and amongst sediments in subtidal and intertidal areas; both benthic diatom and phytoplanktonic diatoms are grazed by zooplankton, small invertebrates, herbivorous and omnivorous fish, and are important in food chains. Seagrasses, as the name suggests, resemble conventional grasses, and unlike algae have true roots, rhizomes, leaves and flowers. Seagrasses live submerged in the shallow waters of Peel Inlet, and are important in food chains, largely via detrital pathways.

Phytoplankton

The size of phytoplankton blooms is largely determined by supplies of the essential nutrients nitrogen and phosphorus. The most important change caused by the preferred management strategy to affect phytoplankton levels will be the considerable reduction in nutrient supply. The expected change in salinity is likely to affect which species within the phytoplankton community become dominant, but this alteration in species dominance is unlikely to affect estuarine ecology, and salinity changes will not of themselves affect phytoplankton levels.

The combination of the Dawesville Channel and catchment management should lead to a considerable decrease in water column nutrient levels, particularly phosphorus. This will in turn lead to a considerable reduction in the abundance of phytoplankton. Increased exchange with the ocean will further dilute any blooms that do occur.

The reduction in phytoplankton blooms should also indirectly aid in reducing the nuisance algae problem. Present phytoplankton/nutrient dynamics in the estuarine system may be summarised as follows: approximately 90% of riverflow and nutrient loading (nitrogen and phosphorus) occurs during the winter months. Diatom blooms immediately follow riverflow, trapping phosphorus which is then sedimented as senescent cells and faecal pellets. This phosphorus is recycled and supports Nodularia growth in the Harvey Estuary in late spring and early summer, and macroalgal growth in Peel Inlet. When the Nodularia blooms collapse in summer, the nutrients released support diatom and dinoflagellate blooms, and to a lesser extent the Peel Inlet macroalgae. Consequently, reductions in the size of both Nodularia and other phytoplankton blooms expected with the preferred management strategy could interact synergistically to reduce the algal problem.

Benthic diatoms

Critical factors affecting benthic diatoms that will be altered with implementation of the preferred management strategy are light and tidal dynamics. The benthic diatom communities will be little affected by expected changes in water column nutrient levels or salinity. By living on or amongst sediments, benthic diatoms have direct access to nutrients released from the sediments on or in which they live, and like phytoplanktonic diatoms, salinity changes do little except favour one species over others within the community.

The present turbidity of waters in the estuarine system, particularly in Harvey Estuary, results in benthic diatoms being most productive in shallow waters and intertidal areas. The improvement in light conditions expected with the preferred management strategy will enable benthic diatoms to become productive in deeper waters, and they will also benefit from the larger and more regularly inundated intertidal area. At present, a large proportion of the intertidal zone is an unfavourable environment for benthic diatoms, due to desiccation stress caused by irregular inundation patterns. Thus benthic diatoms will become more productive in both deeper waters and higher subtidal areas, and their importance as a primary producer in the system should increase. They may become more important primary producers than phytoplankton in the long term, although they are unlikely to exceed the expected importance of seagrasses and macroalgae.

Seagrasses

In addition to being important in food chains, seagrasses provide shelter from predators for small fish and crustaceans, and provide a range of habitats for small animals by virtue of their structural complexity (compared to algae). They are considered more aesthetically desirable than macroalgae; as they are rooted in the sediments, they are less easily washed on the shores, and when accumulations do occur, seagrass rot less offensively than macroalgae. Extensive meadows of seagrass are a feature of many estuaries with nutrient poor waters; in such estuaries a high productivity is maintained because seagrasses utilize sediment nutrients through their roots, in much the same manner as land plants do, and so they are independent of nutrients in the water (Hillman, 1985).

Important factors affecting seagrass growth are light supply, salinity and nutrient levels in the water. The last factor is an indirect effect; although seagrasses are independent of water column nutrients, high nutrient levels in the water promote phytoplankton and macroalgal growth, and these may overly the seagrasses and block out their light supply. Alternatively, high nutrient levels may cause excessive growth of algae attached to seagrasses (epiphytes), which also has the effect of shading the seagrass leaves and inhibiting growth (Cambridge, 1979).

The three seagrasses which grow in the Peel-Harvey system, *Zostera mucronata*, *Halophila ovalis* and *Ruppia megacarpa*, are all essentially subtidal plants (although *Ruppia* can tolerate occasional short periods of exposure), and are therefore restricted to waters that are sufficiently shallow for an adequate light supply to reach them. The ability to survive at low light levels varies between seagrasses; for instance *Halophila* can tolerate lower light levels than *Ruppia*, and is therefore found in slightly deeper water in Peel Inlet. The turbidity of Harvey Estuary water prevents the persistence of extensive meadows of seagrasses. The tolerance of seagrasses to low salinities also varies; *Zostera* only grows near the Mandurah Channel where waters are usually near marine salinity, *Halophila* prefers marine salinities but can tolerate short periods of low salinity, and *Ruppia* grows over a broad range of salinities from freshwater to hypersaline.

