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IMPACTS OF PROPOSED DEVELOPMENTS ON THE BENTHIC MARINE COMMUNITIES OF GEOGRAPHE BAY

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Impacts of proposed developments on the benthic marine communities of Geographe Bay

D I Walker, R J Lukatelich and A J McComb

Department of Botany and Centre for Water Research
University of Western Australia
Nedlands WA 6009

Environmental Protection Authority
Perth, Western Australia
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TABLES

FIGURES

i. SUMMARY

The potential environmental impacts of the following development proposals on the dominant benthic marine communities of Geographe Bay have been assessed:

(i) subtidal sand mining
(ii) the Port Geographe development, and
(iii) possible reopening of the Vasse and Wonnerup estuaries.

Geographe Bay is dominated (ca. 70%) by monospecific meadows of the seagrass *Posidonia sinuosa* Cambridge and Kuo, with smaller areas of other seagrasses, *Amphibolis griffithii* (Black) den Hartog and *Amphibolis antarctica* (Labill.) Sonder ex Aschers, from approximately 2m to 14m depth. Below 14m, seagrasses become sparse and patchy in distribution, with plants present in small clumps. The meadows have conspicuous "blowouts", caused by water movement which may coalesce to form transverse furrows, 100-300m wide. These seagrasses are both physically and biologically significant to the ecology of near-shore environments.

The impacts and possible consequences of the proposed developments are considered. Sub-tidal sand-mining may result in physical removal of seagrass, further losses due to indirect dredging effects and, possibly, heavy metal contamination of filter feeders. The Port Geographe development may cause changes in coastal processes which may affect sediment movements and seagrass distribution. However, only sparse patches of *Posidonia sinuosa* and *Amphibolis* spp persist in the adjacent subtidal, and these patches are relatively small. Only approximately 4 ha of seagrass would be lost due to accretion/erosion of sediment adjacent to the structure, although there may be further losses associated with construction and dredging. Consequences associated with loss of seagrasses are related to their physical and biological significance to the environment. Any loss of seagrass in the shallow subtidal of Geographe Bay is likely to have consequences for shoreline stability.

The Vasse and Wonnerup estuaries together constitute one of the most important temporary bird refuges in southern Western Australia, although nutrient concentrations suggest that they are eutrophic. Removal of the floodgates would increase their aesthetic values, by reducing nutrient and chlorophyll concentrations in the water column as a consequence of increased flushing. Re-opening the estuaries would also allow the estuaries to serve as bird refuges for the entire dry season and to function as fish nurseries which may increase fish stocks in Geographe Bay. Raising the water level in the estuaries may reduce the flow of fresh groundwater into the estuaries and reduce the rate of depletion of any groundwater mound built up by winter rainfall recharge in the dunes. River runoff should be of sufficient magnitude to flush the salt water from the estuaries each winter.

Alternatives to totally opening the estuaries include replacing the existing floodgates with automatic storm-surge gates or the construction of a continuous levee bank around both estuaries.If a decision is made to replace the existing floodgates with similar structures, serious consideration should be given to relocating the floodgate on the Vasse estuary further west. Opening the Vasse and Wonnerup estuaries should have little environmental impact on Geographe Bay.

1. OBJECTIVE

To assess the potential environmental impacts of the following development proposals on the dominant benthic marine communities of Geographe Bay

- (i) subtidal sand mining
- (ii) the Port Geographe development, and
- (iii) possible reopening of the Vasse and Wonnerup estuaries.

2. THE MARINE BENTHIC COMMUNITIES OF GEOGRAPHE BAY

2.1 GENERAL ENVIRONMENT

Geographe Bay is a relatively protected embayment which is north-facing, and so the southwesterly swell which prevails along the south-western Australian coast is refracted around into the bay. The sedimentary geology of the bay has been described by Searle and Logan (1978), and in summary the area has a Holocene sediment veneer (mean thickness, 1m) overlying Pleistocene limestones and clays. There is a gently shelving (2 m/km) nearshore region, which opens onto the inner shelf plain.

2.2 THE BENTHIC COMMUNITY

Geographe Bay is dominated (about 70%) by monospecific stands of the seagrass *Posidonia sinuosa* Cambridge and Kuo, with smaller areas of other seagrasses, *Amphibolis griffithii* (Black) den Hartog and *Amphibolis antarctica* (Labill.) Sonder ex Aschers., and several minor species, which have irregular distributions both spatially and temporally, and are generally found in sand patches. Figure 1 provides a seagrass cover map, and Table 1 a species list.

