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Status of a shallow seagrass system, Geographe Bay, south-western Australia

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Abstract

Geographe Bay, southwestern Australia, is a shallow open embayment with sandy substrata dominated by the seagrass *Posidonia sinuosa*, which has greater than 60% cover of the bay. The surrounding agricultural catchments are sandy and low-lying, with extensive drains contributing anthropogenic nutrients (255 tonnes of N and 34 tonnes of P seasonally) to Geographe Bay. Potential for eutrophication of this system and the subsequent effects on the biota, particularly the health of seagrass communities, has been of concern by local residents. This study documented physical parameters in the water column and the distribution and status of the benthic biota from 1993 to 1995. There were seasonal changes in water temperature (ranging between 14.8 °C in winter to 21.6 °C in summer), and irradiance (ranging between 0 in winter to 850 µmol m^{-2} s^{-1} in summer). These changes followed expected seasonal patterns in a mediterranean climate. Above-ground biomass of the dominant seagrass *Posidonia sinuosa* (115 to 470 g m^{-2}) was similar to that reported for unpolluted systems in southern Australia, as was epiphyte load (0.1 to 26 g m^{-2}). Geographe Bay showed few symptoms of eutrophication despite seasonal increases in nutrient loads

Introduction

Geographe Bay is a 100 km wide north-facing embayment, situated between Cape Bouvard and Cape Naturaliste, on the south western coast of Australia (Fig 1). It is a relatively protected bay with a gentle sloping bathymetry (2 m km^{-1}). A Holocene sediment veneer overlies Pleistocene limestones and clays (Paul & Searle 1978). The shallow subtidal region (2-14 m) is characterised by sandy substrata interspersed with limestone pavements and reef. There are extensive beds of seagrass *Posidonia sinuosa* Cambridge & Kuo, with greater than 60% coverage throughout the bay. *Amphibolis antarctica* (Labillardiere) Sonder *et* Ascherson *ex* Ascherson, often occurs on the periphery of *P. sinuosa* meadows and limestone pavements (Walker *et al.* 1987).

Land bordering Geographe Bay has been cleared extensively for agriculture over the last 150 years. A network of drains was developed to facilitate agricultural and urban development (Fig 1). Cattle farming with lesser amounts of sheep farming and potato and lucerne crops, are the predominant agricultural practices. The soils in the district have poor nutrient retention capacities and are highly leached with low ambient nutrient concentrations (McComb & Davis 1993). The establishment of agriculture has relied extensively on the addition of nutrients, especially trace elements, phosphatic and nitrogenous fertilisers (McComb & Davis 1993). Much phosphorus is lost to drainage from leaching sandy soils (Hodgkin & Hamilton 1993). This results in an increase in nutrients draining from the Geographe Bay catchment. These have been calculated as an annual total of 255 tonnes of nitrogen and 34 tonnes of phosphorus (Holmes 1995).

Increases in nutrient concentrations above a particular level in a system often result in eutrophication (Stirn 1994). Detrimental effects on coastal systems over-enriched with nutrients have occurred worldwide (Nixon 1993) and can be identified as symptoms of eutrophication. These include biological factors such as;

- the presence of phytoplankton amd macroalgal blooms especially an increase in frequency, duration and extent of the blooms (Lukatelich & McComb 1989; Malone 1991);
- high algal epiphyte biomass often measured as epiphyte biomass to seagrass leaf biomass;
- absence of or low biomass of benthic macrophytes (Cambridge *et al*. 1986; Silberstein *et al*. 1986; Neverauskas 1987, 1988);
- shifts in species composition (Lukatelich & McComb 1989);
- decrease in diversity of organisms (Walker *et al.* 1991); and
- increase in diseases of fish and water fowl (Kemp *et al*. 1984);

and physical factors such as;

- high light attenuation coefficient; and
- low dissolved oxygen concentrations (Dubravko *et al*. 1993).