The preferred management strategy will result in several changes favourable to seagrasses. Improved light conditions will allow seagrasses to extend to deeper waters in Peel Inlet. In the Harvey Estuary, improved light conditions will allow *Ruppia* to re-establish, the more marine salinity regime will be favourable to the establishment of *Halophila*, and *Zostera* will probably establish near the Channel. In addition, lower nutrient levels in the water will reduce epiphytic algal loads. The only disadvantages will be the decrease in permanently submerged areas, with some loss of *Ruppia* beds from the shallows of Peel Inlet due to increased exposure. The temporary increase in macroalgae may also result in accumulations overlying the seagrass beds.

Although it is not possible to predict how soon new areas of seagrass will develop in the estuarine system, extensive beds of Halophila may establish in Harvey Estuary in as little as 2 years, as is reported to have occurred in Leschenault Inlet with the opening of a channel to the sea in 1951 (Glover, 1979). If extensive beds of seagrass develop as expected, the primary production of the system may actually increase even though the waters become less eutrophic. Research in the Swan River estuary has found that areas covered by dense beds of Halophila may be up to 5 times more productive than waters containing only phytoplankton, and a number of overseas studies have also indicated that the productivity of seagrass meadows in oligotrophic waters exceeds that of phytoplankton and macroalgae in the most eutrophic of estuarine waters (Round, 1984; Hillman, 1985). The development of extensive seagrass meadows will also provide other ecological benefits, as discussed previously.

WETLAND VEGETATION

Wetland or fringing vegetation occupies the upper tidal zone from about mean water level (MWL) to just above extreme high water mark (EHWM). Fringing vegetation plays an important role in estuarine ecology since it stabilizes the shoreline, provides a sheltered habitat for estuarine birdlife, and represents a major plant nutrient pool. The Peel-Harvey system has only three extensive areas of fringing vegetation: near the southern end of the Mandurah channel, eastern Peel Inlet, and southern Harvey Estuary. The remainder of the system carries only a narrow fringe of wetland vegetation, in part due to the steep slope of some shores (and therefore narrow upper intertidal zone), and in part because of urban and agricultural development. The lack of large fringing wetlands makes what little is left even more important.

There is a zonation of species within the fringing vegetation, related to increasing distance from the water's edge and increasing elevation. This zonation is strongly influenced by the salinity of the soil, which in most estuaries depends on elevation above MWL and therefore on frequency of tidal inundation. Broadly speaking, only plants which can tolerate high salinities and a high degree of waterlogging are found close to the water's edge. Higher ground is less frequently inundated and soil salinities are lower, so that plants which are less tolerant of high salinities and waterlogging may become established. However, in areas of higher ground that are not free draining pools of saline water may be left stranded when the tide recedes, and evaporate to dryness, leaving a crust of salt crystals. Very few species can grow in such highly saline areas.

The species which dominate the fringing vegetation of the Peel-Harvey system have to cope with inundation by hypersaline water in summer and by almost freshwater in winter. The tidal characteristics are also such that the plants may be either waterlogged or exposed for days at a time.

The samphire Sarcocornia quinqueflora is common on clayey soils in areas of low relief that are frequently inundated. This species tolerates high salinities and extreme waterlogging, but requires protection from direct wave action; it forms extensive meadows in shallow depressions behind low beach ridges, and is the pioneer species that colonises new areas when offshore spits or sandbars develop sufficiently to dampen wave action in the shallows between sandbar and shore. In depressions at slightly higher elevations, the samphires Sarcocornia blackiana and Halosarcia spp are common. These species are less frequently inundated but tolerate higher soil salinities than S. quinqueflora, because as previously mentioned, ponding of saline water occurs when the tide recedes, and subsequent evaporation concentrates the salt.