Table 1 Seagrass species found in Geographe Bay

Amphibolis antarctica (Labill.) Sonder ex Aschers.
Amphibolis griffithii (Black) den Hartog
Halophila ovalis (R.Br.) Hook.f.
Heterozostera tasmanica (Aschers.) Dandy
Posidonia angustifolia Cambridge and Kuo
Posidonia australis Hook.f.
Posidonia coriacea Kuo and Cambridge
Posidonia ostenfeldii Ostenfeld
Posidonia sinuosa Cambridge and Kuo
Thalassodendron pachyrhizum den Hartog

Seagrasses are marine higher plants which, unlike the algae have true roots, and produce flowers which are pollinated underwater. Although the production of seedlings allows colonisation of new areas, much of the spread of seagrasses and much of their growth in well-established meadows is by the vegetative production of new shoots along an underground branching rhizome system on which roots are borne (Figure 2). These roots and rhizomes provide an effective anchoring system.

The genera *Amphibolis* and *Posidonia* are most important as they are large and structurally significant in the marine habitats of Geographe Bay; they can form continuous meadows, which are present from approximately 2 m to 14 m depth in Geographe Bay. Below 14 m, seagrasses become sparse and patchy in distribution, with plants present in small clumps.

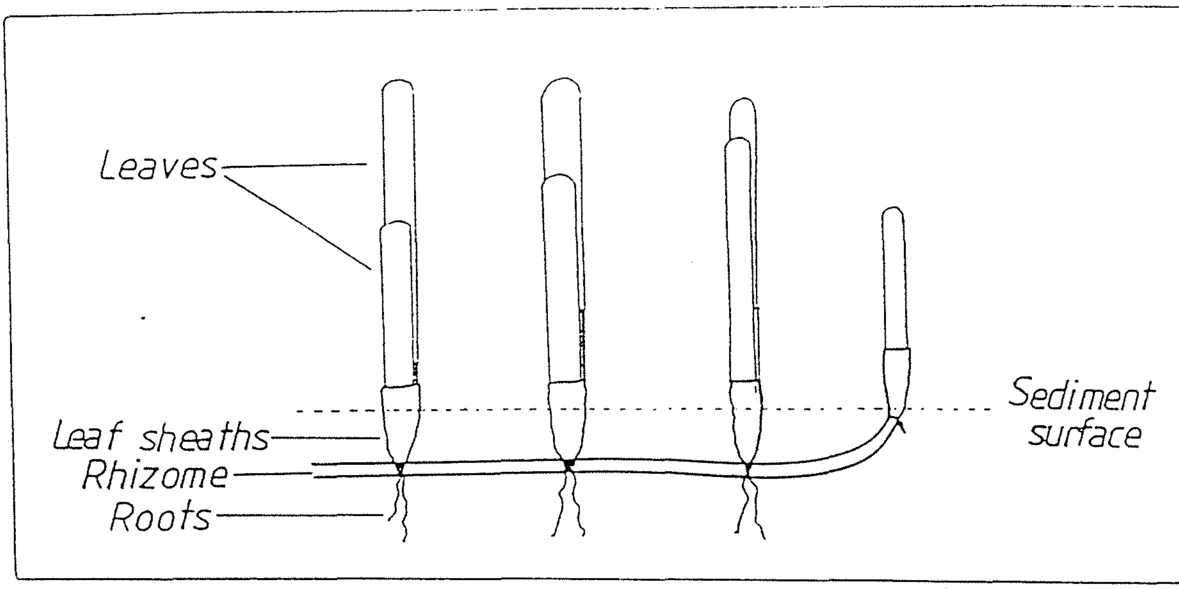

Figure 2. Stylised diagram of a seagrass, showing general structure and position relative to sediment surface.

The upper limit of seagrass distribution is determined partially by the tidal amplitude, as the larger seagrasses are unable to tolerate emersion, and also by the surf zone, as they are unable to withstand high energy environments. The lower limit of seagrasses is usually light dependent, and the offshore waters of Geographe Bay are particularly clear. The deepest seagrass record for the state of Western Australia is for *Thalassodendron pachyrhizum* den Hartog, which grows on rock, north-west of Busselton (32° 34' 20"S, 115° 15' 00" E) at 45 m; *Posidonia* spp. and *Amphibolis* spp. have been reported from 27 m (33° 31' 30" S, 115° 28' 30" E) (Cambridge 1980).

Thalassodendron pachyrhizum and *Amphibolis antarctica* are unusual among seagrasses as both can grow on rock. In Geographe Bay, both are found on scattered outcrops of limestone which are particularly common in the western bay. They are commonly found with a variety of macroalgae, particularly *Scaberia agardhii* Greville, as well as sessile invertebrates. Below 14 m sediment pockets between rock substrata are colonised by *Posidonia sinuosa*, but these are sparse. Also present are *Amphibolis antarctica* and *A.griffithii*. *Thalassodendron pachyrhizum*, and *Posidonia angustifolia* Cambridge and Kuo. Calcareous green algae are abundant.