With nutrient enrichment, phytoplankton can rapidly increase biomass and bloom (Ryther & Dunstan 1971). Chlorophyll *a* is a relative estimate of phytoplankton

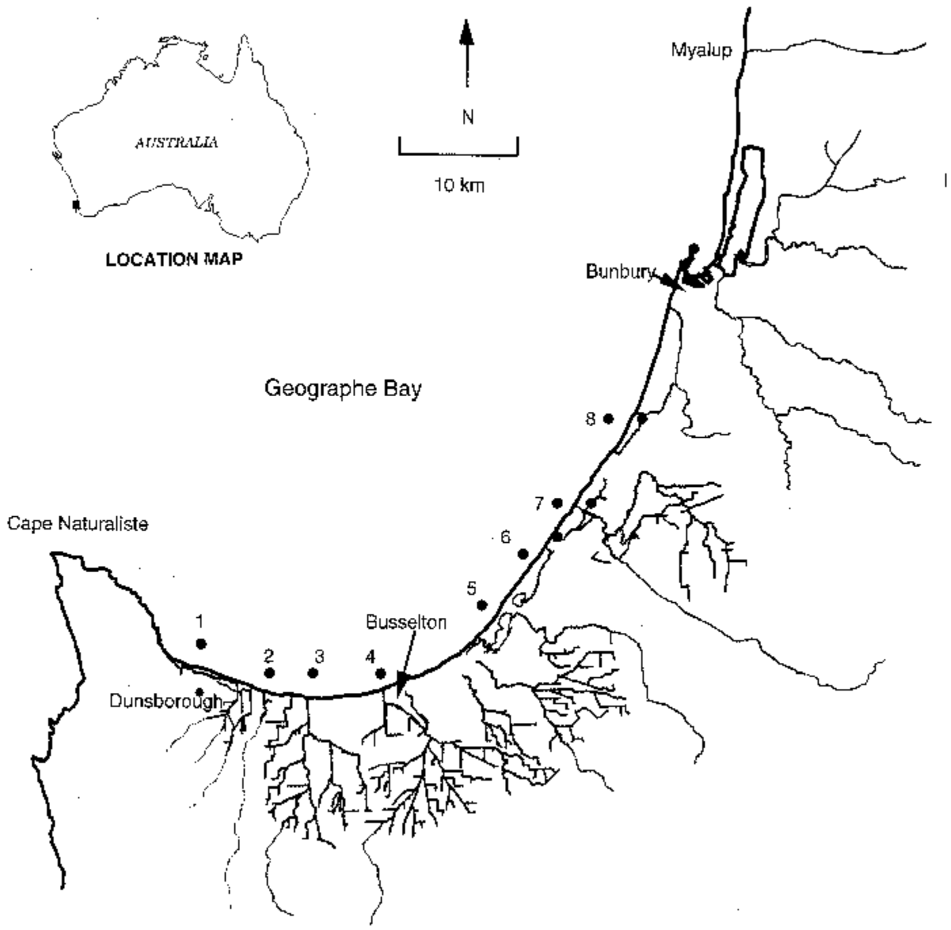

Figure 1. Map of Geographe Bay showing the location of the study sites; 1, Dunsborough; 2, Toby's drain; 3, Buayanup drain; 4, Vasse-Diversion drain; 5, Vasse-Wonnerup Estuary; 6, Forrest Beach; 7, Capel River; 8, 5 Mile Brook diversion.

biomass (Round 1981). Concentrations greater than 1 µg l^{-1} are higher than background levels in the oligotrophic, temperate waters of south Western Australia, and indicate blooms of phytoplankton (Anon 1993). Cyanobacteria may also bloom under conditions of nutrient enrichment (Hallegraeff 1992). Under nitrogen-limited conditions with an adequate phosphorus supply, cyanobacteria can proliferate due to their ability to fix and supply their own nitrogen requirements (Round 1981).

Biomass of opportunistic epiphytes may be boosted under conditions of nutrient enrichment, if other variables are favourable for growth (Pickering *et al.* 1993). The epiphyte to leaf biomass ratio (E/L) is a indicator of excessive epiphyte loads on seagrasses (Penhale & Smith 1977). Values of E/L greater than 0.3 for *P. sinuosa* indicate excessive epiphyte biomass with a deleterious shading effect on the seagrass (Neverauskas 1987).