The rushes Bulboschoenus caldwellii (formerly Scirpus maritimus) and Juncus kraussii are less salt tolerant than the samphires, but tolerate high degrees of inundation, and do not require protection from wave action. They prefer sandier, well-drained soils, and commonly form narrow zones on the higher ground of beach ridges in the Peel-Harvey (behind which are depressions occupied by samphires). They are also the dominant species on the relatively steep sandy shores of the Spearwood dune system (the geomorphic unit of the western shores of the Peel-Harvey, and the northern half of eastern Harvey Estuary). The relief in these areas is usually too steep for samphires, and a mobile groundwater contributes to maintaining relatively low salinities. On the other hand, extensive areas of rushes in low lying areas at the southern end of Harvey Estuary are probably maintained by the freshwater outflow of the Harvey River, which never entirely ceases flowing, even in summer. In the past decade, B. caldwellii has replaced some areas of J. kraussii. There is some indication that B. caldwellii can tolerate higher winter salinities than J. kraussii (since it remains dormant over winter as an underground corm), and may have been favoured by the recent series of dry winters, and therefore higher winter salinities.

Important changes brought about by the preferred management strategy that will affect the fringing vegetation are the increased daily and seasonal tidal amplitudes, the less extreme salinity regime, and anticipated changes to macroalgal levels. Since MWL will not change, the present shoreward edge of the fringing vegetation should remain unaltered, unless sedimentation or erosion patterns change within the estuary. However EHWM will increase by approximately 20 cm, which will allow fringing vegetation to extend to slightly higher ground. This will be a relatively slow process, and is unlikely to be noticeable except in areas of low gradient, such as eastern Peel Inlet and southern Harvey Estuary.

The increased daily tidal range will result in a more regular pattern of inundation and exposure of the upper intertidal zone, which will lead to a decrease in soil salinities, especially when combined with the less hypersaline conditions in summer/autumn. The more frequent inundation and exposure will help to flush salt accumulated because of hypersaline conditions, particularly in poorly drained areas, and there will be considerably less time for evaporation to concentrate salt between inundation events. This will allow less salt tolerant plants to move into areas where they previously could not establish. The changes in species zonation will probably be accompanied by an invasion of opportunistic exotics (eg. Atriplex hastata, Carpobrotus edulis, Watsonia bulbilifera) at least in the short term.

Increased estuarine salinity in winter is unlikely to cause any significant change, since during periods of river discharge in winter the fringing vegetation tends to be inundated by the upper layer of low salinity water (prior to wind mixing events), although B. caldwellii may replace J. kraussii to an even greater extent.

In most respects, the preferred management strategy will lead to an improved environment for the fringing vegetation, the status of which can be expected to improve. The more regular pattern of inundation and exposure will be more favourable than the present pattern of long periods of inundation and water logging, followed by long periods of exposure and desiccation. There are only two unfavourable aspects. The first is the possibility that the increased macroalgal accumulations expected in the short term may be washed onto the shore and smother the fringing vegetation, as happened in eastern Peel Inlet during the 1970's. If necessary, susceptible areas could be protected by mesh fencing, and thought should be given to reestablishing fringing vegetation in previously denuded areas, including those affected by the present weed harvesting programme. The second unfavourable aspect is the occasional inundation of areas of fringing vegetation that are presently completely dry in summer. This may cause an extension of the mosquito breeding season, and the topography of two areas in particular, Geogerup Lake and Yunderup Canals, should be investigated with this point in mind.

THE INVERTEBRATE FAUNA

The invertebrate fauna can be broadly separated into zooplankton and benthic invertebrates. Zooplankton are microscopic animals that live suspended in the water column, where they feed principally on phytoplankton and/or other zooplankton, and are in turn fed upon by small fish. Benthic invertebrates are small animals which live on or in the estuarine sediments and weed beds (macroalgae or seagrass), and feed primarily on detritus microscopic algae, and/or each other. Benthic invertebrates include worms, shrimps, tiny crustaceans and molluscs, and are themselves important food items in the diets of many fish and birds. In most estuaries, including the Peel-Harvey system, benthic invertebrates constitute by far the greatest proportion of invertebrate fauna. They also constitute a major link between estuarine plant productivity and larger consumers such as fish and birds, since they process the large amount of organic detritus generated by estuarine plants.

Zooplankton

Zooplankton levels usually depend on phytoplankton levels (their food source) and on the residence time of water in estuaries, but residence times are of little importance in Peel Inlet and Harvey Estuary since they are too long and because most zooplankton species migrate to the bottom of the water column during the day. Salinities have little effect on zooplankton abundance.