2.2.1 SEAGRASS BLOWOUTS

Seagrass meadows have within them scoured areas of bare sand, known as "blowouts", which have been eroded from the existing meadow. A profile of a blowout is shown in Figure 3. In Geographe Bay, they are generally of a parabolic shape, varying in size from a few square metres to several hectares, oriented in a SW-NE direction, with an overhanging scarp of exposed rhizome fibres, up to 0.6 m high at the apex, tapering to the edges. The scour floor of unconsolidated sediment then rises gently to the level of the meadow. This far edge is recolonized by *Amphibolis* seedlings, which may fill the scour. If the area remains undisturbed there will be recolonization both by *Posidonia* seedlings, and regrowth from the edge of the meadow, so that *Amphibolis* is eventually shaded out. This is a very slow process as investment in below-ground anchoring material, i.e. roots and rhizomes, is very low in both genera for the first few years (Hocking *et al.* 1981) and disturbance by storms can remove all the new growth. If seedlings survive for two years, then recolonization will continue (Cambridge, 1980). The prevailing south-westerly seas tend to maintain the erosion of the scarp, so that the blowout migrates in a southwesterly direction. If recolonisation of the north-easterly edge of the blowout continues, then the size of the scour remains the same.

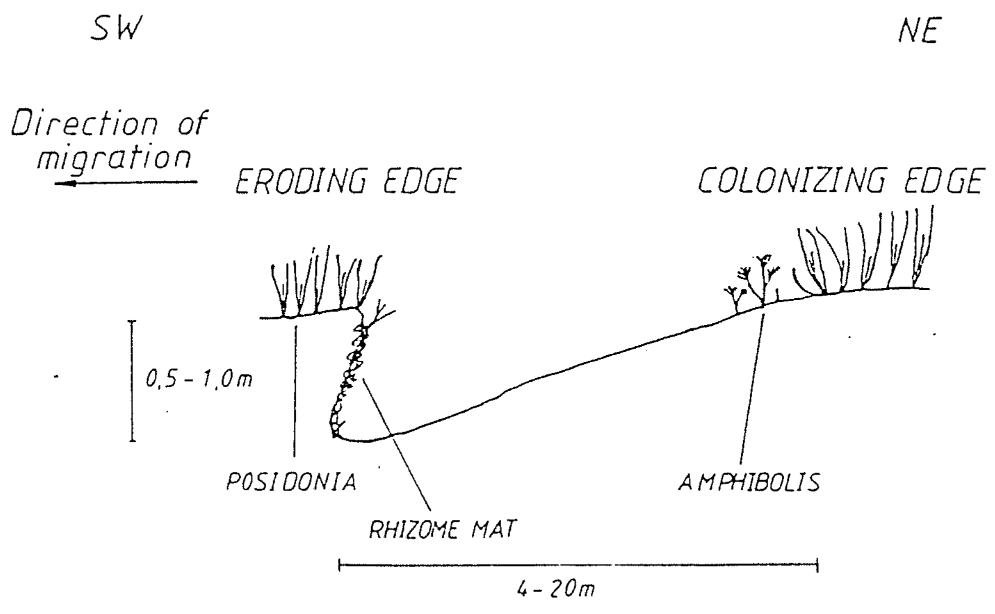

Figure 3. Profile of a "blow-out"

Recolonisation of damaged areas may never occur, as disturbance by storm events prevents the stabilisation of the seagrasses. If seagrass growth rates are reduced by pollution, or sediment dynamics are changed by dredging, the eroding edge will continue to migrate, but the recolonizing edge no longer grows fast enough and so the blowout increases in size.

Blowouts are generally a natural feature, caused by storm damage. However, given the baffling capacity of the intact meadow (Section 2.3.1), the blowouts may indicate a weakening of the seagrass in localised areas. Other factors include the energy distribution of the storm waves; biological influences such as smothering by very patchy epiphyte distributions, and possible ground-water seepage, both of which may decrease growth rates. Grazing, particularly by sea urchins, may lead to seagrass loss (Cambridge et al. 1986), but this is relatively rare. Reduced water flow in the centre of a dense canopy may reduce growth rates by limiting carbon and nutrient availability. At times of low productivity, *Posidonia* has reduced leaf number and length, decreasing the baffling capacity (Walker and McComb, in press). This increases water movement around the plants and if there is then a storm, the erosion of the material around these previously dense patches leads to localized losses. The age of the affected portion of the seagrass meadow may be relevant, and there may also be the effect of slight topography changes.

Geographe Bay has a second type of feature, described by Searle and Logan (1978) as transverse furrows, 100-300 m wide, running at angles of 290° in the eastern bay to 340° in the west, at intervals of 500-1500 m, with increased spacing to the east. The change in angle corresponds to a change in the refraction of swell wave trains around Cape Naturaliste. The furrows are similar in cross section to the scours, but the eroding scarp face may be gently scalloped, with scallop amplitudes of 5-20 m. These appear to be the result of coalescence of smaller scours. Sand lobes are associated with the longitudinal scours, and form irregular fingers within the meadow, up to 40 m long and 30 m wide. These sand lobes terminate in shallow sand bars at their landward end. The furrows also appear to be migrating southwest in a similar way to the blowouts.