The presence of submerged aquatic vegetation can be an indicator of water quality (adequate light penetration) and nutrient status *i.e.* low nutrient concentrations (Walker & McComb 1992; Dennison *et al.* 1993). In eutrophic systems where light is often reduced for extended periods, there may be decreases in the biomass of benthic macrophytes (Neverauskas 1988; Sand-Jensen & Borum 1991). The changes in seagrass biomass can be an indicator of the extent of eutrophication (Hillman *et al.* 1989). For the seagrass *Posidonia sinuosa* in a monospecific meadow down to 4 m deep, biomass ranges between 250 and 500 g m^{-2} (Hillman & Morrison 1994). A decrease from this range may indicate that seagrasses growing in the same depth and under similar conditions are under stress (Neverauskas 1987).

There have been recent concerns about the health of the Geographe Bay system. Losses of seagrass cover in some nearshore areas were documented in the 1970s (Conacher 1993), but the study showed some indication of subsequent recovery. Anecdotal evidence of macroalgal blooms in summer are of concern as potential symptoms of eutrophication. The aim of this study was to document physical and biological conditions in Geographe Bay. Physical profiles of light, temperature and salinity were recorded. Biological measures of seagrass biomass, algal epiphyte load, chlorophyll *a* concentration, the presence or absence of cyanobacterial and diatom aggregations and the presence or absence of seagrass wrack were taken. These were interpreted to assess whether there were any symptoms of eutrophication in Geographe Bay.

Methods

Geographe Bay has a temperate, mediterranean type climate, characterised by warm, dry summers and cool, wet winters (Walter 1979). The annual rainfall is 800 mm a year, with 85% of the rain falling between May and October (Fahrner & Pattiaratchi 1995). In summer the winds are generally easterly in the morning at speeds of 5 m s^{-1} with a south-southwesterly sea breeze in the afternoon, with speeds up to 15 m s^{-1}. Winter weather patterns are dominated by the passage of westerly cold fronts associated with low pressure systems which cross the coast every 7 to 10 days. These result in strong, sustained west to north-westerlies of up to 15 m s^{-1}. An average of 15 days of winter storms occur every year (Fahrner & Pattiaratchi 1995).

Water movement in Geographe Bay is mainly wind driven, as the tidal range is small, generally less than 1 m. Fahrner & Pattiaratchi (1995) predicted a predominantly northerly transport of water along the perimeter of the bay from Cape Naturaliste to Myalup in westerly, south-westerly and southerly winds. South-easterly winds result in the offshore transport of water and easterly winds, in the offshore transport of water in a south-westerly direction. North-westerly winds would result in the onshore transport of water with weak and variable currents. The average flushing time off Busselton is predicted as 3 to 5 days for easterly, southerly and south westerly winds. Longer flushing times, up to 14 days, occur when south-easterly and north-westerly winds dominate (Fahrner & Pattiaratchi 1995). In recent years, a cold current (the 'Capes Current') has been documented in the south west of Western Australia (A Pearce & C Pattiaratchi, *pers comm*); it originates on the western side of Cape Naturaliste, impinges on the nearshore of Geographe Bay, and moves northward, along the coast-line to Perth.

Eight sites were chosen to survey physical and biological conditions in nearshore Geographe Bay (Fig 1). Six were potential impact sites, off-shore from drainage systems (Toby's drain, 33 ° 37.797 'S 115° 10.794 'E; Buayanup drain, 33 ° 38.531 'S 115 ° 14.933 'E; Vasse-Diversion drain, 33 ° 38.339 'S 115 ° 19.303 'E; Vasse-Wonnerup Estuary, 33 ° 36.116 'S, 115 ° 25.401 'E; Capel River, 33 ° 30.194 'S 115 ° 31.362 'E; 5 Mile Brook Diversion, 33 ° 27.572 'S, 115 ° 33.593 'E) and two were used as reference sites with no direct terrestrial run-off (Dunsborough, 33° 36.425 'S, 115 ° 07.112 'E; Forrest Beach, 33 ° 34.265 'S 115 ° 26.783 'E). Over the summers of 1993/1994 and 1994/1995, surveys were undertaken every fortnight. In April, July and September 1994, four sites were sampled more intensively (Buayanup drain, Vasse Diversion drain, Vasse-Wonnerup Estuary and Dunsborough). In July 1994, only Dunsborough and Vasse-Wonnerup Estuary were sampled due to rough weather conditions.