In the Peel/Harvey system phytoplankton levels are greatly in excess of the requirements of zooplankton populations, and so the expected fall in phytoplankton levels following construction of the Dawesville Channel should not directly affect zooplankton levels very markedly. The more marine salinity regime may cause the disappearance of some species which prefer the low salinities that presently occur in winter and spring, but these will be replaced by other estuarine and oceanic species. For instance in Harvey Estuary, cladoceran species which prefer salinities less than 5 ppt will probably be replaced by the estuarine copepods *Sulcanus conflictus* or *Gladioferens imparipes* in winter, and estuarine species will probably be succeeded by other copepods such as *Acartia* by late spring. It is also worth noting that the present blooms of *Nodularia* are not grazed by zooplankton; the blue-green alga appears to be unpalatable. The expected disappearance of *Nodularia* with the implementation of the preferred management strategy, and replacement by diatoms and dinoflagellates (which are grazed) presumably reappearing in its stead, will favour zooplankton. However even if zooplankton levels decrease slightly, this is unlikely to be of significance to overall estuarine ecology, since benthic invertebrates are much more important.

Benthic Invertebrates

This term applies not only to animals which live on the bottom but also to those which live on plants and even to small animals, such as shrimps, which at times swim freely in the water. Moreover some that are conventionally regarded as planktonic may spend much of the time on the bottom, as was mentioned above in respect of copepods. For convenience, benthic invertebrates are often divided into arbitrary size groups. The macrofauna are those animals retained by a 500 m (0.5 mm) sieve, meiofauna those then retained by a 50 m sieve, and microfauna those which pass that sieve. The meiofauna consists largely of nematodes, ostracods and harpacticoid copepods, and the microfauna of Protozoa. The following discussion is concerned mainly with the macrofauna, principally small crabs, shrimps, amphipods and worms.

All estuaries have a very restricted fauna as compared with the littoral of the open sea, and in Peel-Harvey the number is particularly small, even as compared with the estuary of the Swan River, but still greater than in other estuaries of the south west where connection with the sea is more restricted. While the main reason for the small number of species is probably the extreme range of salinity, other factors such as substrate type, tidal range and productivity contribute to determining what species are present and their abundance.

Salinity

Four main categories of benthic animals are recognised with respect to their salinity tolerance (Chalmer *et al*. 1976): marine species which only tolerate salinities near that of sea water (35 ppt), species of marine affinity which live both in suitable marine environments and can survive somewhat lower salinities in estuarine waters, species of exclusively estuarine affinity (species which do not live either in marine or freshwater environments), freshwater species with limited tolerance of saline conditions. These categories are useful but somewhat arbitrary.

In the Peel-Harvey estuary the marine mussel, *Mytilus edulis*, sometimes settles on piles in summer, but rarely survives the lower salinities of winter. Several marine affinity species, such as the bivalves *Sanguinolaria biradiata* and *Tellina deltoidalis*, are present though not abundant, while on the other hand *Spisula trigonella* is sometimes very abundant, but disappears with prolonged low salinity. True estuarine species are much the most abundant: the bivalves *Xenostrobus securis*, *Arthritica semen* and *Anticorbula amara*, and of gastropods *Hydrocccus brazieri*. To which group the abundant worms and amphipods belong is uncertain but probably most should be regarded as estuarine. There are no freshwater species in the estuary.

Substrate

The estuary has restricted range of substrate types; principally sand in the shallows, sandy mud in the deeper water of Peel Inlet, organic mud in deeper parts of Harvey Estuary, and the macrophytes (seagrasses and algae). In consequence a number of species which, with a greater range of substrate types, might be present, are absent or rare. There are a few rocks in the shallows and these support a few species seldom found elsewhere (e.g. *Mercierella enigmatica*).

Depth and Tidal Range

The fauna of intertidal areas is sparse, though the few species present such as *Hydrococcus* and *Arthritica*, may be abundant at the lower levels. The availability of the intertidal area for colonisation depends greatly on duration of exposure at low tide, which can be prolonged with the present tidal regime in the estuary. The majority of species are subtidal, on the sand flats; the somewhat poorer fauna of the deeper water may be attributable more to substrate type than to actual depth of water.

Type and Availability of Food

Despite the great abundance of macrophytes few invertebrates feed directly on either seagrasses or macroalgae, though amphipods can be seen feeding on *Ulva*, and others feed on epiphytes on the plants. Many are deposit feeders eating the plant detritus, with its abundant bacterial flora, and diatoms of the surface sediment, whilst others are suspension feeders taking principally phytoplankton from the water. A number of species are carnivores. The relative abundance of the different species will clearly depend greatly on the availability of the appropriate food type. The present abundance of detrital material clearly favours deposit feeders; densities of as high as 100 000 per m^2 of *Hydrococcus* (Chalmer and Scott, 1984) have been recorded. However, despite the abundance of benthic fauna in the estuary, the results of a recent survey indicate that they only account for 5% of daily primary production (Atkinson and Edward, 1984).