However, in an area of relatively high wave energy and storm frequency, such as Geographe Bay, the recolonization process may not be as rapid as the erosional process, leading to greater areas of seagrass loss. As the area of the blowouts increase there is an increased erosional edge length. Increased sediment movement can cause localised smothering.

2.3 SIGNIFICANCE OF SEAGRASSES TO NEAR-SHORE ENVIRONMENTS

The seagrasses have a very important role to play in the ecology of the near-shore systems for a variety of reasons, which relates to their physical as well as biological impacts.

2.3.1 PHYSICAL EFFECTS

i) Seagrasses slow the rate of water flow over the bottom (Fonseca *et al.* 1982) This enhances the rate of sediment deposition within the meadow, as suspended particles fall from the water column as velocities decrease. These sediments are then bound by the network of growing rhizomes (Scoffin 1971), which stabilise an otherwise unstable environment. Seagrasses therefore allow the establishment and maintenance of sediment communities and also help prevent the erosion of these sediments.

Seagrass leaves have a high tensile strength and are also very flexible, having cell walls of pectin and cellulose (Kuo 1978), which, unlike the walls of many terrestrial plants, are not rendered inflexible by the deposition of lignin. This, in combination with a high leaf density, makes an intact meadow capable of baffling a current speed of 0.5 m s^{-1} (Fonseca *et al.* 1982), and absorbing the wave energy of a 0.6 m wave (Davies 1970). This has an influence on the adjacent beach zone, as the kinetic energy of waves is diminished or dissipated before they reach the shore (Searle and Logan 1978).

ii) The trapping capability of seagrass meadows extends to organic detritus, which is therefore kept within the system and not lost to the open ocean (Walker and McComb 1985). This detritus ensures the recycling of nutrients within the meadow and is of considerable biological significance.

iii) Most importantly, seagrass beds are significant nursery areas for commercially-valuable species. The structure provided by a seagrass canopy acts as a refuge from predation for juvenile fish and crustaceans, many of which are recruited to commercial fish populations after spending much of their growth phase in the relative protection of a seagrass meadow (Pollard 1984).

2.3.2 BIOLOGICAL EFFECTS

i) The area of seagrass leaf surfaces is up to 15 times larger than that of the bottom on which the seagrass grows (McComb *et al.*, 1981). This surface is stable, unlike the uncolonised sediments, and is available for settlement by a large number of plants and animals as epiphytes (Harlin 1975). These epiphytes are extensively grazed, both directly by fish, but also by smaller organisms, such as amphipods, which form an important part of the food chain (Lenanton *et al.* 1982).

ii) Seagrass meadows have high rates of productivity (1-5 g dry wt m^{-2} d^{-1}) which are maintained by rapid production of new leaves, and the shedding of old leaves. This production is thus a "conveyor belt" of continously renewed substrate (Walker, 1985). This is particularly significant as a contribution to sediment production, as calcareous epiphytes are shed and retained within the seagrass meadows, and new substrate is available for colonisation (Walker and Woelkerling, in press).

iii) Most seagrass production is not consumed directly, but is broken down, providing a massive input to the detrital food chains. The microbial populations associated with this decomposition also constitute an energy- and nutrient-rich food source. This particulate material is utilised by filter feeding animals which again may be important components in food chains.

iv) The high biomass of the meadows (1-2 kg dry weight m^{-2}, above-ground biomass) makes the seagrasses an important nutrient pool, as they absorb nitrogen and phosphorus both from the water column and from the sediments. These nutrients can enter the food chain via the mechanisms cited above, and the efficient recycling both within the plants themselves, and within the meadows by decomposition, allows high rates of production to be maintained in nutrient-poor conditions (McComb *et al.* 1981).

3. DEVELOPMENT PROPOSALS

3.1 SUBTIDAL SAND MINING

The mining leases are for exploration within an area which includes sand, seagrass meadows, limestone reef and limestone outcrops. The methods of exploration are likely to be by coring, although in the absence of a Notice of Intent or an ERMP, it is hard to determine the form and frequency of this coring. In general, however, such cores are of small diameter, and therefore unlikely to cause significant damage to the seagrass communities. Any other form of exploration would need to be detailed before an assessment could be made.

It is impossible to assess the precise impact of extractive mining without details of the areas chosen on the basis of the exploratory survey. Damage would be related to the area involved, the composition of the marine benthic community in the area and the method of extraction. In the absence of these details, the following comments are of necessity general.