Each site was located in 5 m of water, approximately 500 m from shore, in the middle of a seagrass bed. At each site, light and temperature profiles were recorded, and benthic communities surveyed. In July 1994, benthic communities were not surveyed due to turbid conditions. The information for the eight sites sampled intensively over the summers was used as general habitat descriptions. The data from the four sites studied over the whole year were used to compare physical and biological conditions.

Light and temperature

Temperature (°C) and light intensity (µmol m^{-2} s^{-1}) were measured with a Hamon Yeokal temperature/salinity bridge and a Licor light meter with an underwater sensor. A vertical profile was carried out at 1 m intervals from the bottom to 1 m from the surface, then at 0.5 and 0.1 m from the surface. Light measurements were used to calculate a vertical light attenuation coefficient as the slope of the line between log of light and depth (Kirk 1994). Secchi disk depth (Z_{sd}) readings were made and attenuation coefficients were then calculated using the formula $K_d = 1.44 / Z_{sd}$, where K_d is the attenuation coefficient (Kirk 1994).

Benthic communities

A 300 m equilateral triangular transect (100 m each side) was swum with SCUBA at each site to document benthic communities and physical features. Observations were made at 10 m intervals along the transect. The type of substratum was recorded as sand, low pavement rock or high rock and the percentage cover of benthic biota was noted. This percentage cover was a visual estimate of the amount of substratum covered by seagrass and/or macroalgae over a 10 m distance and the value was estimated at 1 m distance above the transect, taking into consideration 1 m either side of the transect. Macroalgae were collected for identification. The presence or absence of monospecific diatom and blue-green aggregations and their relative abundances along the transect were also noted. The number of times each group was present along the transect was summed and then divided by the total number (30) of possible observations. The relative presence value ranged between 0 for no occurrence to 1 for occurrence along the whole transect. This information provided a general habitat description of the area.

P. sinuosa and epiphyte biomass estimates

Seagrass dry weight biomass was estimated at each site by stratified sampling (Walker 1988). Six 20 x 20 cm quadrats were placed haphazardly within a 5 m radius, in the middle of the dominant seagrass bed, at each site. All the above-ground material originating from inside the quadrat was collected and frozen. On return to the laboratory, each sample was scraped with an industrial razor blade to remove the erect algal epiphytes (encrusting epiphytes were not removed) and separated into red (Rhodophyta), green (Chlorophyta) and brown (Phaeophyta) algae. Seagrass and epiphytic material were dried for 24 hours and then weighed to give an estimate of dry weight in grams (Neverauskas 1987). These values were extrapolated to dry weight (dw) biomass of seagrass and epiphytes in grams per unit area (g m^{-2}). The epiphyte to leaf (E/L) ratio was calculated for each site and sampling period. This is the ratio of epiphyte dry weight biomass to seagrass dry weight biomass (Neverauskas 1987).

As extensive amounts of seagrass wrack accumulated over winter; in July the cover of seagrass wrack on the beach was quantified along a 1.5 km stretch of shoreline westward from the entrance of the Vasse-Wonnerup Estuary. Large accumulations of seagrass wrack (mainly *Posidonia sinuosa*) were present on the sandy beach out to 100 m from shore, between Vasse-Wonnerup Estuary and Vasse Diversion drain in July. The cover was estimated at 30 m intervals along a ten metre wide strip from the shore-line up the beach. Along a 350 m stretch, the volume of wrack was determined by measuring the height, width and depth of each wrack "lump". The area from which this total volume of seagrass may have originated was calculated by estimating dry weight biomass of the wrack from the volume of wrack present (Hansen & Brearley, *pers comm*) and then relating this to average biomass (g m^2) in the area offshore.

Results

Physical conditions

Drain flow and water colour. During summer (December to February) and in April, the water in Geographe Bay was calm and clear; the bottom was visible at 5 m depth. None of the drains or the estuary were flowing. In July, all drains and the estuary were flowing rapidly, discharging a large volume of brown-coloured fresh water. Vasse Diversion Drain was flowing fastest followed by the Vasse-Wonnerup Estuary and then Buayanup drain. The water offshore was extremely turbid, the bottom was not visible in 1 m of water, and brown discolouration was visible 3 km out to sea. This discolouration extended from Toby's drain to Forrest Beach. There was no discolouration in the water column at Dunsborough, the reference site. In September, the estuary had ceased to flow but the two drains were flowing more slowly, with Buayanup drain flowing faster than Busselton drain.