It is doubtful if there have been any significant changes in the species composition of the fauna of the estuary during the last 50 years, apart from the appearance of *Spisula* probably during the 1960s. However there have undoubtedly been great changes in the relative abundance of species and their distribution in the estuary as a result of the progressive eutrophication and consequent changes in composition of the flora, the increase in detrital material and phytoplankton, and the periodic serious deoxygenation of the bottom water and associated massive mortality of benthic fauna. An estuarine fauna is very resilient because of the great changes to which it is naturally exposed, especially from the variation in salinity, on a daily, annual and longer term time scale, and the Peel-Harvey fauna is no exception in this respect.

Table 1 lists the common species of benthic macrofauna. Of these, three species of worms, four molluscs and the three amphipods probably constitute over 90% of the biomass.

Table 1. Common benthic invertebrates of the Peel Harvey estuary.

ANNELIDA: Polychaeta	
Capitellidae	*Capitella sp.*
Orbinidae	*Scoloplos simplex*
Spionidae	*Prionospio* sp.
Serpulidae	*Mercierella enigmatica*
Nereidae	*Ceratonereis erythraeensis*
Eunicidae	*Marphysa sanguinea*
MOLLUSCA: Bivalvia	
Mytilidae	*Mytilus edulis*
	Xenostrobus securis
Erycinidae	*Arthritica semen*
Tellinidae	*Tellina deltoidalis*
Psammobiidae	*Sanguinolaria biradiata*
Mactridae	*Spisula trigonella*
Lyonsiidae	*Anticorbula amara*
MOLLUSCA: Gastropoda	
Hydrobidae	*Potamopyrgus sp.*
	Hydrococcus brazieri
Nassidae	*Nassarius pauperatus*
Amphibolidae	*Salinator fragilis*
CRUSTACEA:	
Amphipoda	*Corophium sp.*
	Paracorophium sp.
	Melita sp.
Mysidae	Mysid
Decapoda	*Palaemonetes australis*
INSECTA:	
Chironomidae	*Chironomus sp.*

Anticipated Effects of the Proposed Management Measures

The reduction in primary production is unlikely to greatly affect productivity of the benthic fauna in the short term because of the present great excess of primary over secondary production and the abundance of detrital material on which many species are dependant. In the longer term there may well be a change in relative abundance of the various species because of the change in composition of the flora, from algae to seagrasses, and perhaps some overall reduction in abundance.

The change in salinity regime resulting from construction of the Dawesville Channel has the potential to increase both the number of marine affinity species entering the estuary and their abundance, particularly in and near the two channels, and a few marine species may be able to establish in the estuary, at least on a seasonal basis. However it is not anticipated that the changes will be great and the estuary is likely to continue to be dominated by the present suite of estuarine species, as is the case in Leschenault Inlet.

The low salinities experienced in winter not only restrict the diversity of species that can persist in the estuary, but wet winters with very low salinities can result in considerable mortality. Opening the channel will reduce the degree and duration of these low salinity periods, thus preventing this mortality. With the cessation or infrequent occurrence of Nodularia blooms, there will no longer be the massive mortalities associated with the collapse of these blooms.

In summary, the successful species of benthic fauna are very tolerant of the extreme environmental conditions which prevail. With the expected change to a less extreme environment they may be expected to persist as the dominant species despite the incursion of more marine fauna. They are common to other estuaries of the south west. The addition of the less tolerant marine affinity species is unlikely to present any threat to existing species and the greater number of species present may well increase the stability of the ecosystem. These conclusions are supported by the evidence available from Leschenault Inlet, where a new channel was cut through to the sea in 1951, and from the Swan River estuary from which the bar and tidal delta were removed in the 1890s. The benthic fauna of both these estuaries is in a healthy state, and while changes in the fauna have occurred there is no reason to think that they have been detrimental to the ecology of the estuaries.

FISH LIFE

The species composition of fish and large crustaceans in the Peel-Harvey estuarine system is very similar to that of the Swan River estuary. Species can be divided into three main groups, according to the way they utilize the estuaries:

Group 1 : species which are capable of spending their entire life in the estuary.

Group 2 : species whose juveniles mature in estuaries. The mature adults mate and spawn at sea, and the juveniles subsequently move into estuaries. The juveniles are capable of remaining in the lower reaches of estuaries during years of reduced freshwater flushing in winter, but the low salinities experienced during years of heavy freshwater flushing may force them into coastal waters.

Group 3 : species which only use the lower reaches of estuaries as mature or maturing adults, during those months when marine salinities prevail.

Species belonging to Group 2 form the basis of the commercial and recreational fisheries of the Peel-Harvey system, and include the mullets, the whitings, blue manna crabs and king prawns. In a more general sense, the bulk of fish and large crustaceans are recruited from the ocean; they move in from coastal waters as either juveniles or adults (Groups 2 and 3), and utilize the system when salinities are relatively high (greater than approximately 1/2 marine salinity). An obvious consequence of this is that species diversity and abundance are lowest in late winter/early spring.