3.1.1 NATURE OF IMPACTS AND POSSIBLE CONSEQUENCES

3.1.1.1 Physical Removal of Seagrass e.g. by Cutter Suction Dredge

Total removal of large seagrasses such as *Posidonia* spp by any method has long-term consequences for the communities associated with the seagrass. Monitoring of natural blow-outs in south-west Australia reveals no recolonisation by *Posidonia* over 8 years in the Marmion Lagoon (Kirkman 1985), and the existing blow-outs and transverse furrows in Geographe Bay have been stable or have increased in size in the period 1941-1986 (Walker, unpublished). In Spencer Gulf, South Australia, where *Posidonia* fibres were mined in 1917, the mining scars are still visible. So are the circular scars left by the explosion of depth charges in Jervis Bay in New South Wales during the Second World Wa. (King 1981). Thus any removal which occurs is likely to have long-lasting effects. Recolonisation by minor species may occur, but storm removal is a severe problem for these species (Kirkman 1985). The significance of this to Geographe Bay will depend on the size of the area involved. Once the integrity of a meadow is breached, erosion occurs along the edges, and severe storms will have a greater effect than on an intact meadow. Thus any assessment of the significance of seagrass removal must include a longer term view of the system with serious consideration of the problems of coastal erosion.

3.1.1.2 Indirect Dredging Effects

Decrease in light reaching the seagrass communities, due to increased turbidity associated with dredging, may have deleterious effects on photosynthesis and hence on leaf production (Silberstein *et al.* 1985). Reduced productivity by *Posidonia australis* in Shark Bay in winter lead to a reduction in leaf density and length (Walker and McComb, in press), diminishing the baffling capacity of the meadow, and making it more vulnerable to erosion. Thus, there may be a considerable area around that of total removal which would be chronically affected by mining operations.

In addition, resuspension of sediments can lead to increased availability of nutrients in the water column. These can stimulate phytoplankton and epiphytic algal blooms which also reduce light available to the seagrass for photosynthesis (Silberstein *et al.* 1986), with similar effects to those described above.

This type of seagrass loss can occur in times of months to years, and the loss may not have an immediately obvious cause. For example, the cause of the recent loss of seagrass from Parmelia Bank, Cockburn Sound, is unknown, but may be found to have resulted from these types of processes.

3.1.1.3 Pollution Effects

Increased sediment resuspension resulting from dredging may be particularly significant. Fine sediments trapped under the seagrasses would be mobilised, and have the potential to clog filter feeding mechanisms, and smother benthic organisms. The scale of this effect will depend on the method employed to extract the sand, the prevailing wind and tide conditions and the nature of the site.

Aside from the physiological effects on seagrasses documented above, the mineral sands involved contain radioactive minerals such as monazite, which would also be suspended in the water column. These have the potential to be taken up by filter feeders such as scallops and mussels, and passed up the food chains by other organisms. The scale of this effect again will depend on the composition of the mineral sands and how the extraction is performed.

3.1.2 CONSEQUENCES OF SEAGRASS LOSS

Consequences associated with loss of seagrasses are related to the physical and biological roles of the seagrass (Section 2.3). The amount of seagrass lost and the significance of this loss can only be determined after more details of the mining proposal are available. Given the availability of detailed maps of seagrass cover area, it will be feasible to calculate what proportion of the seagrass would be removed. However, of more general concern, is that any loss of seagrass in shallow water is likely to have consequences for shoreline stability. Searle and Logan (1978) made the following statement in their synopsis: ".... any reduction in seagrass cover must increase energy levels and longshore transport rates in the beach zone. Eventually these factors could be sufficient to tilt the equilibrium of the system towards nett coastal erosion".

3.2 PORT GEOGRAPHE DEVELOPMENT

The proposed development will occupy a sub-tidal area which has extensive sand bars and unstable sediments. Possible impacts include:

i) changes in coastal processes which may affect sediment movements and seagrass distribution

ii) changes in water quality

iii) changes in recreational pressure on benthic communities.

Only the first of these is regarded as significant, as water quality within the development will have to conform to public health and other standards, and high levels of recreational activity already exist. None of the specific areas which might be affected are regarded as significant or vulnerable.

The progressive loss of seagrass from areas such as the Busselton jetty has lead to increased accumulation of sediment in areas such as the site of the proposed development. The site has been recognised by the developers as requiring considerable sand bypass each year, from the western side of the main breakwater to the eastern beach of the site (Orientation Report p.3).

Only sparse patches of *Posidonia sinuosa* and *Amphibolis* spp. persist in the adjacent subtidal, and these patches are relatively small. The significance of seagrasses to nearshore environments, detailed in section 2.3, is largely dependent on the functioning of an intact seagrass meadow, and so these processes cannot be assumed to be significant in sparse patches of seagrass.