Temperature. Water temperature peaked at the end of summer (February) with a mean of 21.6 ± 0.4 °C. The mean minimum temperature was recorded in July at 14.8 ± 0.4 °C (Table 1). There was a gradient of temperatures along the coast in summer with 1 °C cooler temperatures in the south-west of the bay in comparison to the north-easterly sites.

Light. The amount of light above the seagrass canopy, at 5 m depth, also peaked in summer (mean of 620 µmol m^{-2} $s^{-1)}$ and was lowest in winter (Table 1). Turbidity increased dramatically in winter at sites associated with drains. The attenuation coefficient was higher in July and September than in January and April (0.22 - 0.96). There was a slight increase in attenuation coefficient (0.13 - 0.35) in winter at the site not associated with a drain (Table 1).

Water column phytoplankton concentration. The water column chlorophyll *a* concentration was generally low over the year (Table 2). The highest chlorophyll *a*

Table 1

Temperature, light and attenuation coefficients in Geographe Bay. Temperature is averaged over four sites. Both temperature and irradiance were measured at the bottom of the water column, above the seagrass canopy. Site 1 is Dunsborough, the site without an associated drain. Sites 3, 4 and 5 are all associated with drains, and are Buayanup drain, Vasse-Diversion drain and Vasse-Wonnerup Estuary respectively. Values are mean (± standard deviation, with a sample size of 4, except July with a sample size of 2).

	Temperature (°C)	Irradiance (µmol m^{-2} s^{-1})					Light attenuation				
		Site					Sites				
		1	3	4	5	Mean	1	3	4	5	Mean
Jan. 1994	20.8 ± 0.4	830	400	565	700	624 ± 106	0.113	0.101	0.081	0.217	0.128 ± 0.04
Apr 1994	21.3 ± 0.2	234	269	197	292	248 ± 24	0.134	0.125	0.054	0.117	0.108 ± 0.02
July 1994	14.8	ns	ns	ns	ns		0.350	ns	ns	0.960	0.655
Sep 1994	15.5 ± 0.1	50	43	41	4	35 ± 12	0.215	0.340	0.28	0.385	0.305 ± 0.04
Jan 1995	21.6 ± 0.3	550	570	430	420	493 ± 45	0.062	0.008	0.105	0.167	0.086 ± 0.04

Table 2

Temporal and spatial variation in *P. sinuosa* biomass, epiphyte biomass and chlorophyll *a* concentration at Geographe Bay in 1994-995. Values are mean (± standard error, with a sample size of 6).

Month	*P. sinuosa* biomass (g m^{-2})				Algal epiphyte biomass (g m^{-2})				Chlorophyll *a* (µg l^{-1})			
Sites	1	3	4	5	1	3	4	5	1	3	4	5
Jan 1994	234 ± 32	469 ± 40	287 ± 47	234 ± 32	5 ± 2	1 ± 1	8 ± 3	26 ± 9	0.12	0.22	0.22	0.20
April 1994	113 ± 19	282 ± 31	180 ± 38	162 ± 27	10 ± 3	12 ± 2	9 ± 2	2 ± 1	0.08	0.14	0.18	0.12
July 1994	152 ± 20	ns	ns	116 ± 15	24 ± 6	ns	ns	0 ± 0	ns	ns	ns	0.63
Sept 1994	154 ± 26	196 ± 17	152 ± 20	119 ± 24	17 ± 5	3 ± 1	1 ± 1	0 ± 0	0.12	0.17	0.23	0.49
Jan 1995	159 ± 21	281 ± 28	244 ± 29	271 ± 11	2 ± 1	5 ± 2	11 ± 3	3 ± 1	0.09	0.27	0.13	0.13

Table 3

Species recorded at eight study sites in Geographe Bay, 1993 and 1994.