The two different types of nuisance algae in the Peel-Harvey system have had quite different effects on the fish and crustaceans. Although Nodularia blooms have been a problem during the 1980's, professional fish catches have continued to increase. However, there is little doubt that fish avoid areas of dense Nodularia blooms, and those that stray into such areas soon die. Macroalgae, on the other hand, appear to have had a beneficial effect on the fishery. This effect appears to be not so much macroalgae supplying additional food for fish, rather the algal detritus provides abundant food for the benthic invertebrates on which fish mainly feed. The macroalgae also afford cover for small fish from predators.

The main effects of the proposed management strategy on fish and crustaceans can be summarized as follows:

i) The additional ocean entrance (the Dawesville Channel) will provide a further avenue for the recruitment of blue manna crabs, king prawns and fish from Groups 2 and 3. It is difficult to predict the extent of utilization of the new entrance.

ii) The more marine conditions in Harvey Estuary will result in a greater variety of fish species. Longer periods of marine conditions will also lead to prolonged colonization of Harvey Estuary by species from Groups 2 and 3, including commercially important species such as blue manna crab (Portunus pelagicus), cobbler (Cnidoglanis macrocephalus), yelloweye mullet (Aldrichetta forsteri) and tailor (Pomatomus saltator). However the expected changes in salinity are not likely to favour other species such as the sea mullet (Mugil cephalus), which feeds mainly on detritus and is presently more abundant in Harvey Estuary than Peel Inlet, and appears to be favoured by lower salinities. There is also evidence from other parts of Australia that the juveniles of the western king prawn (Penaeus latisulcatus), which utilize the Peel-Harvey during the summer months, prefer salinities from seawater strength to hypersaline conditions. A lessening of the summer hypersaline conditions may make the system less attractive to this commercially important species. The ecology of juvenile king prawns in the system and the adjacent ocean is being studied with this point in mind, as is the ecology of the school or greasyback prawn (Metapenaeus dalli).

iii) The expected increase in daily and seasonal tidal amplitudes will reduce the area of shallows permanently under water, and produce more extensive intertidal areas. Both of these changes are likely to affect the manner in which fish and crustaceans utilize the shallows, which are a favoured feeding area.

iv) The expected reduction in Nodularia blooms should reduce the incidence of fish and crustacean deaths, and allow greater numbers of juveniles and adults to be distributed in areas previously affected by Nodularia. The increase in macroalgae expected in the short term could also result in increased numbers of fish and crustaceans, but the expected longer term reduction in macroalgae levels has the potential to cause a corresponding drop in numbers, more especially of sea mullet.

v) The expected changes in the aquatic plant and benthic invertebrate communities may in turn affect fish and crustaceans. The favourable effects of increased macroalgae levels are mentioned above, and the predicted increase in seagrass meadows should have a similar beneficial effect. The effect of expected changes in the dominant type of aquatic plant(s) in the system and therefore on detritus composition, and in the species composition of the benthic invertebrate community, are harder to predict. However, there is a wide variety of detrital food resources and benthic invertebrates throughout southwestern Australian estuaries, and most fish and crustaceans display a high degree of opportunism in their feeding habits. Therefore since neither total plant productivity nor benthic invertebrate abundances are expected to fall significantly, anticipated changes to the composition of these communities should not affect commercial species of fish and crustaceans greatly.

BIRD LIFE

Predictions on the effect of the Dawesville Channel upon waterbirds are highly speculative, in part because these birds will be affected by the changes to most of the categories of estuarine flora and fauna discussed so far, and in part because there are so many gaps in existing knowledge about waterbirds of the Peel-Harvey system. What is certain in that in terms of both numbers of birds and species diversity, the system is the single most important waterbird site in the south-west of Western Australia, and any deleterious effects should be viewed seriously.

Significant gaps in waterbird knowledge include the composition of diets and the way in which the birds utilize the system (feeding and roosting patterns, what water levels are preferred, etc). There is also very little known about the role of the system in a regional or international context. For instance, the system presently experiences only minor daily tidal fluctuations, and its extensive areas of slow-changing shallow flats are believed to be utilized by many migratory birds that are forced from nearby estuaries such as Leschenault Inlet or the Swan River estuary during occasional periods of continual high tides in summer. These same extensive areas of shallow flats may also be extremely important to migratory birds during pre-migratory fat deposition in late summer/early autumn, since feeding opportunities between Peel-Harvey and Shark Bay are limited at this time of year.