However, structures protruding into the subtidal have generally been found to influence sediment distributions along the shoreline for a distance of 6 times the length of the structure (confirmed for an experimental groyne in Warnbro Sound (Riedel & Byrne 1986)). The sediment transport estimate of 10 000 m^3 for this structure, produced accretions/erosions of >1 m in 6 months, adjacent to the structure, with changes >0.25 m occurring over 200 m away from the structure. The amount of annual sand bypass for the Port Geographe development as estimated by the developers, 150 000 m^3, is more than an order of magnitude greater than that at Westport. Even changes of 0.2 m are extremely significant on a biological scale. This type of sand bypass, i.e. dredging, will also produce unsorted sediment which will be subject to resuspension, causing increased turbidity and some smothering by sediment. The coastline is also receding, and is subject to considerable sinuosity.

The combination of all these factors may result in considerable erosion and accretion, and disruption of normal sediment movements along the coast. Seagrasses within approximately 2 km of the structure may be affected by these movements. Further away from the structure, the sediment changes will be inshore of the seagrass upper depth limit, and so only approximately 4 ha of seagrass would be affected. This is based purely on accretion/erosion changes, and does not allow for losses associated with construction and dredging. Although this is still a relatively small area of seagrass in comparison with the total area of seagrass within Geographe Bay, there have already been localised losses of seagrass of up to 45% (Searle and Logan, 1978) associated with construction of breakwaters, and increases in area of transverse sand furrows offshore of drainage channels, perhaps associated with increased water flows from cleared catchments (Walker, unpublished). For the reasons detailed in Section 3.1.2, any further loss of seagrass must be viewed as likely to result in increased coastal erosion.

3.3 REOPENING OF VASSE AND WONNERUP ESTUARIES

The Vasse and Wonnerup estuaries ceased to function as typical estuaries in the early 1930's, when floodgates were installed at each estuary mouth . The purpose of these was to stop the flooding by saltwater of low-lying pasture around the margins of the estuaries. The Water Authority of WA utilises the estuaries as a compensation basin for regional drainage. Each year at the end of winter stoplogs are inserted in the floodgates by the Water Authority to halt the loss of freshwater (G. Holtfreter pers. comm.). During summer and autumn the estuaries gradually dry by evaporation.

The Vasse and Wonnerup estuaries together constitute one of the most important temporary bird refuge areas in southern Western Australia (B. Masters pers. comm.). However as the estuaries dry the birds are forced to migrate to other wetlands. Removal of the floodgates would allow the estuaries to serve as bird refuges for the entire dry season. Lt. H. E. Bunbury, in 1837, reported the waters of the Wonnerup area to be: *"a haunt of black swans and cygnets, duck, pelican, grey heron, and white crane "* (Bunbury and Morrell 1930). This seems to indicate that in its natural state the estuaries were frequented by waterbirds.

The floodgates are a barrier to fish utilisation of the estuaries, and presumably only fry can enter the estuaries through leaks in the floodgates when sea level exceeds estuary water level. Fish kills have been recorded during summer-autumn in both estuaries in recent years. As the water evaporates, during summer, nutrients are concentrated in the remaining water and dense phytoplankton blooms may result causing deoxygenation of the water. Reopening the estuaries would allow the estuaries to function as fish nurseries and may increase fish stocks in Geographe Bay.

The aesthetic value of the estuaries would be greatly increased by removing the floodgates. In summer-autumn nauseous odours emanate from the remaining water and drying sediments and tidal exchange would dramatically improve the water quality in both estuaries. The diurnal tidal range at Busselton is about 0.5 m, but the tidal range in the estuaries would be smaller due to attenuation caused by the long narrow inlet channels. In its natural state the entrance to the ocean was always open, although very shallow at times (Bunbury and Morrell 1930).

No adverse hydrogeological effect from allowing seawater into the Vasse and Wonnerup estuaries is envisaged (B. Masters pers. comm.). Raising the water level in the estuaries may reduce the flow of fresh groundwater into the estuaries and reduce the rate of depletion of any groundwater mound built up by winter rainfall recharge in the dunes. River runoff should be of sufficient magnitude to flush the salt water from the estuaries each winter.

If the floodgates are removed some alternative measures may be needed to stop flooding of low-lying land around Busselton during winter storms. Landowners around the the margins of the estuaries may seek monetary compensation for the loss of pasture due to flooding by saltwater.

A compromise to totally opening the estuaries would be to replace the existing floodgates with automatic storm-surge gates. If linked to the Water Authority's computer system these gates could be automatically either closed or opened when the sea level exceeded or fell below a predetermined height. This would allow the estuaries to be open to the sea most of the time while preventing flooding of low-lying land.

Another alternative to the existing floodgates would be the construction of a continuous levee bank around both estuaries. The levee would prevent flooding of pasture by seawater, and small floodgates would allow drainage of water through the levees into the estuaries. Construction of the levee banks would cost about the same as replacing the floodgates, and would require less maintenance (G. Holtfreter pers. comm.). The Vasse floodgates are due to be replaced in 1987-1988 at a cost of about $289,000, while the Wonnerup floodgates are scheduled for replacement in 1988-1989 for about $308,000.