Site	1	2	3	4	5	6	7	8
Seagrass								
Posidonia sinuosa	+	+	+	+	+	+	+	+
Posidonia angustifolia		+				+		+
Amphibolis antarctica	+	+	+	+	+	+	+	+
Amphibolis griffithii	+	+			+	+	+	
Halophila ovalis	+				+	+	+	+
Macroalgae								
Chlorophyta								
Caulerpa cactoides							+	
Caulerpa sp					+	+	+	+
Codium sp								+
Halimeda cuneata							+	+
Rhipiliopsis sp								+
Caulocystis uvifera						+		
Dictyopteris muelleri						+	+	
Ecklonia radiata						+	+	
Hydroclathrus clathratus								+
Lobophora variegata	+							
Padina sp	+					+	+	
Scaberia aghardii	+				+	+	+	
Sargassum sp					+	+	+	+
Rhodophyta								
Asparagopsis armata						+		+
Dictymenia sonderi								+
Gelidium asperum								+
Gelidium sp							+	
Gigartina disticha								+
Laurencia clavata								+
Osmundaria prolifera						+		+
Phacelocarpus alatus								+
Epiphytic algae								
Cladophora montagneana			+	+	+	+	+	+
Cladophora dalmatica	+		+	+	+	+	+	+
Polycerea nigrescens	+	+			+	+		+
Pachydictyon paniculatum	+	+	+	+	+	+	+	
Pachydictyon polycladum	+	+	+	+	+	+	+	
Metagoniolithon chara	+	+		+	+	+		+
Lenormandia marginata					+	+		
Chondria sp								+
Microalgae								
Mastogloia sp	+	+	+	+	+	+		
Chroococcus sp	+	+	+	+	+	+	+	+

concentration was recorded in winter at Vasse-Wonnerup Estuary (0.63 µg l^{-1}) and the lowest in summer at Dunsborough (0.08 µg l^{-1}). The average concentration over the year at the four sites was 0.22 ± 0.05 µg l^{-1}.

Benthic communities - general description. Seagrass and algal species found in Geographe Bay are detailed in Table 3. The benthic substrata of Geographe Bay can be divided into three main categories; sandy substrata, a combination of sandy substrata and low relief reef and a combination of low and high relief reef. Sandy substrata were present in the south-western portion of the bay between Dunsborough and Vasse-Wonnerup Estuary. These areas were dominated by monospecific meadows of *Posidonia sinuosa*, with *Amphibolis antarctica* and *Amphibolis griffithii* (J Black) den Hartog often on the periphery of the meadows. Closer to Dunsborough the cover of *Amphibolis* spp increased and a number of large meadows occurred. The brown macroalga, *Scaberia agardhii* Greville, was also present in patches.

Sites with sandy substratum and low relief reef were found north of Wonnerup, around Forrest Beach, with a combination of seagrasses (*P. sinuosa, A. antarctica, A. griffithii* and *Halophila ovalis* (R Brown) JD Hooker) in small patches. Dominant macroalgae included *Osmundaria prolifera* Lamouroux, *Scaberia aghardii*, *Sargassum* spp, *Caulerpa* spp and *Padina* spp. Plate corals and sponges were also present.

At Capel and 5 Mile Brook Diversion, there was low and high relief reef. There were small patches of the seagrasses, *A. griffithii* and *A. antarctica*, at Capel. *Posidonia angustifolia* was found on sandy bottoms surrounding high relief reef, further north. Most common benthic macroalgae were the kelp, *Ecklonia radiata* (C Agardh) J Agardh, and *Sargassum* spp. Many small red turf algae were present along with erect red and green algae such as *Caulerpa* spp.

Three main types of epiphytes were noted in the bay; macroalgal epiphytes (Table 3), diatom aggregations and cyanobacterial aggregations. There was temporal variation in these epiphytes, with *Cladophora* Kuetzing (Chlorophyta), *Pachydictyon* and *Polycerea* (Phaeophyta), dominant in summer and red algae such as *Metagoniolithon* Ducker more common in winter. *Amphibolis* bore a greater load of red algal epiphytes than did *Posidonia*. An extensive bloom of *Cladophora* occurred in December of 1993 and 1994 at Capel River and Forrest Beach. This disappeared after one month.