Although the regional and international role of the Peel-Harvey estuarine system is yet to be assessed, reasonable guesses can be made concerning the diet of waterbirds, and the way in which they utilize the system, on the basis of general information from Australian and overseas research. These will of course remain speculative until the necessary research is carried out, but the following comments on various types of waterbirds can be made:

i) Migratory waders feed mainly on intertidal areas at low tide, but may also be found in shallow waters on inland, non-tidal wetlands. The lack of daily tides in the Peel-Harvey estuarine system means that these species may feed uninterrupted in suitable depths of water for many days at a time during the September to April period they visit our shores. However since they also feed during receding, low or advancing tides in other countries on their migratory path that may experience twice daily tides, they are unlikely to be affected by the introduction of daily tides in the Peel-Harvey, and their principal food items (benthic invertebrates) are also unlikely to decrease. The introduction of daily tidal variation will, however, decrease the available area of favoured roosting sites (sandy cays, spits) during periods of high tide, and may allow boat access into previously undisturbed areas. Thought should be given to providing additional roosting sites (possibly using dredge spoil) in areas of difficult access.

ii) Resident waders are usually found in shallow inland (and therefore non-tidal) wetlands; they are rarely found in estuaries with marked tidal influence. The Peel-Harvey system is somewhat unusual in supporting large numbers of these birds, which is probably a consequence of the effective lack of daily tidal variations. The introduction of such tidal variations with the Dawesville Channel may detrimentally affect these species by limiting or interrupting feeding oportunities, or affecting accessibility of preferred prey species (benthic invertebrates).

iii) Fish-eating birds such as pelicans, cormorants and terns, are found in sizable numbers in the Peel-Harvey all year round, and feed in deeper waters than waders. It is unlikely that feeding opportunities and fish abundances will be detrimentally affected by the Dawesville Channel for these species, but roosting opportunities during high tides may be. These species also roost on sandy cays and sand bars, and may suffer from a decrease in suitable areas, and increased access by boats, during high tides when daily tidal variations are introduced.

iv) Long-legged waders feed in shallow waters on a variety of small fish, crustaceans and benthic invertebrates. They generally roost in trees near the waters edge. They are unlikely to be affected by the Dawesville Channel since suitable prey species will remain abundant, and no loss in suitable roosting trees is anticipated.

v) Waterfowl (ducks, swans) and coot are found in large numbers on the Peel-Harvey, and feed on large aquatic plants (eg. Ruppia and some macroalgae) and a variety of benthic invertebrates. These species will be less affected by a reduction in roosting sites with the Dawesville Channel, since most species "loaf" on the water. However unlike other birds discussed so far, waterfowl depend to some extent on access to low salinity water for drinking. Important sites for this include the mouths of Harvey River and Coolup Drain, but should be unaffected by the Dawesville Channel since they never cease flowing.

vi) Birds of the rushbeds are few in number, but the extensive rushbeds at southern Harvey Estuary may be an important sheltering site for other waterbirds during high winds, and the seeds of rushes may be an important food source. It is not anticipated that areas of rushes will decline due to changes caused by the Dawesville Channel.

vii) Gulls are omnivorous scavengers, and are most unlikely to be adversely affected by the Dawesville Channel.

SUMMARY - THE WELLBEING OF THE ESTUARY

There is little doubt that the proposed management measures, catchment management and the Dawesville Channel, will achieve effective control of Nodularia blooms. These blooms should cease almost immediately following opening of the Dawesville Channel. However there can be no guarantee that macroalgae accumulations will lessen in the short term, since the water will be clearer and it will probably take some years to exhaust the large supply of phosphorus in the surface sediment.

The remaining estuarine plants, including benthic diatoms, seagrasses and fringing vegetation, are all likely to benefit from the proposed management strategy. Benthic diatoms and in particular seagrasses are expected to extend their distribution within the system, and the status of fringing vegetation is expected to improve. Zooplankton levels are expected to change little, nor should benthic invertebrates be detrimentally affected to any degree; the successful species of this latter group are very tolerant of the present extreme environmental conditions in the system, and the Dawesville Channel will render the environment less extreme.

The effects on fish and birds are less easy to predict. Beneficial aspects of the proposed management strategy for fish and crustaceans include an additional entry point to the system for the juveniles and adults of many commercially and recreationally important species, the reduction of Nodularia blooms, the extended period of favourable salinities, and the expected short-term increase in macroalgae levels. On the other hand, the higher winter salinities expected in Harvey Estuary may adversely affect some species, including the commercially important sea mullet, and less hypersaline conditions in summer may adversely affect king prawns.