If a decision is made to replace the existing floodgates with similar structures, serious consideration should be given to relocating the floodgate on the Vasse Estuary further west. This would have two effects:

1. Flooding would be reduced by moving the floodgates further west. Storm waves have breeched the narrow strip of land between Geographe Bay and that section of the Vasse Estuary upstream of the present floodgates in the past and flooded low-lying land with seawater.

2. A greater length of the Vasse Estuary would be downstream of the floodgates, with resulting improvements to fishing, recreation and general aesthetics of that section of water.

Table 2. Nutrient and chlorophyll levels in the Vasse and Wonnerup estuaries and major river systems draining into them. (All concentrations in $\mu g\ l^{-1}$).

Site	Date	Phosphorus		Nitrogen			Chlorophyll
		PO_4-P	Org. P	NH_4-N	NO_3-N	Org. N	
Ludlow River[1]	19-5-87	12	4	365	405	599	
Abba River [1]	19-5-87	17	19	36	68	913	
Sabina River [1]	19-5-87	50	75	35	6	1547	
Vasse River [2]	19-5-87	142	26	16	65	897	
Vasse River Upstream[3]	19-5-87	15	25	323	4	443	
Vasse Estuary [4]	20-5-87	29	112	11	11	1398	6.9
Vasse Estuary [5]	20-5-87	54	118	59	4	1268	10.4
Wonnerup Estuary [4]	20-5-87	15	205	8	6	1689	60.7
Wonnerup Estuary [6]	20-5-87	7	160	8	3	3903	14.5
Ocean Entrance	20-5-87	11	33	17	5	569	1.7

[1] Bussel Hwy bridge
[2] Strelly Street bridge
[3] Evans Road crossing
[4] 20 m behind the floodgates
[5] Bignell Street bend
[6] 1 km upstream from floodgates

In order to assess the likelihood of macroalgal blooms in the estuaries, should the floodgates be removed, a number of water and sediment samples were collected for nutrient analysis from the estuaries and river systems draining into them. Unfortunately no previous nutrient data were available for comparison. The predictions made on the basis of this very limited data set should be regarded as highly speculative.

Nutrient concentrations in each of the major river systems draining into the Vasse-Wonnerup estuaries are shown in Table 2. Water levels were low with only base flows in all rivers at the time of sampling. High phosphate phosphorus concentrations were recorded in the Sabina and Vasse rivers (Table 2). The Ludlow River and Vasse River upstream had high ammonium nitrogen concentrations and the Ludlow also had a high nitrate-nitrite nitrogen concentration (Table 2). If the Vasse-Wonnerup catchment behaves in a similar way to the Peel-Harvey catchment, nutrient concentrations in winter would be considerably higher than those recorded under base flow conditions (Birch et al 1985). The annual nutrient load would depend on the relative contribution of each of the rivers to total flow. If the Sabina and Ludlow rivers contribute a significant proportion of the flow the annual nutrient load may be sufficient to support algal blooms.

The organic nitrogen, organic phosphorus and chlorophyll concentrations in the samples from the Vasse-Wonnerup estuaries were much higher than those in the sample collected at the ocean entrance (Table 2). The organic phosphorus and chlorophyll concentrations were higher than those typically found in the Peel-Harvey estuarine system at this time of year (Lukatelich and McComb 1985). If these samples are representative of the whole Vasse-Wonnerup system these estuaries may be regarded as eutrophic. Re-opening the estuaries should result in a reduction in nutrient and chlorophyll levels in the water column as a consequence of increased flushing.

Nitrogen and phosphorus concentrations in the top 20 mm of sediment are shown in Table 3. The nitrogen and phosphorus concentration in the sediment increased dramatically upstream of the floodgates in both estuaries. The nitrogen and phosphorus concentrations at these sites were similar to that found under algal beds in the Peel-Harvey system. The water, organic and nutrient content of the sediment collected behind the floodgates were similar to that found in the sediment collected from the ocean entrance.

Table 3. Characteristics of the top 20 mm sediment in the Vasse-Wonnerup estuaries.

Site	Water Content (%)	Organic Content (%)	Total Phosphorus ($\mu g\ g^{-1}$)	Total Nitrogen ($\mu g\ g^{-1}$)
Vasse Estuary [1]	60.6	6.7	415	1587
Vasse Estuary [2]	84.3	20.2	1234	8134
Wonnerup Estuary [1]	36.2	2.6	352	842
Wonnerup Estuary [3]	75.6	12.9	1155	5210
Ocean Entrance	48.4	3.9	359	528

[1] 20 m behind the floodgates
[2] Bignell Street bend
[3] 1 km upstream from floodgates

The nutrient content of the sediments at the upstream sites is more than sufficient to support macroalgal growth. Assuming these sites to be representative of the sediment nutrient content of the Vasse-Wonnerup system, there is a strong likelihood that macroalgal blooms would follow re-opening of the estuaries. Low water levels during summer and autumn probably preclude macroalgal blooms at present.