Mastogloia Hustedt (Bacillariophyta) aggregations were found in the south-western portion of the bay. They increased in cover over summer. After a storm in summer, the majority of the aggregations were gone and remained absent throughout the rest of the year. *Chroococcus* Nageli (cyanobacteria) aggregations were present at all sites. They increased in cover over summer, especially at Vasse River Diversion drain and Vasse-Wonnerup Estuary, but were not present during the rest of the year.

***P. sinuosa* biomass.** Highest biomass was recorded in summer and lowest in winter (Table 2). The mean maximum biomass for *P. sinuosa* occurred during summer (470 g m^{-2} at Buayanup drain) and the mean minimum biomass occurred in winter (115 g m^{-2} at Vasse-Wonnerup Estuary). Buayanup drain had the highest biomass of the four sites examined.

Epiphytic algal biomass. There were temporal and spatial variations in the epiphytic communities on the seagrass (Table 2) with two main patterns in algal epiphyte biomass. At the site without a drain, the highest epiphyte biomass was recorded in winter (24 g m^{-2}) and the lowest in summer (2 g m^{-2}). However at sites with drains, the highest biomass in summer (26 g m^{-2}), and the lowest in winter (0.1 g m^{-2}). The E/L ratio never exceeded 0.2 throughout the year.

Seagrass wrack accumulations. Cover of beached seagrass wrack ranged between 0 to 45% of the area surveyed at each ten meter interval. Along a 1.5 km stretch of beach the average cover was 24%. Along a 350 m stretch of beach, the total volume of wrack present was estimated at 81 000 m^3.

Discussion

The marine benthic communities examined at 5 m depth in Geographe Bay were dominated by seagrass, particularly *Posidonia*, although sites with more reef had more *Amphibolis*. The seasonal variation in seagrass biomass was relatively consistent and within the range of other studies (Hillman *et al.* 1989). Algal communities were typical of Western Australian coastal reefs and seagrass beds. There were no large accumulations of drift algae, in summer or winter. Algal epiphytes species and the change of species seasonally were typical of seagrass communities along the south-western Australian coast (Hillman & Morrison 1994)

Extensive wrack deposits were observed in winter, mainly composed of seagrass as reported elsewhere on the Western Australian coastline (Kirkman & Walker 1989). The volume of wrack accumulated on a 350 m stretch of beach had an estimated dry weight biomass of 2-8.0 10^6 kg dw. This equates to 4.8 km^2 of seagrass at maximum biomass. The area that this is likely to originate from is 15 km^2 of seagrass meadow.

A number of parameters measured in Geographe Bay varied over the year. The water column temperature decreased from a summer and autumn maximum of 21.6 °C to a winter and spring minimum of 14.8 °C. The 6.8 °C reduction in temperature between summer and winter is expected for this latitudinal position (Dring 1992). The water temperature in Geographe Bay was 1 °C less than that recorded for Perth coastal waters at the same depth (Buckee *et al.* 1994). This probably reflects the cold Capes Current which moves northward along Geographe Bay and the warmer Leeuwin Current which passes Perth (Cresswell & Golding 1980).

Vertical light attenuation coefficient increased in July and September, indicating that light was dissipated more quickly through the water column. Phytoplankton and organic and inorganic particles held within the water column all affect attenuation (Kirk 1994). High turbidity from suspended particles and tannins discharged from the drains increased the attenuation in July and September, at sites with drains. The accumulation and breakdown of seagrass in nearshore waters in July, especially at Vasse-Wonnerup Estuary also contributed to increased light attenuation.

Light and temperature often determine the relative growth rates of algae, with lower temperatures and irradiances interacting to reduce relative growth rates (Round 1981). In July and September, at the drain sites, very few epiphytes were found on *P. sinuosa*. The low irradiance at the seagrass bed may have restricted epiphyte growth. Dunsborough, the site without the drain, had the highest epiphyte load in July and attenuation was not as high as the other drain sites. Algal epiphytes were most likely not limited by light at this site. Dunsborough was the only site conforming to the pattern described in the literature of higher epiphyte loads on *P. sinuosa* in winter (Hillman & Morrison 1994).