The major group of waterbirds likely to be detrimentally affected by the proposed management strategy is resident waders. These are usually found in inland, non-tidal wetlands, but large numbers are present in the Peel-Harvey estuarine system, probably because of the small daily tidal variations. Other groups of birds should be less affected since the extensive areas of tidal flats will if anything increase, although feeding patterns will have to adjust to daily tidal fluctuations. Major dietary items should also remain abundant. Detrimental changes could be a decrease in area of suitable roosting sites (sandy cays and spits) during high tides when daily tidal variations are increased, and increased access by boats to presently undisturbed areas. Management consideration should be given to these potential problems.

In an overall sense, the proposed management strategy will have more beneficial than detrimental effects on estuarine ecology. The major "detrimental" effects, including the expected short-term increase in macroalgal levels, and possible declines in numbers of some commercially important fish and crustaceans (sea mullet and king prawns), are more detrimental in human terms than in terms of the wellbeing of the estuary. It is also worth pointing out that two other local estuarine systems have undergone modifications similar to the Dawesville Channel. Leschenault Inlet had a channel cut through to the sea in 1951, and the Swan River estuary had a rock bar at the mouth removed in the 1890's. There is little doubt that both systems have changed, but they are still viable, productive ecosystems. Finally, it should be emphasized that although considerable changes will be made to the Peel/Harvey system with the implementation of the proposed management strategy, this will not cause the loss of a unique environment when viewed in the context of the large number of estuaries and coastal lagoons in southwestern Australia, and the correspondingly large range of salinity and tidal regimes, and suites of biota.

RECOMMENDATIONS

If the proposed management plan is carried out, it is essential that effects on estuarine biota be monitored and related to the considerable amount of data already collected. Apart from the need to monitor changes in order to correct or minimise any deleterious effects, the scientific knowledge gained would be of enormous interest in its own right, and of considerable use in environmental management, both locally and overseas. However, it is also clear that information in certain areas would be extremely useful for a fully informed assessment of the impact of the proposed management strategy to be made. Ideally, the following areas should be investigated:

(i) Sediment movement expected with the opening of the Dawesville Channel. There is no information available on how quickly the fine suspended sediments in Harvey Estuary may be lost with increased oceanic exchange, or whether an influx of marine sediments, and/or changes in erosion/sedimentation patterns with increased tidal action will alter the present shoreline. The former will affect water clarity and therefore most aquatic plants, and the latter will affect the fringing vegetation.

(ii) The topography of low-lying areas near Goegerup Lake and Yunderup Canals. More frequent inundation of the fringing vegetation in these areas could lead to an extension of the mosquito breeding season.

(iii) The ecology of the king prawn and greasyback prawn. Predictions about the effects on these commercially important species are severely hampered by a general lack of knowledge on their salinity preferences and habits within the Peel-Harvey.

(iv) Waterbird diets, and the ways in which different species utilize the system. Although educated guesses about waterbird habits can be made, concrete facts would be considerably better.

ACKNOWLEDGEMENTS

A large number of people contributed a considerable amount of time and effect in helping the author to prepare this report. The freely given advice and encouragement of the following people in particular was much appreciated:

Mr R. Atkins	Waterways Commission
Dr M. Atkinson	University of Western Australia, Dept. of Zoology
Mr D. Backshall	Environmental Consultant
Mr M. Bamford	Murdoch University, School of Environmental and Life Sciences
Dr P. Birch	Department of Conservation and Environment
Dr P. Chalmer	Le Provost, Semeniuk and Chalmer, Environmental Consultants.
Dr D. Gordon	University of Western Australia, Dept. of Botany
Dr E. Hodgkin	Department of Conservation and Environment
Ms A. Huber	University of Western Australia, Department of Soil Science
Mr R. Jaensch	Royal Australasian Ornithologists Union
Mr J. Lane	Department of Fisheries and Wildlife
Dr R. Lenanton	Department of Fisheries and Wildlife
Mr N. Loneragan	Murdoch University, School of Environmental and Life Sciences
Mr R. Lukatelich	University of Western Australia, Centre for Water Research
Assoc. Prof. A. McComb	University of Western Australia, Department of Botany and Centre for Water Research
Mr R. Masini	University of Western Australia, Dept. of Botany
Ms E. Moore	Department of Conservation and Environment
Mr L. Pen	Murdoch University, School of Environmental and Life Sciences
Mr J. Penn	Department of Fisheries and Wildlife
Mr G. Tong	University of Western Australia, Centre for Water Research
Dr D. Walker	University of Western Australia, Dept. of Botany
Dr F. Wells	Western Australian Museum

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