Opening the Vasse and Wonnerup estuaries should have little environmental impact on Geographe Bay. Almost all of the nutrient load from the river systems is discharged into Geographe Bay at present. The Capel and Vasse Rivers, the two largest river systems, have been diverted so that they flow directly to Geographe Bay. Some nutrient loss from the estuaries may occur during summer-autumn but this is most unlikely to have any impact on Geographe Bay.

In summary, no serious environmental effects are envisaged by opening the estuaries to the sea at the present time, and on the contrary the value of the estuaries as a habitat for waterbirds and fish would be greatly improved. Unless the water level in the estuaries is controlled, flooding of low-lying pastures may result.

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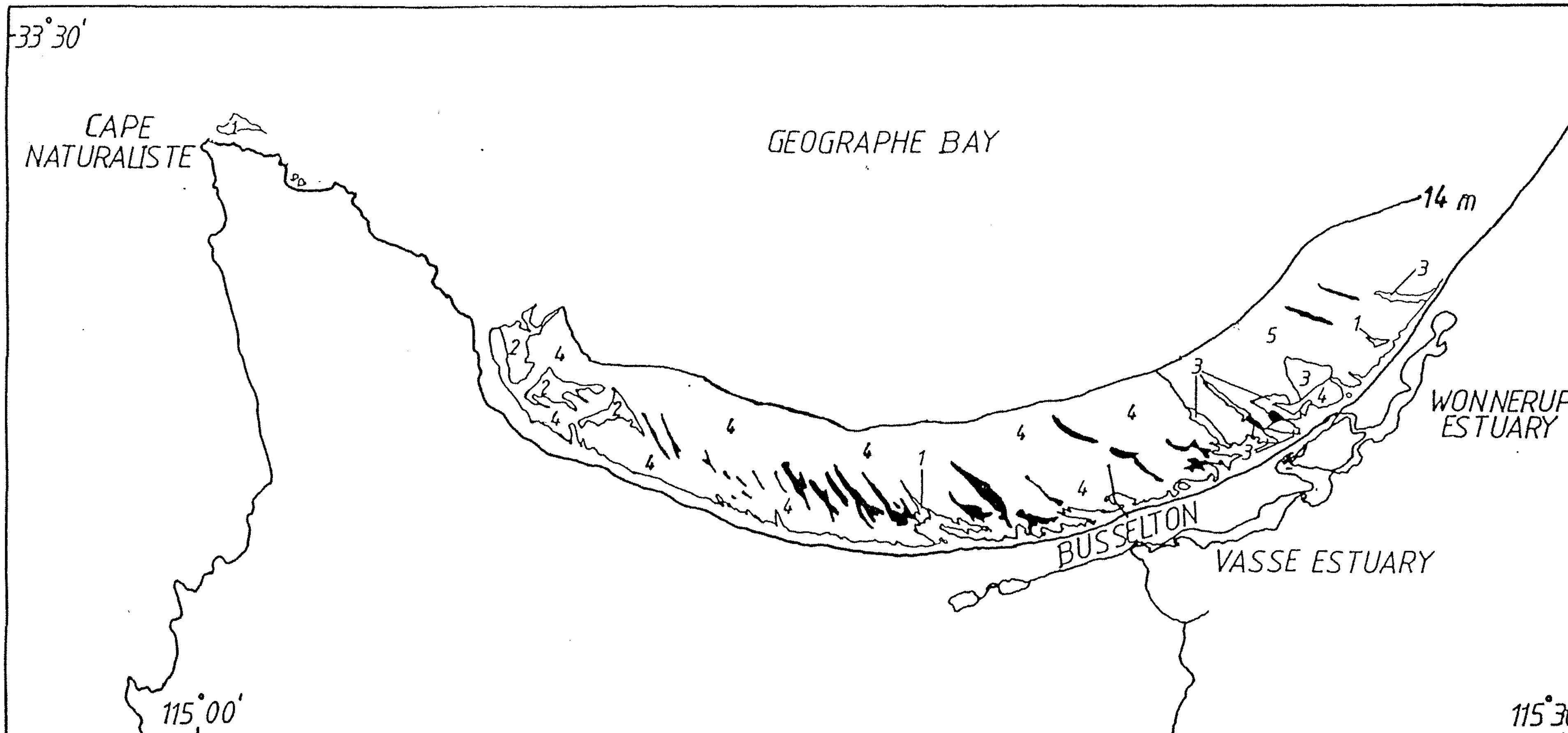

Figure 1. Seagrass distribution in Geographe Bay, to a depth of 14m. Locations of the Vasse and Wonnerup estuaries are also shown. Seagrass blow-outs are shown in black. Numbers within patches refer to the cover of seagrass within the patch.

Category 1 = 1-19% cover
Category 2 = 20-39% cover
Category 3 = 40-59% cover
Category 4 = 60-79% cover
Category 5 = 80-100% cover