Phytoplankton concentrations (estimated from chlorophyll *a*) were low through out the year at all sites, with no blooms detected. There was a noticeable increase in phytoplankton in the water column at Vasse-Wonnerup Estuary in July and September. This may be a reflection of higher nutrient concentrations in the water column at this time and follows the expected seasonal pattern of spring blooms.

The biomass of *P. sinuosa* seagrass varied seasonally and was similar to values described in the literature (Hillman *et al.* 1989). There was a three fold reduction in seagrass biomass from 350 g m^{-2} in summer to 120 g m^{-2} in winter. This seasonal variation is influenced by leaf loss through storm events and shedding of leaves after growth in summer (Patriquin 1975).

Studies of net production in the seagrass *P. sinuosa* under different light and temperature regimes have estimated the minimum temperature and light required for positive net growth (Masini *et al.* 1995). In relation to these studies, net production of seagrass in Geographe Bay at Dunsborough, Buayanup and Vasse-Diversion drain, would be positive from September to April, over spring, summer and autumn, with temperatures greater than 15 °C and irradiance at the top of the seagrass canopy greater than 30 µmol m^{-2} s^{-1}. At Vasse-Wonnerup Estuary in September, irradiance at the top of the seagrass canopy was 4 µmol m^{-2} s^{-1} and in July this would be less because attenuation coefficients were much higher at this time. Therefore at Vasse-Wonnerup Estuary between July and September, net production is likely to be negative. Respiration would be greater than photosynthesis and a net loss of organic carbon could be expected. A mechanism for maintaining growth over winter would be required for seagrasses with net negative productivity. Pirc (1989) found that *P. oceanica* (L) Delile was able to store carbon and nitrogen in the rhizomes during summer and autumn, which could be mobilised and accessed for leaf growth in winter. A similar mechanism could maintain *P. sinuosa* in winter when light and temperature limit photosynthesis. The seagrass at Dunsborough, where light did not fall below 50 µmol m^{-2} s^{-1}, could maintain a positive net production throughout the year.

A reduction in light reaching a seagrass bed for extended periods, by epiphyte shading or high turbidity in the water column, can cause a decrease in density of seagrass (Neverauskas 1987; Cambridge *et al.* 1986). Limited light during winter from high turbidity in the water column at Vasse-Wonnerup Estuary and the shading in summer by cyanobacterial aggregations at Vasse Diversion drain and Vasse-Wonnerup Estuary make these sites susceptible to reduction in seagrass density. However to test this hypothesis a longer period of study would be required.

Potential symptoms of eutrophication noted in this study were blooms of *Cladophora* at Capel and Forrest Beach in early summer (December 1993 and 1994). These blooms are expected seasonal phenomena, where elevated nutrient concentrations from winter and warmer conditions promote algal growth. If such a bloom was to continue for extended periods, detrimental effects such as reduced oxygen concentrations and shading effects could occur.

There were also aggregations of diatoms and cyanobacteria. Cyanobacteria are often present in eutrophic systems (Hallegraeff 1992). In Geographe Bay, the increase in relative presence of cyanobacteria and diatom aggregations over the summer may be attributed to warmer temperatures and calm conditions. Some cyanobacteria can fix nitrogen and therefore can proliferate in nitrogen-poor conditions if required phosphorus is available (Smith 1984). Cyanobacterial aggregations were dominant around Busselton and diatom aggregations were dominant in the southern end of the study area, near Dunsborough. When strong wind and wave action were present, the blooms were dispersed. There were no blooms in winter and after summer storms; all diatom aggregations disappeared. Aggregations of diatomaceous mucopolysaccharides (“slime”) have also been observed in the mediterranean sea, in summer, under low nutrient concentrations in the water column, less than 1 µg l^{-1} nitrate (Stirn 1994; I M Munda, pers. comm.). The nitrate concentration varied from 1 to 3 µg l^{-1} in the waters of Geographe Bay in summer (unpublished observation).

Conclusions

This study has identified seasonal variation in physical and biological conditions in the nearshore waters of Geographe Bay. They conform to the expected seasonal patterns in a mediterranean shallow seagrass system. The seagrasses at most sites are in a healthy condition, without exceptional epiphytic loads. Blue-green and diatom aggregations were the only symptom of eutrophication noted in this study and require further study.

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